Bean Technology Toolkit Catalogue

TAAT Clearinghouse

Clearinghouse Technical Report Series 010

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The Technologies for African Agricultural Transformation (TAAT) is funded through a grant from the African Development Bank and is implemented by the International Institute of Tropical Agriculture (IITA) in close collaboration with other centers of the Consultative Group for International Agricultural Research (CGIAR) and specialized institutions such as the African Agricultural Technology Foundation (AATF), the Forum for Agricultural Research in Africa (FARA), the International Fertilizer Development Center (IFDC) and others. For more information, email contact: i.musabyimana@cgiar.org or plwoomer@gmail.com.

Front cover photos: Farmer tends to her climbing bean crop (left). Nodules of N-fixing bacteria on roots of common bean (right). Photographic credits: Jean-Claude Rubyogo, Alliance – Bioversity International and CIAT

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TAAT offers to become your broker of modernizing agricultural technologies!

Purpose and Introduction

This catalogue describes a series of technologies related to the modernization of common bean production in Africa. It is based on the combined efforts of the Project Platform for Agricultural Solutions (ProPAS), an information portal, and the Technologies for African Agricultural Transformation, a large collaborative program that is deploying agricultural solutions across the continent. Both of these activities are addressing the imperative to better connect proven technologies to those who need them but each undertakes this goal in a very different manner. Common bean crops are one of TAAT's priority commodities because of its huge importance to food and nutritional security, and livelihood improvement across Africa. It is also targeted as an agro-industrial crop for processing and trading on domestic and regional markets. In the course of its compilation, ProPAS has accumulated several technologies that specifically address this commodity and we have compiled them into a "technology toolkit" designed to advance understanding and encourage adoption and investment into the proven agricultural solutions that advance this crop. This is one of several catalogues that are produced as a joint ProPAS-TAAT activity. For more information on the featured technologies or other solutions toward transformative impact on agriculture on bean and other crops in Sub-Saharan Africa (SSA), contact Dr. Innocent Musabyimana i.musabyimana@cgiar.orgat or visit the TAAT internet site www.taatafrica.org.

About ProPAS. The Product Platform for Agricultural Solutions (ProPAS) provides a mechanism to compile and access innovations and manage technologies and products needed for Africa's agricultural transformation. The platform provides two pathways: it permits users to enter their proven and promising solutions into a database, and then encourages others to sort through its options to reveal the suite of opportunities that can assist their agricultural objectives. ProPAS results from the recognized need by the International Institute of Tropical Agriculture (IITA) to more systematically compile the full range of agricultural solutions available to modernize and transform African agriculture. Its overall goal is providing easy access for different institutions or individuals to accelerate technology uptake and progress towards agricultural transformation in Africa. Many solutions are available to improve and modernize Africa's food systems but many beneficiaries are too often unaware of the best options at hand. In addition, multiple solutions are in the research and development pipeline that can best be advanced through wider exposure and validation. Solution profiles are submitted by technology holders, compiled into a user-friendly software platform and released in a systematic manner for use by an expanding base of clients. A small committee of agricultural experts oversees this process while recognizing that its strength is through open-ended access to a marketplace of solutions. ProPAS is therefore managed through a three-phase process that involves solution submission, database management, and client access. The database allows for solutions to be identified through selection of several search fields related to the form, type, commodity application and target beneficiaries of a given solution, sequentially narrowing the number of platform recommendations.

About TAAT. The Technologies for African Agricultural Transformation (TAAT) is a program led by the International Institute of Tropical Agriculture (IITA) that has pioneered new approaches to the deployment of proven technologies to African farmers. TAAT arose as a common effort of IITA and the African Development Bank (AfDB); and is an important component of the latter's Feed Africa Strategy. TAAT is organized around 15 "Compacts" that represent priorities in terms of achieving Africa's potential in achieving food security and advancing its role in global agricultural trade. Nine of these Compacts relate to specific priority value chains of common bean, rice, wheat, maize, sorghum and millet, cassava, sweet potato, fish, and small livestock. Weaknesses in the production and supply of commodities are viewed as responsible for Africa's food insecurity, need for excessive importation of food, and unrealized expansion of Africa's food exports. Together these Compacts design interventions in collaboration with national programs to introduce technologies and innovations that are designed to meet targets for agricultural development. In many cases, these targets are addressed through the implementation of projects resulting from sovereign country loans awarded by development banks, where TAAT's role in the design, planning and execution of these loan projects is a vital element of their success and uptake.

About PABRA. The newly formed Alliance of Bioversity International and the International Center for Tropical Agriculture (ABC) is facilitating the Pan Africa Bean Research Alliance (PABRA). PABRA unites research institutions, national agricultural development agencies and private sector companies from 31 countries to foster partnerships that strengthen the common bean value chain to enhance food and nutritional security, incomes and climate resilience in an equitable manner. PABRA is rolling out the Bean Corridor Approach which addresses bottlenecks in the commodity's production, distribution and consumption through the linkage of value chain actors and sustainable intensification of cropping systems, trade and value addition. The model recognizes the critical role of private sector and technology-driven agricultural transformation in Africa. Strategic actions are taken through this platform that facilitate market entry and private sector investments along the bean value chain in order to up-scale proven solutions. Ultimately the model seeks to increase bean yields and nutritive values, boost enterprise development along the value chain, and enhance the livelihoods of farming communities. For effective assimilation of research products into business ventures, PABRA collaborates with many different private sector partners that are operating across the entire bean value chain.

PABRA
Pan - Africa Bean Research Alliance
Better Beans for Africa

The TAAT Top 100 Technologies. The Clearinghouse developed a database of the Top 100 Technologies that are transforming African agriculture. It is based upon the approaches of the TAAT Commodity Compacts but also includes those from the CGIAR Collaborative Research Programs that are recently described as ready for next user. These technologies are divided between those involving improved genetics and plant and animal breeding (23%), those based upon the distribution of digital information (3%), production input products of proven efficacy (21%), crop and animal management technologies of utility within agricultural extension messaging and campaigns (27%) and the availability of appropriately designed labour-saving equipment (26%). These technologies have a direct role towards the achievement of the Sustainable Development Goals in relation to farm productivity, food security and hunger reduction, responsible food consumption, improved household nutrition and diets, economic growth, climate-smart innovation, partnerships for the goals, and improved human equity and empowerment. These technologies form the basis for selecting entries into ProPAS, including those advancing bean production.

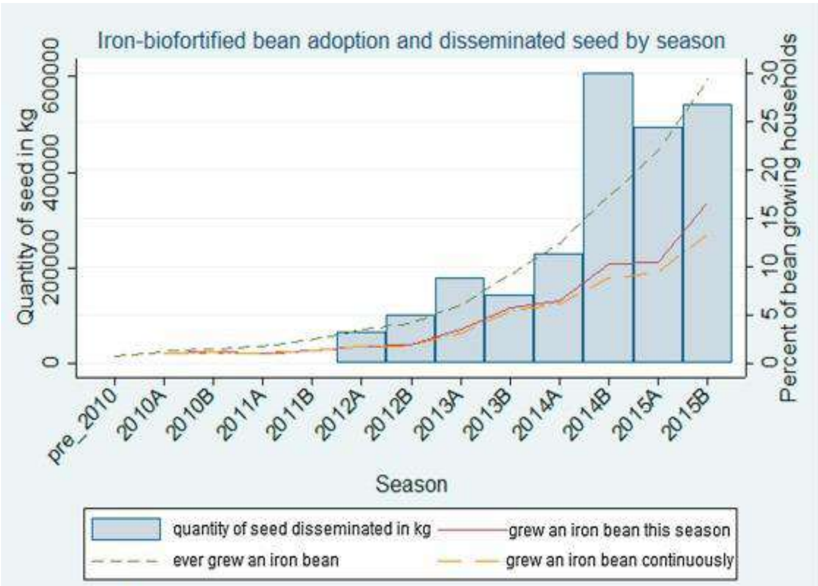
The Top 10 Common Bean Technologies. This catalogue presents 12 technologies that serve to modernize the production and processing of common beans in Africa. These technologies include: 1) biofortified bean varieties for improved nutrition and income generation, 2) climbing beans with high yield potential and nitrogen fixation, 3) inoculation with elite strains of rhizobia to address nitrogen deficiencies, 4) seed dressing with fungicide and insecticide for protection during storage and seedling emergence, 5) specialty fertilizer blends that ensure balanced crop nutrient supply, 6) low-cost staking options for climbing bean, 7) mechanical and herbicidal strategies for labor-efficient weed management, 8) integrated strategies for control of insect pests, diseases and weeds, 9) mechanized threshing operations, 10) hermetic bags for safe storage of harvests, 11) manufacture and marketing of pre-cooked beans as products attractive to time- and energy-conscious consumers, and 12) production of bean flour as a value addition process. Details about each of these technologies follow.

Technology 1. Biofortified Beans for Improved Nutrition

Summary. Poor nutrition, including deficiencies of iron and zinc, is a major concern across Sub-Saharan Africa. Iron deficiency is expressed as anemia, impaired motor and cognitive development, elevated risk of maternal death and premature births, and low birthweight. Zinc deficiency results in weakened immune systems, more frequent infection and stunting. Eating biofortified varieties of beans results in higher uptake of micro-nutrients and improved health. Biofortification is the process of increasing nutritional value by conventional breeding, good agronomic practices or biotechnological modification. A series of recently released biofortified high-iron bean (HIB) varieties offer an effective technology for improving nutritional security and human health. For more information on this technology please contact Dr. Josey Kamanda from The Alliance of Bioversity International and the International Center for Tropical Agriculture (ABC) by email at j.kamanda@cgiar.org.

Some common bean varieties cultivated in Uganda

Technical Description. Biofortification of bean aims at increasing the concentration of dietary iron and zinc. This approach stands in contrast to supplemental sources and their associated costs. HIB varieties were developed by crossbreeding elite lines adapted to local growing conditions with American landraces of common beans that are naturally enriched in these micronutrients using materials from the gene bank of the Alliance of Bioversity International and International Center for Tropical Agriculture. Increasing concentrations of iron and zinc in common bean are mutual breeding priorities, but most success was achieved with iron because this genetic trait is more rapidly transferred and better conserved within improved varieties. Further selection of these lines through participatory breeding strategies has



The rapid scaling potential for iron biofortified beans in Rwanda (Source: Vaiknoras et al. 2019) resulted in bean varieties with high yield potential, tolerance to drought and diseases, preferred color and size, low flatulence, quicker cooking and favorable culinary characteristics. The greater productivity, nutritional and commercial value of HIB varieties enables small-scale farmers to allocate more resources to this crop, making it a main agricultural enterprise and source of income. At the same time, consuming these varieties results in substantial improvement in household nutrition reflected in improved maternal, children and adult health.

FarmFresh frozen beans, a HIB product manufactured in Rwanda

Uses. To date, 31 high-yielding varieties of HIB were released in major production zones across Sub-Saharan Africa. These include: Angaza, Nyota, Faida and Metameta for Kenya; NAROBEAN 1, 2, 3, 4C and 5C for Uganda; JESCA, Selian 14 and 15 for Tanzania; MAC 33, RWV 1129 and MOORE88002 for Burundi; MAC 44, HM 21-7, RWR 2154, NAMULENGA and RWV 1129 for DR Congo; MAC 44, RWV 2269, 2887, 2361 and 3316 for Rwanda; NUA 45 and 764, Cherry and Sweet Violet for Zimbabwe; and NUA 35, 45 and 59 for Malawi. Breeding institutions continue to make adaptations to address specific challenges so it can be grown across many agro-ecological zones on the continent. Breeders have also directed efforts to combining iron with tolerance against drought and resistance to diseases such as Bean Yellow Mosaic Virus. Most HIB are used for home consumption, but in some African countries like Kenya, Rwanda and Zimbabwe, a recognized market is developing for high-iron precooked beans, pasta and composite flour.

Composition. HIB varieties contain about 44 mg more iron per kg than non-biofortified varieties, allowing them to meet about 30% of the average daily iron requirement by consuming 200 grams per day for adults and 100 grams per day for children. The biofortified varieties retain up to 90% of the bioavailable iron after cooking which makes it ideally suited for boosting nutrition. Iron levels may vary as a result of growing conditions and management practices but consistently exceed that of common lines. In addition to greater nutritional value, HIB varieties have various other improved traits such as a high degree of pod-filling, high yields and adaptation to environmental stresses.

Application. HIB varieties are produced using the same management as other varieties. Beans are self-pollinated so farmers can save the best grains from their harvest to maintain a stock of planting materials for the next season, although this practice is discouraged to avoid accumulation of disease and insect pests. Usually beans are planted on flat land, but sowing on hills or ridges may be practiced in areas with heavy soils, slopes or where the water table is high. Soil preparation for common bean crops includes tillage followed by incorporation of inorganic fertilizers and seed inoculation with rhizobia. Farmers are advised to recycle seeds not more than three times to avoid reduced productivity. Bean is typically grown as either a monocrop or intercropped with maize, sweet potatoes, cotton, coffee, bananas, sunflower and other crops. Farmers can grow one, two or more bean crops per year depending on the rainfall patterns or access to irrigation. Seed rates are high in pure stands of bush types, whereas for intercropped bean crops the seed rates are lower. Normally, inter-row distances measure 50 to 75 cm while distance within rows or between hills is 10 cm for single seeds or 20 cm for two seeds per station. Higher planting density between the rows eases management of the bean crops, while lower planting density results in greater yields, but also increases the risk from weeds and disease.

Commercialization and Start-up Requirements. Seed of HIB varieties is produced and marketed by the NARS and private seed companies in several countries across Eastern, Central and Southern Africa. National programs also offer access to the newest varieties in places where the multiplication is not commercialized. Entering into production of HIB simply requires farmers to replace seed from common varieties with that of the biofortified ones. To achieve widespread deployment of this innovation several steps are taken: 1) Raise awareness about the accessibility, availability and affordability and benefits of HIB in bean-growing communities, 2) Provide community-based seed banks, farmer groups and commercial multipliers with quality HIB varieties seeds, 3) Link producers of HIB to buyers and food processors for ensuring sustainable market demand, 4) Enhance demand for iron-rich beans through promotional campaigns that target different consumer groups, and 5) Establish financial incentives to farmers' adoption of HIB varieties.

Production Costs. Breeding HIB varieties first involves advanced techniques in the laboratory and greenhouse, followed by extensive testing in the field. These steps bear a significant investment which is typically borne by research institutions. Once available, the commercial costs associated with multiplying seed of iron-rich beans are similar to from other improved varieties. Producers must recognize that HIB is not a stand-alone technology and that accompanying technologies and management practices are also needed.

Customer Segmentation and Potential Profitability. Adoption of HIB involves a diverse array of stakeholders including small-scale and commercial producers, national research and extension systems, private seed companies, traders and food processors. Under optimal management, HIB generates comparable returns to cereal crops because of its higher value. HIB varieties are well-suited for manufacturing into flour and pre-cooked beans as products traded in domestic and regional markets. Many business opportunities are created by iron-rich beans, ranging from seed multiplication, grain production, grain distribution, trade, processing and consumption. The total value of HIB varieties that has been created in Rwanda over the period 2010-2018 by productivity gains, improved diets and reduced health risks is close to US $25 million. Moreover, by 2025 the scaling of iron-rich beans in Rwanda is expected to generate benefits worth up to US $100 million.

Licensing Requirements. HIB varieties are sometimes marketed under a commercial license and often a certification is required following national regulations of seed systems. Once released the diffusion of the varieties also proceeds through community-based and informal seed systems owing to the crop's reliable trait of self-pollination. The iron-rich varietal technology exists as a Regional Public Good by The Alliance of Bioversity International and CIAT in collaboration with the international program HarvestPlus. National programs and private companies also take part in breeding and evaluation of materials prior to release as well as promoting the HIB at country level.

Technology 2. Climbing Beans Offer Higher Yields

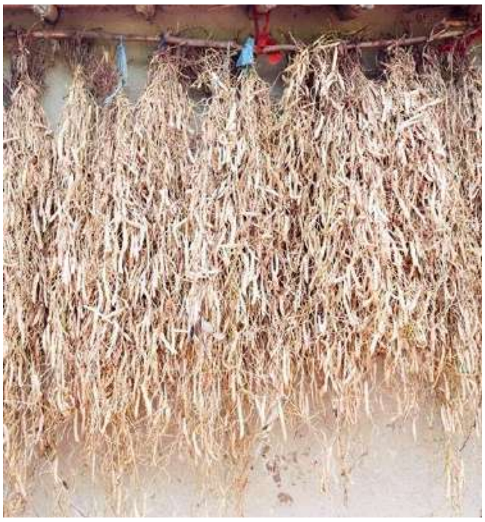
Summary. Climbing bean varieties offer higher yields but require more intensive cultivation compared to bush types. Improved varieties of climbing bean with high yield potential, resistance to pests and diseases, and tolerance to abiotic stresses are now available in Eastern and Southern Africa. Breeding and selection for higher biological nitrogen fixation in climbing bean has served not only to cut costs for farmers but also makes it possible to grow the crop in nitrogen depleted soils. Climbing bean cultivation by small-scale farmers in Africa is highly effective in alleviating hunger and malnutrition, and enhancing incomes. For more information please contact Dr. Josey Kamanda from ABC by email at j.kamanda@cgiar.org.

Inspection of climbing bean in Rwanda

Technical Description. Climbing beans, also called pole beans, are characterized by long, indeterminate growing vines that reach up to 4 or more meters in height and require support from stakes or trellises. Conventional breeding approaches resulted in a number of climbing bean varieties for different agroecosystems across Sub-Saharan Africa, including elite lines with higher nitrogen fixing ability and landraces adapted to local conditions. Traits such as bean productivity, nodulation efficacy and resistance to drought, diseases and insect pests are the focus of this varietal improvement, and HIB varieties are also available (see Technology 1). Climbing beans are capable of giving two to four times the bean harvest of bush varieties since they develop a vertical canopy and have a longer harvest period.

Uses. Climbing beans offer the best option for small-scale farmers where landholdings are diminishing and degrading, and available varieties have been adapted to the soil and weather conditions in diverse production zones across Sub-Saharan Africa. For instance, targeted breeding of early maturing and heat tolerant lines has enabled expansion of climbing beans from its traditional high altitude to medium and low altitude areas with semi-arid climates. Their high nutritional value makes climbing bean varieties well-suited for processing into flour or other products, such as canned and pre-cooked beans, which can be retailed on local and international markets (see Technologies 11 and 12).

Composition. A large diversity of improved climbing bean varieties is available for multiplication by farmers, community-based seed producers and private seed companies. These varieties include Mid-Altitude Climbers (MAC) 13, 34 and 64 in Kenya, NABE 12 and NABE 26C/28C in Uganda, MAC 44 and RWV 1129 in Tanzania, and Gasillida, RWV 3317 and RWV 3006 in Rwanda. Improved varieties of climbing beans are ready for harvest within a period of 95-120 days, and have excellent palatability and a high starch content.



Beans drying on a homestead (Source: One Acre Fund)

Application. Availability of a suitable climbing bean variety and its accompanying crop and soil management practices form a technology bundle that must be tailored in accordance with agro-ecological conditions and socio-economic contexts. Climbing beans must be supported by stakes or trellises. Furthermore, they are best cultivated as a monocrop but it can be intercropped with maize, banana, roots and tubers, sorghum or millet. Planting is usually done on hills or ridges receiving organic inputs, particularly in clay soils or where the water table is high. Plant densities are determined by the particular trellising system and degree of mechanization, with the spacing between rows for a monocrop typically at 75-100 cm. To achieve the full yield potential of climbing beans and maintain soil fertility on farmlands, there is need for seed inoculation with rhizobia, timely planting, fertilization, strong and tall staking and proper weeding (see Technologies 3, 5 and 8).

Commercialization and Start-up Requirements. Improved climbing bean varieties are marketed by private companies in Rwanda and Zimbabwe, whereas access to them in other countries of Eastern and Southern Africa is provided through national programs. The following actions need to be undertaken for entering into production of climbing beans: 1) Promote the availability of improved climbing beans and their benefits with regard to yield, climate resilience and return on investment, 2) Transfer elite varieties to community-based and commercial seed multipliers as a new product line, 3) Connect producers of climbing beans with buyers and food processors to create wider market opportunity, and 4) Provide financial support to farmers so they can make necessary and timely investments into quality seed, fertilizer inputs and staking. For commercial producers, the availability of netting streamlines trellising operations.

Production Cost. The development of new climbing bean varieties carries substantial costs for selective breeding and field testing which are typically carried by the public sector and donors. The transfer of improved climbing beans from institutions to private seed companies and farmers may require licensing agreements. Multiplication of climbing bean varieties is easy and inexpensive, and since they are self-pollinated farmers can save the best grains as planting material for the next season. Growing climbing bean is labor-intensive since they require staking and because of their large biomass production, climbing beans also require more nutrient inputs.

Customer Segmentation and Potential Profitability. Scaling the production of climbing bean involves a diverse customer base, including national programs, small-scale and commercial producers, private seed companies and food processors. Food security and incomes of farmers are significantly increased when they grow climbing beans, as has been demonstrated in Rwanda where for each additional kilogram of planted climbing bean there was an increase of 2.8% in bean consumption and 0.9% in total food intake. Households that grow climbing bean increase food security and decrease the likelihood of financial hardship.

Licensing Requirements. Varieties of climbing bean are sometimes marketed by private seed companies or national programs under a commercial license. However, the diffusion of the varieties happens through various integrated seed systems approaches including informal seed systems and community based seed production. Climbing bean varieties with high yield potential and nitrogen fixing ability have been developed as a Regional Public Good by ABC through the Pan African Bean Research Alliance (PABRA) in collaboration with national partners, who share the responsibility for delivering the technology to farmers via local and regional initiatives for agricultural transformation.

Technology 3. Seed Inoculation for Enhanced Nitrogen Fixation

Summary. The productivity of common bean is often limited by the availability of soil nitrogen (N), a condition that may be addressed not only through application of mineral fertilizers and organic resources but through symbiotic Biological Nitrogen Fixation (BNF). This process occurs in root nodules where rhizobium bacteria transform plant sugars and nitrogen gas into amino acids. This process is increased by inoculating planted seed with elite strains of rhizobium (such as CIAT 899) that have been selected for high plant compatibility and N fixation ability. These bio-fertilizers are available as dry or liquid formulas for seed inoculation from private companies, national agricultural systems and research laboratories. Seed inoculation of common bean crops with elite rhizobium has demonstrated to be a cost-effective technology for increasing legume production on small-scale farms in Africa that depend on it for food, nutrition and income. More information on inoculation of bean is available from Dr. Boaz Waswa of ABC by email b.waswa@cgiar.org.

An example of a commercial inoculant for common bean manufactured in Kenya

Technical Description. Seed inoculation involves coating elite rhizobial bacteria onto seed just before planting, a practice that ensures effective symbiosis and high levels of nitrogen fixation. As legumes germinate, the beneficial microorganisms colonize the roots by developing nodules where the host bean plant supplies carbohydrates in exchange for readily-available N fixed by the rhizobium that the crop uses for assimilating proteins and other compounds. Nodules are visible on root surfaces and when actively fixing N their interior is pink or red. Rhizobium bacteria are specific as to which type of legumes and crop variety they effectively associate with and this forms the basis of matching strains with hosts like common bean. Because many agricultural soils in Africa lack highly effective native rhizobial in their soils, it is recommended that farmers introduce elite rhizobia. The manufacturing of high quality inoculants enables widespread deployment of this technology in common bean production across African countries. Improvements to formulations and the advent of inoculants' quality control systems have played an important role in this commercialization. The technology however needs to be carefully implemented since the presence of large numbers of less effective native rhizobia in soils may reduce the benefits of inoculation, confusing those who seek to adopt it.

Uses. Seed inoculation with elite rhizobia is a financially and environmentally sustainable approach to increase N availability for common beans. The low cost of the BNF technology compared to inorganic fertilizers makes it attractive to both small-scale farmers with limited resources and commercial farmers who seek to reduce costs of production. N fixation is sensitive to soil pH (the optimal being 5-8), low phosphorus availability, extreme temperatures, drought and excessive moisture. There is large scope for inoculation of common beans on soils that suffer from nutrient depletion but requires accompanying inputs of phosphorus, micronutrients and lime to effectively harness its benefits for enhancing production.

Nodules with N-fixing bacteria on bean

Composition. Inoculant products for common beans typically contain single or mixed strains of rhizobium such as USDA 9030 or CIAT 899, strains with widely proven abilities for nitrogen fixation. The exact strain that is used for inoculation may vary between particular regions since it needs to out-compete less effective native populations. Solid formulation inoculant products also contain a carrier material that protects rhizobia during storage and transport, and allows for ease in handling and application. These inoculants are mixed with adhesives such as gum Arabic solution to coat the inoculant onto seeds just before planting. There are also liquid formulas that can be applied to seed that are better suited for mechanized planting.

Application. Elite strains of rhizobia are conserved by dedicated laboratories and transferred to commercial manufacturers who produce inoculant products by culturing them under controlled conditions. Proper storage and handling of these inoculants is key to protecting the efficacy of this product. This includes protection from direct sunlight and overheating. Dry inoculants may be applied using either the two-step or slurry methods, with the latter approach preferred for larger quantities of seed. Liquid formulas are sprayed onto seed or applied within mechanical seed hoppers. Inoculated bean seed is planted in a manner that restricts direct exposure to sunlight and it is best to inoculate and plant the seed during the same day.

The "two-step" procedure of seed inoculation that results in effective coverage with elite rhizobial (Source: the N2Africa Project)

Commercialization. Inoculant products for common bean are available from private companies and public institutions in several African countries and the products are marketed through networks of agro-dealers. Improvements of the inoculants' shelf-life and ease-of-use as is the case with liquid formulas offer an avenue to readily expand their use in common bean production. The product is best stored under refrigeration (but never frozen). Once a company produces inoculant for one legume (e.g. beans), it is easy to do so for additional legumes by simply adjusting the strain of rhizobium.

The "slurry method for inoculating large quantities of seed with elite rhizobia (Source: the N2Africa Project)

Start-up Requirements and Production Costs. Bringing inoculant products to agricultural input markets and realizing widespread adoption by farmers requires a set of actions: 1) Sensitization about the benefits of inoculation on common bean yields and input use efficiency, 2) Manufacturing of proven effective inoculant products that meet quality standards, and 3) Providng access to the biofertilizer technology and related agronomic advisory for farmers through agrodealer networks. The isolation, identification and field testing of elite rhizobia for common bean crops suitable for specific growing areas demands significant investments from the public or private sector. The total cost of manufacturing one ton of dry inoculant is about $15,000 with 40% going to equipment and materials and 60% to labor and packaging. Market prices for one sachet of 100 g dry formula inoculant are US $2.5 to $4, and this suffices to dress 10 to 15 kg of seed.

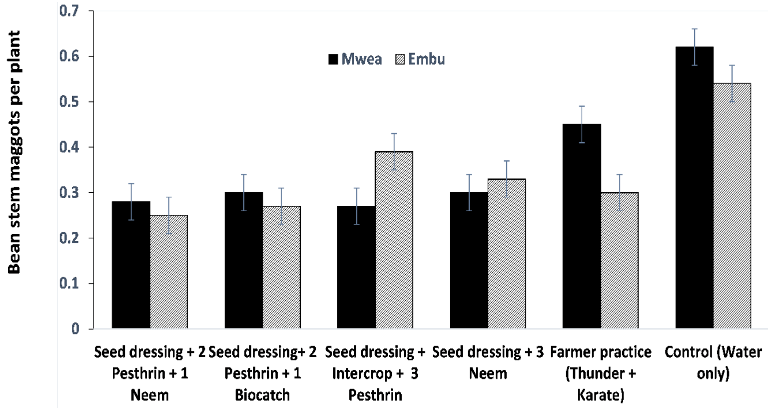
Customer Segmentation and Potential Profitability. Seed inoculation of bean is suitable for both small-scale and commercial farmers. Manufacturing and marketing of the biofertilizer products involves commercial input suppliers and agro-dealers. Seed inoculation with rhizobia reduces the cost of production owing to the fact that BNF replaces the use of mineral fertilizer while achieving the same or higher yield. In this respect, farmers save about US $50 per ha on fertilizer and US $30 ha on labor. High levels of N fixation in common bean realized through inoculation moreover reduce N fertilizer requirements for cereal crops grown in rotation, substituting 30 to 80 kg of N fertilizer per hectare (i.e., US $32 to $86). Seed inoculation presents a cost-effective and sustainable approach for intensifying the production of common bean in farming systems across Africa.

Licensing Requirements. Developers of inoculants for common bean issue commercial licenses to private companies or national programs for its production and marketing, and quality control is conducted by regulators. Elite strains of Rhizobium that are provided by research institutions are Regional Public Goods, and both ABC and IITA assist in this area.

Technology 4. Dressing of Seed with Fungicide and Insecticide

Fungal wilting of seedling (left) and damage to bean sprout by stem maggots (right)

Summary. Attacks of common bean by fungal diseases such as anthracnose, damping off or root rots, and insect pests like stem maggots are responsible for large yield losses in Africa. Control measures against these pathogens have to be taken early on in the season for avoiding damage of common bean crops. The small gains in common bean yields across Eastern and Southern Africa that were made over the past 30 years despite an increase of the cultivated area is in large part attributed to diseases and insects. Such infestations also pose major risk to the profitability of improved varieties and fertilizer inputs by farmers. Dressing seed of common bean with chemical control agents for diseases and pests offers a cheap and environmentally friendly technology to prevent losses and enhance production. The seed treatment approach uses minimal amounts of pesticides and results in better seedling emergence that in turn strengthens the resistance of crop stands throughout the growing season. For more information about this technology please contact Dr. Boaz Waswa of ABC by email at b.waswa@cgiar.org.



Effect of seed dressing and other control measures on infestation by bean stem maggot in Kenya (Source: Muthomi et al. 2018)

Technical Description. Common bean **d**iseases such as anthracnose, bacterial blight and angular leaf spot, and insect pests such as bruchids are harbored by seed, and lead to destruction of planting stocks and potentially affect large areas of farmland. On the other hand, soil-borne diseases like wilts, rots and rusts, and insect pests like bean stem maggots plague seedlings of common bean which can lead to sparse plant density or even total crop failure. The technique of seed dressing makes it possible to keep common beans free of these diseases and pests during seed storage and seedling emergence. Use of seed dressing achieves a very high degree and efficiency of crop protection since it guarantees uniform application of control agents and delivers these where they are needed most. In this way the method minimizes undesired effects on non-target organisms in soils and spillage of chemicals into water bodies such as is the case for broadcast spraying of crop stands. The advantage of seed dressing is that it doesn't require specialized equipment and can be easily performed at farms and factories, making it a solution that can be widely adopted. Farmers producing their own bean seed may also take advantage of this technology by purchasing inexpensive packets of seed dressing pesticides. It is important that seed dressing products be colored in a way that they are identifiable and accompanied by warning messages so that treated seeds are not consumed as food.

Uses. Seed dressing technology for fungicides and insecticides is strongly recommended in all major production areas of common bean due to the high prevalence of diseases and pests. Seed dressing products such as Syngenta's APRON STAR® contain a fungicide and insecticide mixture for controlling fungal diseases (e.g. Pythium and Fusarium) and early season insects pests (e.g. stem maggots, termites, thrips and whiteflies) including ones that serve as disease vectors. As a result, root development is stimulated leading to vigorous starts, uniform growth and higher yields. Benefits continue for about three weeks after planting. The approach is very suitable for tropical regions with cool and humid climates that favor the proliferation of fungal pathogens. Control agents for a large number of pathogens can be coated onto seed in ways adjusted to soil type and pest and disease conditions. Fungicide and insecticide seed treatment lies at the foundation of precision agriculture and integrated pest management, contributing largely towards sustainable intensification and strengthening resilience of common bean.

Example of common bean seed treatments with fungicide and insecticide

Composition. Control agents for seed dressing are sold in both liquid and dry formulations. Combinations of different chemical substances can be used for seed treatment based on guidelines provided by the suppliers and should not be confused with products intended to protect beans during storage as food. The most common broad-spectrum fungicides for seed dressing are tetramethylthiram disulfide and N-trichloromethyl-thio-4-cyclohexene-1, 2-dicarboximide, which have low toxicity. Some systemic fungicides, such as metalaxyl, offer protection against fungal diseases up to maturity of the plant. Insecticides against bean stem maggot and thrips used for seed dressing include N-methylcarbamate, imidacloprid and thiamethoxam. "Do it yourself" seed treatment products containing both fungicides and insecticides are also available.

Application. Bean seeds have to be weighed for ascertaining the dosage of chemicals that is required. Liquid formulas may be directly coated or after dilution, whereas dry formulas contain adhesives and are added directly to seeds. Seed dressing can be carried out manually using common receptacles or mechanically in mixers and hoppers. Treating smaller volumes of seed can be done inside a plastic bucket or basin, or by spraying seed with the solution on top of a polythene sheet. For dressing large volumes, community-based and commercial seed producers can make use of a rotary drum that is powered by hand or motor. Common beans that are treated with control agents are planted following recommended land preparation, spacing and fertilizer inputs in a particular growing area.

Commercialization and Start-up Requirements. Fungicide and insecticide products for seed dressing of common bean are sold by companies in Sub-Saharan Africa and on international markets. This technology is widely used by commercial seed manufacturers to safeguard the quality of its planting material and reach high levels of emergence. Ironically, the uptake of seed treatment techniques by small-scale farmers in Africa remains low. Accelerated deployment of this innovation can be realized across common bean growing areas through these actions: 1) Identifying and developing effective pesticides for seed treatment to control diseases and insect pests, 2) Raising awareness with farmers about the benefits and availability of seed dressing pesticides, 3) Providing access to seed treatment for community-based and commercial seed multipliers, and by agrodealers and 4) Linking producers to financial support and markets. Bean seeds marketed by commercial seed companies are almost always treated, but seed bought as grain and used for planting are not. Creating further demand for these seed coating products, both inoculants (see Technology 3) and pest and disease management is an important step in the commercialization of bean production among small-scale farmers.

Production Costs. Fungicides and pesticides for seed dressing have variable retail prices depending on its level of concentration and efficacy. At prescribed dosages the chemicals alone cost US $0.5 to $1 for treating one or two kilograms of seed. Manual application makes use of equipment that can be purchased for less than US $50, whereas rotary drums for mechanized application are sold at US $500 for a small unit and US $2,000 for a large unit. Training is important because treating seed requires knowledge and skills to be performed properly and safely.

Customer Segmentation and Potential Profitability. Seed dressing with chemical agents to control seed and soil borne pests in common bean production is attractive for small-scale and commercial farmers, and opens a new product line for community-based multipliers and local agro-input dealers. This way of delivering fungicides and insecticide has several advantages over broadcast spraying as it enhances the precision and effectiveness of crop protection while reducing the required dosage and associated costs per land area. Studies in major production zones with diverse soils and climate have shown that seed dressing leads to greater numbers and evenness of plant stands. Treatment of seed with pesticide reduces common bean yield losses up to 70%.

Licensing Requirements. Agrochemical companies and agrodealers may require a phytosanitory and product safety license to distribute seed dressing pesticides in compliance with regulations from national regulatory bodies specific to the different countries. Intellectual property about the composition of fungicides and insecticides for common bean crops is commercially owned.

Technology 5. Specialty Blends of Fertilizer for Basal Application

Summary. Common bean production in Sub-Saharan Africa suffers widely from low nutrient availabilities in soils. To counter this conditions, blends of fertilizers specifically for common bean are known and available that provide a balanced supply of nutrients. These fertilizer blends contain phosphorus, potassium, sulfur and other nutrients in proportions that are aligned with soil fertility status and crop requirements. In some cases, small amounts of "starter nitrogen" are included. Readily accessible types of fertilizers and manufacturing facilities in Sub-Saharan Africa can be used to make additional specialized blends for bean farmers. Applying the right fertilizer at the right time and place to common bean greatly enhances nitrogen fixation, productivity and nutritional value, and strengthens resilience to drought and pests. Specialty fertilizer blends allows farmers to obtain greater returns on input investments. For more information on this topic contact Dr. Boaz Waswa of ABC by email at b.waswa@cgiar.org.

Example of a fertilizer blend

Technical Description. Formulations of blended fertilizers balance and replenish nutrient stocks in soils, which ensures that the added inputs are utilized more efficiently for increasing common bean production. The various elements that are mixed together have specific benefits; i.e., phosphate and potassium enhance flowering and pod filling, sulfate reinforces photosynthesis and transpiration, and calcium, magnesium and zinc promote the uptake of nutrients and water from soils and raise the nutritional value of beans. Use of specialty fertilizer blends for common bean has very strong synergies with biological nitrogen fixation (Technology 3), as they are made in a way that boosts symbiotic activity. Mixing phosphorus fertilizer with potassium, calcium, magnesium and zinc provides consistent yield advantage because it allows the crops to absorb more nutrients, particularly under acid soil conditions common across the tropics. In some cases, small amounts of mineral nitrogen (e.g. 25 kg per ha) stimulate root growth and results in greater early nodulation. Blending technology offers a very large degree of flexibility to adapt fertilizer formulations in line with general soil characteristics and production objectives, as is prescribed by the guiding principles of Integrated Soil Fertility Management.

A multichannel blender in operation at MEA Fertilizers used to produce SYMPAL for grain legumes in Kenya

Fertilizer mixes designed for common beans can be suitable on other types of grain and forage legumes and this versatility is advantageous for input manufacturers and farmers.

Uses. Fertilizer blending technology is suitable for all major growing areas and especially important in low fertility soils. Specialty blended fertilizers applied at the rate of 100 to 150 kg/ha in common bean fields, combined with improved bean varieties and rhizobium inoculants greatly improves the health of plants and their yields and nutritive value. This approach is particularly important when farming highly weathered soils characterized by low fertility status and pH imbalance.

Composition. Specific nutrient formulas can be made by blending a wide range of solid granular types of fertilizers like sulphate of potash (50% K_2O), potassium chloride (50% K_2O), single Superphoshate (16 to 20% P_2O_5, 11 to 21% Ca and 11 to 12% S) or Triple Superphosphate (46% P_2O_5). In addition blending with small amounts of nitrate-bearing fertilizers providing "starter N" is sometimes necessary especially for common bean. Micronutrients like zinc, boron and copper, amongst others can be added in solid form or impregnated as liquid. A good example is the legume fertilizer blend manufactured in Kenya known as Sympal containing: 23% P_2O_5, 15% K_2O, 10% CaO, 4% S, 1% MgO and 0.1% Zn.

Application. Information about the nutrient deficiency and imbalance in specific growing areas is contained within soil maps and past agronomic trials, sufficient for developing blended formulations. However, since soil fertility varies a lot even in specific locations, it is recommended that farmers have their soils tested. The production of the specialty fertilizer blends is also subject to the availability of different single fertilizers. Manufacturing of specialty blended fertilizer is done using a dry rotary system available at medium to large sizes, and is best packaged into sizes needed by farmers.

Commercialization and Start-up Requirements. Fertilizer blends designed specifically for legumes such as common bean are becoming available across Africa but only manufactured by a few fertilizer companies. Their specific composition, formulation and means of combination are often protected by trade secrets. To produce a new blended fertilizer, the following steps are required: 1) Derive the formula of blended fertilizers based upon nutrient demands and the soil fertility conditions requirements across a large production area, 2) Establish manufacturing protocols for mixing different sources of fertilizer and packaging the blend, 3) Sensitize agro-dealers about the benefits and profitability of specialty fertilizer blends and provide customer information about them, 4) Provide these branded fertilizers at affordable prices on local markets and monitor their sales, and 5) Conduct demonstrations and trials to assess the efficacy of a blend compared to other management options, and refine the formulation and branding campaigns over time as needed when entering into new bean production zones.

Production Costs. Designing a new fertilizer blend needs not be expensive as it can be based upon desk study from a wealth of secondary information, including the composition of similar products. Refining that blend over time based upon agronomic trials and plant and soil analysis is considerably more expensive. Manufacturing specialty blended fertilizers bears a considerable start-up cost based upon capital investment for multi-channel dry rotary systems and automated packaging. There is also the cost of assembling the primary fertilizers to be blended. These costs are considerably reduced for fertilizer companies with existing blending capacity that is seeking to expand their product lines. Smaller, more labor-intensive blending systems may be developed for localized operations, and even operated as a community-based operation once specific formulations are known.

Customer Segmentation and Potential Profitability. Blended fertilizers are intended for use by common bean producers through distribution via agro-dealer networks. The profitability of fertilizer blending is not based upon crop response to individual component fertilizers, but rather their improved response to strategic combinations of those ingredients, a feature that well informed farmers are willing to buy. Basically, blended fertilizers should offer returns that are greater than the sum of the ingredient parts. Combining two or more needed fertilizers offers more efficient labor operations as well. The profitability of using blended fertilizer for common bean (legume) production can increase returns by 50%. In some cases where nutrients are extremely limited, application of combined nutrients can result in a 10- to 16-fold return on investment.

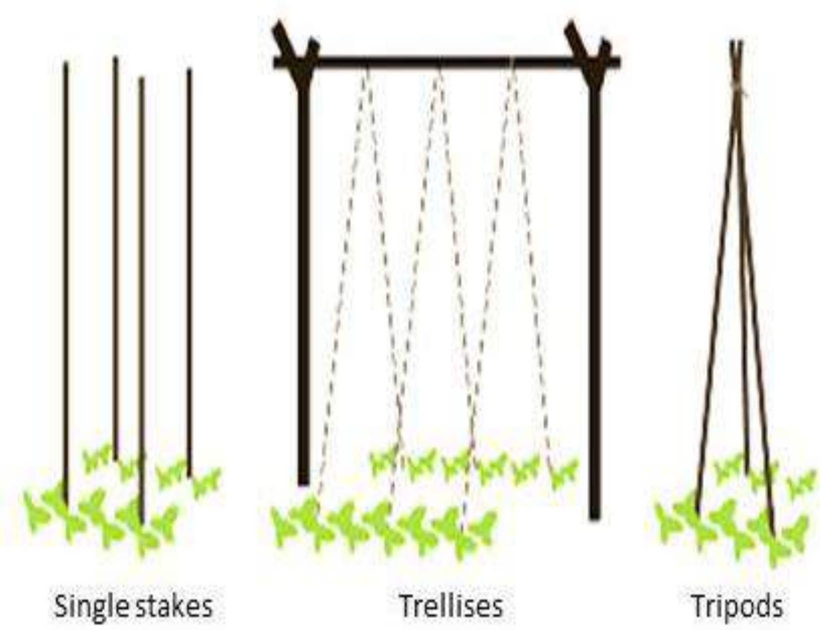
Licensing Requirements. The formulations of fertilizer blends may be subject to licensing but are more often protected as trade secrets. Those with knowledge of fertilizer composition may easily calculate desired blend proportions from different primary fertilizer materials. Responses to fertilizer application and combination are abundantly available as published information, particular when performed by research institutions as Regional Public Goods. ABC and IITA offer support for testing and scaling of specialty fertilizer blends.

Technology 6. Low-cost Staking of Climbing Beans

Summary. Adopting climbing bean offers a potential for increasing bean production in Africa (see Technology 2), however a major challenge to growing climbing beans is the requirement for plant support. Many farmers find this added expense difficult to meet and inadequate staking results in yield loss of 50% to 90%. This challenge is the most limiting factor for optimized yields and advancing wider adoption of climbing beans. Optimal staking of 50,000 stakes per hectare is challenged by a paucity of available wooden stakes. Overharvesting of stakes is also associated with deforestation and delayed afforestation, placing it at odds with environmental gains. Adequate staking requires an understanding of optimal plant density, appropriate length, and durability. A suite of farmer-acceptable, lower-cost and environmentally-friendly staking innovations is available. In particular, tripod arrangement or a strategic combination of stakes and string trellises results in the reduction of the wooden stakes needed. For more information about staking climbing beans please contact Dr. Boaz Waswa of ABC by email at b.waswa@cgiar.org.

Single stakes for climbing beans

Technical Description. Several low-cost staking methods present a range of options. Selection is largely dependent on availability and durability of different materials, labor requirements and costs. These technologies promote innovations that reduce the number of stakes per unit area and make the best use of readily available materials. Generally, the highest yields are obtained with stakes that are at least 2 meters tall and a staking density of at least 20,000 stakes per hectare. Up to that point, the taller and more sturdy the stakes are, the higher the yield! There are also returns to increasing the number of stakes to 50,000 per hectare. Stakes may be obtained from agroforestry species and tall grasses such as elephant grass (*Pennisetum atropurpeum*). Fast-growing agroforestry species suitable as stakes include *Acacia angustissima*, *Alnus acuminata*, bamboo, *Calliandra calothyrsus, Gliricidia sepium, Sesbania sesban and Vernonia amygdalina.* Such low cost staking arrangements include 1) single staking with less expensive materials, 2) wood and string trellis combinations, 3) tripod staking, and lastly 4) live plant support. When the beans reach the top of the trellis, the growing point of the main shoots should be pruned. This reduces height for easy harvesting and increases the growth of lateral shoots. If sticks are too short, the tip of the bean plant will flip over and fewer pods will form on those unsupported branches, while if stakes are too long (e.g. > 2.5 meters) the beans plants will produce excessive vegetative growth and provide fewer but less unreachable pods.



Different types of stakes for climbing beans

Uses and Composition. Low-cost staking of climbing beans assumes adequate supply of agro-forestry tree species or larger shrubs. Single staking relies upon stronger, longer woody stakes. These may be produced around farm boundaries or in small woodlots. Stakes may be recovered from larger trees as well such as Eucalyptus or Grevillea but care should be taken to not actively deforest areas, especially hillsides. Tripod staking has been adopted in regions with shallow soils and where the available staking materials are not very strong such as those from Pennisetum and involves tying 2, 3 or 4 long stakes together. Staking is often combined with string or wire trellises. From this horizontal stake or string, many ropes fall vertically over the climbing beans and act as support. Live staking in combination with additional woody stakes uses intercrops stems such as maize and cassava to support the climbing bean.

Application. Climbing beans can be planted in both row and hills. In rows, seeds should be spaced 15-25 cm apart allowing 50 cm between rows. Two seeds are placed in each station to give a plant population of approximately 200,000 plants/ha. The sticks are sharpened prior to staking for ease in ground penetration. The stakes should have a rough surface to help the plant to grip and should be at least 2 meters in height. Staking is required about two weeks from seedling emergence. In single staking, a stake can support 1 to 4 plants with an inter-stake space of 0.4 meters while each stake of the tripod can support 1 to 3 plants. Connecting stakes increases their strength. Wooden string trellises can accommodate two adjacent bean rows. Vertical strings may be replaced by nets with openings of 10 cm (e.g. “cucumber netting”) secured to the ground with stakes or wires. Lower cost vertical support may be obtained from reeds, strips of tree bark or even stems of a creeping plants and vines. In live staking, after maize harvest, the strongest stalks are left to serve as stakes for the climbing beans the following season. Alternatively, four maize stalks are tied together at the top to form a tent-like structure, forming the basis for a maize-climbing bean rotation.

Commercialization and Start-up Requirements. The construction of stakes is mostly done by farmers themselves but as climbing bean production and marketability expands there are opportunities for service providers and suppliers to set up commercial staking enterprises. Widespread adoption of the low cost staking approaches can be achieved by: 1) Raising awareness about the benefits of proper staking on climbing bean yields, 2) Sensitizing farmers on the available low-cost technologies that can be used for staking, 3) Disseminating decision support tools and recommendations through farmer networks and extension agencies, and 4) Ensuring access to small loans that help offset initial investments for staking materials and labor.

Production Costs. Information on these low cost staking innovations is free and can be downloaded from the internet. Larger wooden poles are relatively expensive and their harvesting may raise environmental concerns. The construction of trellises or use of live stems for staking significantly reduces the number of wooden stakes. Production and use of rapidly growing multipurpose agroforestry species enables farmers to produce their own stakes and when purchased, are less expensive.

Customer Segmentation and Potential Profitability. Low cost staking is important to smallholders’ farming systems, especially poorer households. The technology has also enabled adoption of climbing bean cultivation by farmers in new and non-traditional bean growing areas. Climbing beans have potential to provide farmers with yields three times greater than bush beans. The construction of trellises or use of live stems in combination with wooden stakes significantly reduces the number of wooden stakes needed and the minimum loss of grain yield benefits per unit area. In Rwanda, farmers preferred a staking density of 16,667 wooden stakes per hectare combined with string trellis that resulted in reduction of the staking rate by 67% with insignificant yield reduction. A promising trend is that in areas where climbing bean is widespread, the cost of stakes may decline as more farmers take interest in their production and sales.

Licensing Requirements. Farmers do not require licenses for adopting the low cost staking innovations, while the cutting of trees for poles may be subject to environmental regulations and community by-laws. Manuals for implementing low cost staking technologies in climbing beans and other crops requiring support are disseminated as a Regional Public Good by several research and development organizations including the TAAT High Iron Bean Compact.

Technology 7. Mechanical and Chemical Weed Management

Summary. Common bean is a relatively weak competitor with weeds and when overgrown by them yield losses from 60 to 100% can occur. Encroachment of weeds causes inefficient use of fertilizer inputs and may harbor pests and diseases, or exude chemicals that have negative impact upon bean root systems (allelopathy). Tall-growing weeds shade the crop, making stems weak and easily lodged by wind or rain. Effective weed control is key to achieve high levels of bean yield and climate resilience, yet manual removal from fields involves drudgery and expense. Chemical and mechanical techniques are available that reduce the costs and keep bean crops free from weeds throughout the growing season. These approaches give rise to greater productivity, nutritional quality and palatability of common beans in comparison to manual removal methods in ways that increase profit margins. For more information on weed management strategies in bean please contact Dr. Boaz Waswa from ABC by email at b.waswa@cgiar.org.

Green foxtail (Setaria viridis) encroaching upon bush beans

Technical Description. Weed encroachment has particularly negative effects on common bean from the time of planting up to canopy closure. The use of chemical and mechanical techniques removes weeds that would otherwise compete for light, nutrients and moisture thereby improving the development of roots and shoots. Pre-emergence control of weeds is possible by applying herbicides shortly before or at the time of planting beans which ensures bean crops do not become overgrown at early growth stages. Post-emergent control between seedling and pod filling stages can be accomplished with herbicides, weeders or a mix thereof. Farmers are able to control grassy weeds inside bean stands with common types of herbicides whereas for broadleaf weeds they need to apply selective herbicides that will not harm the growth of the legume crop. Motorized equipment that greatly reduces labor requirements compared to hand methods are available for controlling weeds but are limited to evenly planted rows and the row spacing must be adjusted to available equipment to avoid damage to the crop. Small-scale farmers tend to grow beans alongside with other food crops like maize, cassava or banana in which case both mechanical and chemical control options become less available.

Uses. Weed management with herbicides and weeders is suitable for all types of bean growing areas in Sub-Saharan Africa. The time saving and yield gains that are achieved by these approaches strongly resonate with small-scale farmer communities where availability of labor for manual removal is limited. Herbicides are available for most weed species that occur in SSA and their application is not restricted by soil conditions. Motorized weeding units of various sizes and configuration match the technical and financial capacity of small-scale and commercial farmers, however they are not appropriate when the foliage of beans has fully developed and on fields with a steep slope or during times of soil wetting as this reduces access and workability.

Mechanized weeders: A mini-tiller with vertical tines (left), a cutter with horizontal rotating blade (center), and a multi-purpose backpack weeder (right)

Composition. There is a large assortment of pre- and post-emergence herbicides for weed management in pure stands of common bean, such as Catapult® 480SL, Hotline® 450 SC, Bentagran Top® 240EC, and Forester® 150 EC. For maize-bean intercrops the pre-emergence herbicide DUAL GOLD® 960 EC offers a solution to avoid encroachment by grassy and broadleaf weeds. Before application to fields, the chemical agents must be diluted with clean water, and often adjuvants are added to pre-made formulations or spray tanks for enhancing herbicidal activity and adhesion. Equipment for weeding row-planted crops either cut them at the base or bury weeds through shallow tillage. These weeders can be fitted onto walking tractors and backpack kits for greater maneuverability.

Application. Chemical weed control management should be prioritized on fields with the highest level of weed encroachment and the more difficult to control weeds to maximize returns, with the intention to steadily decrease weed seed banks over time. Herbicide sprays should take place one week after tillage or latest before the bean crop is 10 cm in height. Soils should be moist, not too wet or too dry, when fields are sprayed thus requiring the time of application to be synchronized with rainfall and time of day. Protective clothing should be worn by workers that apply the herbicides to avoid contact with chemical agents. Use of motorized weeders requires that bean crops are planted in evenly spaced lines so the work can be done at pace without damaging the stems or roots. Depending on the level of infestation and rate of canopy growth, farmers are required to use power weeders once or twice during a season. The equipment can be operated by only one person, but to cover larger areas two or more operators working in conjunction are needed.

Commercialization and Start-up Requirements. Agro-input suppliers and local dealers in most African countries are marketing herbicides that are designed for eradicating different types of weeds, including those of common bean and other field legumes. Power sprayers and small-sized rotary weeders are less widely marketed but nonetheless available. Scaling of chemical and mechanical weed control strategies by farmers requires the following steps: 1) Awareness raising about the benefits of chemical and mechanical weed management techniques on production, 2) Capacity development on safe practices for use of herbicide spraying and motorized weeders, and 3) Access to financial support for local suppliers, farmers and service providers that catalyzes investments in small-scale mechanical devices.

Production Costs. Spraying pre-emergence herbicides requires some investment by farmers to purchase herbicides and access spraying equipment. Pre-emergent herbicide and the labor to apply these cost about US $27 per hectare. Mechanical weeders range in price between US $250 and $500 depending on type and selection of attachments. For a single row motorized weeder operating at a rate of 0.026 ha per hour the costs for equipment are about US \$7 ha^{-1}, while the costs for labor is about US \$39 ha^{-1}, resulting in a total cost of US \$46 ha^{-1}. This cost decreases as larger, multiple-row weeders are employed. As with all other farm equipment, knapsack sprayers and power weeders require periodic maintenance and availability of replacement parts. There is advantage in collective purchase and shared use, or private agricultural service contractors, for scaling the technology across low-income bean growing communities.

Customer Segmentation and Potential Profitability. Chemical and mechanical weed management techniques intended for small-scale and commercial bean farmers are reinforced when products, equipment and recommendations are delivered by agro-input suppliers and local enterprises. Mechanical weeders are not commonly available and agrodealers should consider expanding their product lines to include them, possibly through franchise arrangements with importers and industrial distributors. In Ethiopia, applying the herbicide S-metolachlor at 1 kg ha^{-1} one day after planting common bean alongside with uprooting of weeds at 4 weeks after emergence reduces weed biomass by 50% and increases grain yield by 1.1 ton ha^{-1} compared to non-treated fields. This weed management strategy resulted in a net profit of US \$743 ha^{-1} which is 35% higher than conventional hand management.

Licensing Requirements. Distributors of herbicides must comply with national regulations and agrodealers require licensing to supply local markets. Mechanical weeders are for the most part imported and many, but not all African countries have laws permitting their duty-free entry. The development and scaling of herbicides and power weeders is performed primarily by private companies, often in collaboration extension advisors.

Technology 8. Integrated Management of Insects, Diseases and Weeds

Summary. Common bean is susceptible to diverse pests and diseases that strongly impact on its productivity. At the same time, inappropriate chemical use may cause health and environmental risks and result in resistance to pesticides. For instance, use of chemical substances to control pests like beetles, aphids, cutworms, leaf spots, crown rots and common grassy or broadleaf weeds poses selective pressure on these organisms that leads to the emergence of biotypes that are resistant to those pesticides. Failure to address this issue results in food insecurity and loss of income as well as distorting natural control mechanisms. Integrated pest management (IPM) is based upon diverse biological, mechanical, physical and cultural methods that bring about effective and longer lasting crop protection without posing dangers to food safety and the environment. For more information on IPM for common bean please contact Dr. Boaz Waswa from ABC by email at b.waswa@cgiar.org.

Severe attack of black bean aphids

Technical Description. IPM aims to harness natural control mechanisms for pests and use chemical pesticide substances as little as possible. The primary focus is maintaining a well-balanced population of beneficial organisms based on current knowledge of their life cycles and interactions with the environment. IPM strategies involve carefully selected mixes of biological, mechanical, physical and cultural techniques that are tailored to local conditions and ensure the yield benefit exceeds implementation costs. A wide range of biological measures can be used that directly affect the target pest such as releases of natural predators and enemies, or sterile insects that dilute breeding populations. Increasing the abundance of beneficial communities or introducing new species must be done cautiously to avoid detrimental impacts on non-target organisms. Mechanical and physical interventions involve equipment that deter or disturb pests including rodents and migrating insects. Cultural measures avoid accumulation of pest and weeds and include practices such as precision sowing, shifting planting dates, removing residues of diseased plants, establishing plant strips that shelter natural predators, deployment of pheromone traps, and reliance upon pest-resistant varieties. IPM interventions can suppress multiple threats at the same time such as the case for aphids which transmit diseases like bean common mosaic virus.


Hoverfly larva feeding on aphids

Uses. Effective IPM strategies are available for many important pests of common beans, including aphids, mites, maggots and cutworms, diseases like anthracnose, white mold and bacterial blight, and weeds like wild oats, sedges and pigweed. The principles of IPM can be implemented across different soil types and climatic conditions. Mechanical, physical and cultural techniques may match a very broad set of agronomic and environmental conditions, and can be easily modified to local contexts. Biological techniques suit a narrower range of geographies that is delimited by the physiological traits of beneficial organisms and the composition and management of native communities.

Composition. Release of beneficial control agents follows two basic approaches; ‘inoculative’ where a limited number of advantageous organisms are introduced and accumulate up over time, or ‘inundative’ where massive rearing leads to the dispersal of large numbers of organisms. The inoculative technique is suitable for long term interventions, whereas the inundative technique immediately results in suppression of pests that counteract severe outbreaks. Reproduction and survival of natural predators and enemies can be enhanced by providing alternative nesting and feeding sites. The sterile insect method effectively decreases reproduction rates of pests by releasing infertile males that rival fertile males and cause unsuccessful breeding with females. The cultural practices for managing pests in common bean include use of early maturing and disease resistant bean varieties, clean seed and irrigation water that is free from insects, diseases and weed seeds, rotation with non-host crops, mulching, and adjusted row spacing and planting times. Increasing crop density and decreasing row spacing is effective to suppress the growth of weeds and their seed banks over time. IPM strategies minimize the need and application rate of chemical substances to control pests by methods like seed coating (see Technology 4) and pre-emergent herbicides (see Technology 7).

Application. Implementing IPM strategies begins with identifying the type and number of harmful and beneficial organisms on a farm, and establishing critical thresholds in the community structure when economic injury to common bean take place. Monitoring pests is performed using simple tools such as traps and handheld magnifying glasses, or with advanced high resolution cameras fitted onto drones that allow rapid surveillance of large areas. Inspections of weeds is performed between emergence and canopy closure, and again post-harvest to avoid carry-over. Insect and disease surveys are conducted simultaneously and must be repeated at different growth stage from emergence through early flowering and pod filling. Software tools and participation in specialized social media offer means to track and identify pests and natural enemies, and refine IPM strategies. Once the threshold population of harmful organisms is reached then prescribed actions are taken, a strategy very different than precautionary spraying with agro-chemicals.

Commercialization and Start-up Requirements. IPM techniques for common bean are offered as part of consulting services by private companies and extension messages. Farmers may adopt IPM solutions after 1) Identifying the full range of pests and beneficial organisms that counteract them, 2) Defining management strategies in comparison to conventional practice, 3) Understanding the benefits for pest control and production costs in the short- and longer-term, and 4) Accessing control agents such as reared predators and bio-pesticides agents and seeking advise on how best to use them.

Production Costs. Detailed surveillance of pests and their natural enemies for implementing IPM strategies requires specialized skills best provided by public agencies. For example, rearing colonies of parasitoid wasps requires inexpensive materials and planned releases across large areas requires only US $5,000 to install and a further US $6,000 per year to operate. Cultural measures to control pests slightly increase the workloads of farmers. Coating seed costs between US $0.50 and $1 per kilogram for strategic placement of insecticide and fungicide (see Technology 4). Use of pre-emergence herbicides requires as little as US $25 to $35 per hectare.

Customer Segmentation and Potential Profitability. Biological, mechanical and cultural techniques for IPM in common bean are intended for small-scale and commercial farmers, with products, equipment and use advisory being delivered by agro-input suppliers, local services providers and agricultural extension. Proactively managing the use of synthetic pesticide agents by implementing IPM-based control measures avoids outbreaks and large production losses when pests become resistant. The design of IPM strategies must be performed in a way that the cost and labor requirement of control techniques is lower than the economic damage to bean yields without taking those measures.

Licensing Requirements. Permits from national plant health agencies are needed for the rearing and release of biocontrol technology. Biological, mechanical and cultural measures included under IPM strategies are developed as a Regional Public Good. Intellectual property related the composition of fungicides and insecticides for seed treatment, and herbicides for weed control are commercially owned. The development and scaling of chemical control measures is done primarily by private companies, often in collaboration with regulatory authorities and research institutes.

Technology 9. Mechanized Threshing Operations

Summary. Threshing refers to the separation of seeds or grain seed from the harvested plant, and this is a tedious operation when performed by hand. Typically, women are assigned this task of hitting piled harvest with sticks until the grain falls loose and, in the case of beans where the whole plant is harvested and dried, it requires about four hours of work to recover 100 kg of seed. This labor requirement is becoming streamlined through increased reliance upon small-scale mechanical threshers able to process 300 kg of seed per hour. These machines are powered by small petrol engines and consist of a feed chute that leads to a threshing chamber where crop residues are separated from seeds in a rotating drum, and then a blower removes smaller residues. Multi-crop threshers are available to process additional crops such as maize, wheat, sorghum, sunflower and pigeon pea. Smaller threshers can be transported to farms by motorcycle and offer business opportunity to local service providers. More information on mechanized threshing is available from Alfred Chengula by email at info@imaratech.co.

Hand threshing of beans (Source: One Acre Fund)

Technical Description. Threshers are power equipment that separate crop residues from seed and grain in a time-efficient manner. Operators feed dried harvest materials through a feed chute, pushing materials into an internal spinning drum where seeds are physically separated from crop residues and then fall through a screen. Remaining crop residues are then expelled through an exit chute. Whole shoots may be passed through the machine rather than pods alone. These chopped materials have further use as organic resources. The seed is passed by a blower that removes finer materials (e.g. dust) that winnows (cleans) the seed, passing through a collection chute that allows the seed to be bagged. Different types of crops may be processed based upon the screen mesh. These threshers are often mounted on wheels and have handles that permit their movement. These threshers are operated by small engines (5 to 8 HP), weigh as little as 100 kg and consume only 1 to 2 liters of fuel per hour. These machines are able to process seeds and grain many times more rapidly than traditional threshing and winnowing operations.

The Imara Tech Multi-crop thresher consists of a 1) feed chute, 2) threshing chamber, 3) exit chute, 4) blower, 5) seed collection chute, and 6) petrol engine

Uses and Composition. Mechanized threshing is very labor efficient, allowing for the processing of between 150 to 500 kg of saleable product per hour, depending upon the crop. The smaller the seed, the more rapid the processing time. Harvest materials must be dried to harvest maturity before passing through the machine. Softer materials risk breakage and clogging the screens. Portable threshers are positioned next to piles of harvest on a level surface. Bags are readied to collect cleaned seed and grain. Multi-crop threshers are available that can process beans and other grain legumes, maize, sorghum and millet, wheat, sunflower and other crops, although on some cases the drum and internal screens must be adjusted to different crops. The smallest threshers weigh only 100 kg and may be mounted on motorcycles for on-farm use. Slightly larger machines may be established within communities for use by farmer groups. Owners and operators of these machines must be trained in the maintenance, minor repair and safe use of this equipment.

Application. Currently women and youth bear the major burden of threshing, and use of mechanized threshing frees their time for other more rewarding tasks. One example of this is provided by use of the IMARA TECH Multi-Crop Thresher, claiming to process beans 75 times more rapidly than is possible by hand. Not only is processing more rapid but also more thorough because the in-built blower cleans grain more completely than traditional winnowing. Typically beans are harvested as cut stems and allowed to dry. The thresher is provided by a service operator and set up in close proximity to these piles. Materials are passed through the thresher, separated into grain and residues. Care is taken not to pass dried root balls or stones through the machine as these are harmful. A tarp is set below the collection shoot to keep the seeds clean and to facilitate bagging. Residues must be periodically raked away as they are ejected from the exit chute. Operators must add plant materials into the feed chute with care, being cautious not to damage the equipment or themselves; hands or tools must never be placed into the feed chute. When the equipment jams, as when screens become clogged, the machine must be shut off before cleaning it. Also the threshers are cleaned before they are moved from one location to another, in part for purposes of field sanitation.

Small threshers are portable, permitting service provision at the farm level

Commercialization. There is scope for commercial provision of threshing services that make better quality grain available to households sooner after harvest. This post-harvest service may be provided by independent business interests or as a means of assuring grain quality to produce buyers. Marketing threshers is a different matter. This involves either distributing fabricated equipment or importing it. Some threshers are produced in Africa, and a large number are available for import. The description of the costs required to establish a manufacturing facility or the number of and comparison of models for importation are beyond the scope of this catalogue. A quick internet search discovered 110 such models from India and 52 from China, although some were intended for use on only one crop or for small grains only. Equipment powered by electricity cost less than those requiring petrol or diesel. Large discounts are available to those importing equipment in larger quantities.

Start-up Requirements, Production Costs and Profitability. IMARA TECH offers a detailed description of the commercial opportunity from the purchase and use of its Multi-Crop Thresher in Tanzania. The device costs US $780 and allows operators to earn income by reducing drudgery in small-scale farms with less than 80 hours of paid operation required to break even. Operators charge US $10 per hour and are able to process up to 225 kg of maize or 280 kg of beans per hour, claiming to relieve households of 40 hours of drudgery per acre of harvest. Assuming the lowest of farm wages, this results in savings of US $35 per day and reduces the cost of threshing by over 50% compared to paid manual threshing. One operator owns several machines and employs 20 people as a profitable business.

Licensing Requirements. These equipment are manufactured under patent and are marketed to users under warranty. Some generic thresher designs are available as Regional Public Goods but considerable expertise is required in their fabrication.

Technology 10. Hermetic Bags for Safe Storage of Beans

Weevil damage to stored beans

Summary. Large post-harvest losses of bean occurs across Sub-Sahara Africa because of improper storage techniques resulting in pest infestation that threatens the food security and livelihoods of farmers. As a result, farmers may opt to sell their produce immediately after harvest when market prices are at their lowest as a risk avoidance strategy. Grain storage pests such as weevils (bruchids) can be controlled by physical, chemical and biological methods. Some of the physical methods include use of hermitic storage bags and containers. The hermetic storage technology for grains avoids grain damage using sealed bags that prevents movement of air and moisture. The bags preserve the quality of grains and obstruct the entry of insects and microbial organisms through depletion of oxygen levels and accumulation of carbon dioxide. These conditions prevent damage by insects like weevils, moths and mites, curb development of fungi like aflatoxin that contaminate the grain, and maintain the taste and color characteristics of food. Hermitic bags allow for storage of grain without need to chemicals. For more information on hermetic storage bags please contact Dr. Boaz Waswa from ABC by email at b.waswa@cgiar.org.

Design of a hermetic storage bag

Technical Description. Hermetic bags are air-tight which prevents oxygen and moisture from getting to the grain stored within them. A multi-layer technology is used to modify the environment and restrict gas exchange with the outside atmosphere. Under this system, farmers can store grains for up to two years while retaining their palatability and cooking quality. This ensures that farmers have enough to eat in between harvests and can sell their beans when the price is more favorable. Grain quality is conserved through the regulation of moisture inside the bag and inhibits fungal growth that lead to build-up of carcinogenic mycotoxins. The cooking time of grains preserved in hermetically sealed bags remains the same as freshly dried ones whereas loss of moisture in traditional storage techniques may double the amount of time and energy that is needed for preparing grains as food. A germination test is recommended for the beans stored in hermitic bags if they are intended to be used as planting material.

Uses. Storage of grains is particularly susceptible to damage by insects and microorganisms under the hot and humid weather in Sub-Saharan Africa because these conditions promote the multiplication of pests. Losses of more than 25% in storage are common because current bagging and silo techniques of farmers, traders and food manufacturers do not provide ample safeguards to exclude and inhibit pests. Hermetic storage bags are well suited to the operations and infrastructure of both small-scale and commercial growers and processors, and the low cost of storage bags and ability to reuse these for several years are another advantageous feature of their use. This grain preservation technology is especially suitable in regions where the transportation infrastructure is poor, and where markets and processing industries are distant, as is the case across many bean production areas.

Composition. Hermetic storage bags have several protective layers with two separate inner liners made of high-density polyethylene with a thickness of about 0.8 mm and a polypropylene woven bag on the outside. A sealed environment is created by the inner bags that have very low permeability of gasses and are water repellent, allowing it to maintain stable moisture levels in stored grains under both dry and humid external atmospheric conditions. The outer bag provides strength to withstand handling and is adjusted to the weight of the grains it contains. A series of hermetic storage bags are marketed by different brands including the Purdue Improved Crop Storage (PICS), ZeroFly Storage Bags, Elite Storage Bags, GrainPro Storage Bags, and AgroZ Storage Bags.

Application and Commercialization. Threshed grains are dried to an appropriate moisture level and then placed into high-density polyethelene bags with a capacity of 50 kg or 100 kg. The first bag is filled completely, but with a 20-30 cm neck allowance, and tied securely. The second bag's neck, surrounding the inner bag containing the beans, is also tied securely. Finally, these two bags are placed in a third woven nylon or polypropylene bag. With the third bag tied securely, the container can be handled without bursting the inner bags and is

Many different brands of hermetic grain storage bags are available from agrodealers

readily accepted by grain buyers and handlers. An alternative method is to fold both liners together and twist tie them together, an approach that considerably reduces time spent on bag sealing. The hermetic bagging process can be performed entirely by hand or fitted into automated fill-and-seal machines. Bean grain can be stored for up to 2 years with this preservation technology. It is important to note that filled hermetic bags must be protected from rodents that may chew through the different layers, disturbing the hermetic protective environment.

Commercialization and Start-up Requirements. Hermetic bags are becoming widely available across Sub-Saharan Africa. To date, the storage technology has been introduced, piloted, adopted and now commercialized in countries not limited to Kenya, Ghana, Uganda, Ethiopia, South Sudan, Niger and Burkina Faso through various programs and interventions. Promotion and awareness creation among the supply chain actors including manufacturers, distributors, and retailers generate considerable interest in the business of hermetic storage as a cross-cutting value chain. The adoption of this safe storage technology can be scaled through the following steps: 1) Sensitize commercial and small-scale growers and processors on the benefits of the hermetic technology for preserving harvested grain, 2) Build capacity on how to fill and seal bags, and how to manufacture them from raw materials, and 3) Provide access to financial support for production and marketing of hermetic bags and mechanized fill-and-seal equipment.

Production Costs, Customer Segmentation and Potential Profitability. The raw material and labor to manufacture triple-layer hermetic grain storage bags costs about $1.00 to $1.50 per piece, and these bags are marketed at $2.00 to $3.00 per piece by suppliers. High-density tube plastic and fully automated machines needed to cut and seal the inner liners are available in larger markets across the continent. Small-scale and commercial farmers are the consumer base of the hermetic storage for beans and the technology is readily scalable to millions of people in Africa through increased manufacturing, distribution, and retailing, as demonstrated by its success to date. Post-harvest losses can be reduced by up to 90% when using the preservation technology, improving the supply and prices of locally produced and domestically traded beans. Multiple businesses have included hermetic bags in their product lines, and in 2019 they sold a total of 20 million pieces across Sub-Sahara Africa countries.

Licensing Requirements. Designs and manufacturing techniques of hermetic bags are more often protected by trade secrets than patents. Manufacturers and suppliers may require business licenses to produce and distribute hermetic bags, however, knowledge on their composition, application and effectiveness in dry grains storage is readily available online.

Technology 11. Pre-Cooked Beans for Consumer Convenience

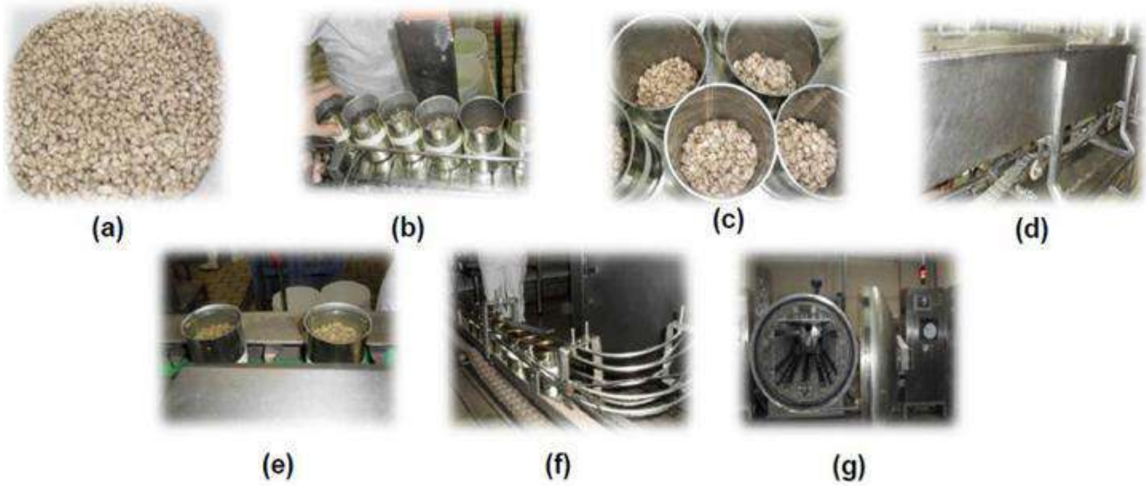
Summary. Common bean is a major staple food in eastern and southern Africa, the second-most important source of human dietary protein and the third-most important source of calories. Yet the sale and consumption of whole dried common beans is discouraged by their long cooking time, and high energy and water requirements. Pre-cooking combined with canned or frozen preservation techniques substantially decreases preparation time and fuel use, making it more attractive to urban and middle-class consumers and creating a growing commercial opportunity. This technology not only improves food and nutritional security but also the income of farmers by stimulating demand and opening up access to higher-value markets. Pre-cooked products further strengthen the common bean value chain in Sub-Saharan Africa, offering greater marketability and profit margins. Homemakers especially benefit from the time savings to prepare meals with beans as they are freed up to do other more productive activities. For more information on pre-cooked beans please contact Dr. Robert Fungo from ABC by email at r.fungo@cgiar.org.

Frozen pre-cooked beans manufactured in Kenya

Technical Description. Pre-cooked whole beans come as dried, canned and frozen products which can be prepared in only 10 to 30 minutes, saving over 1.5 hours of cooking time, eliminating the need for soaking and hugely reducing fuel expenditure. The process of making pre-cooked beans starts with sorting, washing and sizing for which air and water is passed over the food product. This is followed by blanching at 95°C for 3 minutes, soaking at 45°C for 120 minutes, sterilization and cooking of hydrated beans at 97°C for 120 minutes, and drying at room temperature for approximately 24 hours. Beans are then packaged and frozen. Processing of canned beans involves the same soaking, blanching and cooking procedure which is followed by brine addition, cooling, canning and labeling. Pre-cooked frozen and canned beans can be commercialized for both local and export markets.

Uses. The pre-cooking technology for whole beans is ideally suited to make nutritious diets more widely available to consumers. It serves as a way for marketing biofortified bean varieties with higher iron and zinc levels (see Technology 1) to middle-class urban populations that are decreasingly reliant upon beans. This food processing technique can be implemented by artisanal and industrial enterprises as simple low-cost equipment setups are required. Frozen pre-cooked bean products require cold chain storage and transport, reliable delivery infrastructure and strong links with markets.

Composition. High-quality soft-cooking varieties of common bean with appealing taste and color should be used for this processing technique, such as is the case with NABE 4, NABE 14, Rosecoco and Wairimu in Kenya and Uganda. The equipment needed for producing



Industrial preparation of canned pre-cooked beans: a) sorting and cleaning, b) adding brine, c) adding beans, d) deoxygenation, e) filling with brine, f) seaming lid on can, and g) cooking and sterilization

pre-cooked beans includes sorters for color grading, sieves and screens for removing stones and woody stems and shells, baths for washing and soaking, and vessels for boiling which are available as manual or automated systems in different sizes and that draw power from wood fuel, natural gas or electricity.

Application. Selecting common bean varieties for pre-cooked products that meet the dietary preference and culinary practices of consumers is based upon a series of factors such as ease of growing, preparation time, color and micronutrient content. Farmers operating as out growers for processing facilities require access to quality seed, fertilizer and other accompanying inputs to ensure adequate supply of whole beans. There are a number of ways to achieve this which have proven very efficient for the commercialization of pre-cooked bean products in Kenya and Uganda. Among the most popular schemes are the seed credit model involving contracts with loans that are amortized in cash from sales to processors, and the revolving seed model where credit gets repaid through delivery of whole grain. Preparing frozen products typically involves cooking very large batches of whole beans whereas for canned products this step is done inside metal tins as it eases the work and improves food hygiene. Different models can be employed for the production and marketing of pre-cooked products, such as collective enterprises with a single common processing plant, or pooled enterprises with multiple small plants at separate locations.

Commercialization and Start-up Requirements. Equipment for small-scale production of pre-cooked beans is available locally while large-scale industrial processing systems must be custom built or imported. Pre-cooked bean products are already manufactured and sold in several African countries. Entering into this food processing venture follows these steps: 1) Awareness raising with farmers, agri-food companies and investors about the business opportunities created by the technology, 2) Formulating appropriate product standards, packaging sizes and prices based on consumer demand, 3) Identifying profitable, durable and equitable models for production and marketing of pre-cooked beans, 4) Organizing reliable supply of beans by contracting nucleus farms and out grower networks, 5) Installing energy-efficient and labor-saving equipment to minimize production costs, and 6) Training operators and workers on safety and quality adherence throughout the process.

Production Costs. The main investments for this food processing technology are related to the supply of whole beans, hiring of skilled labor and purchase of equipment. Industrial-scale operations require considerable investment but operations for frozen and canned products may be modified around other existing manufacturing lines. A small electric cooker system for making pre-cooked beans with a capacity of 100 liter is sold at US $1,500, whereas a large hot water boiler powered with petrol or natural gas with a capacity of 0.5 ton per hour costs US $20,000. The total initial investment required for a 12,000 ton per year bean canning facility in Rwanda totaled US $8 million, with construction of the yard and purchase of the equipment requiring US $4.6 million and the acquisition of a 450 hectare nucleus farm costing an additional US $3 million.

Two popular varieties of beans are available as pre-cooked product

Client Segmentation and Potential Profitability. Whole bean pre-cooking technologies appeal to small-scale processors, community-based or cooperative enterprises and large industrial food manufacturers. Rural and urban households in African countries form the largest consumer base for pre-cooked beans, and are more than willing to pay for the convenience of faster preparation time. There is large demand from schools, armed forces, hospitals and prisons for this nutritious food as well. Poorer households are discouraged from consuming whole dried beans because of the time, fuel and water requirements, and this is addressed through pre-cooking. In particular, owners of small eateries expected to serve beans earlier in the day recognize the advantage of preparing pre-cooked bean products and consumer acceptance of their precooked beans is nearly identical to conventional preparations. Households relying upon precooked beans save about US $0.30 per meal. One of the main benefits of the food processing technology is that it lowers cooking costs by 90% which leads to saving in energy expenditure of households. Decreases of wood and fossil fuel use for cooking beans furthermore conserve forests and mitigate carbon emissions. The total market size for pre-cooked beans in Rwanda alone is estimated at US $50 million to $85 million with a demand of 2,628 metric tons of per year. Economic analysis has shown that investments on bean processing can achieve an internal rate of return of 32% to 53% which allow a processor to realize a positive cash flow in three years.

Licensing Requirements. Pre-cooked beans are readily advanced as consumer-friendly products through public-private partnerships. Producers of pre-cooked bean products must comply with food safety regulations applicable locally, regionally and internationally depending on the target market. Most of the simple cottage style machinery and equipment can be fabricated free of license, while larger industrial systems fall under intellectual property protection. Some technologies for processing pre-cooked bean products are a public good, and ABC and its partners are actively involved in disseminating this information across Sub-Saharan Africa.

Technology 12. Bean Flour and Flour Products

A flatbread made from bean flour

Summary. The time and energy required to prepare whole beans for consumption restricts their appeal to urban consumers, even for pre-cooked products described in Technology 11. In response, an increasing number of processed and ready to eat products made from common bean are emerging. Preparing high-quality flour from common beans is the first step in the manufacture of these products, and use of this flour by homemakers is becoming increasingly appreciated. In comparison to conventional bean preparation by lengthy boiling, use of flour offers substantial savings on cooking time and fuel cost, and improves the bioavailability of vitamins and micronutrient in derived food products. Bean flour is produced by similar milling processes as performed for cereal grains and other legumes. This technology provides a diversity of the bean-based products and recipes useful among rural and urban communities. Manufacturing of flour and food products from common bean creates a lucrative market that benefits the livelihood of both farmers and entrepreneurs. Further details about bean flour technology can be obtained from Dr. Robert Fungo of ABC by email at r.fungo@cgiar.org.

Technical Description. Common beans contain substances that interfere with absorption of proteins, starch and minerals in the human gut. Processing bean grains into flour serves to ameliorate digestibility and nutritional qualities, increases consumer appeal, extends shelf-life and generates additional income. Freshly harvested and hard-to-cook beans can be made into flour through various procedures. Wet methods generally involve a combination of soaking, malting, dehulling, pressure cooking or steaming, oven drying and fine milling. Soaking dry beans prior to cooking is a common practice which extrudes substances that cause flatulence. Malting and sprouting provides this same service but also increases the availability of vitamin C, folic acid and iron. Dehulling eliminates phytates and tannins, and increases protein digestibility. Apart from making foods more palatable and safe, the cooking or pressure steaming of beans inactivates and leaches anti-nutritional compounds. In the case of dry milling methods, whole beans first are desiccated in the sun or an oven before being ground, then the flour is passed over a sieve for removing chaff and large particles, and lastly it is vacuum packed, allowing it to be stored for longer periods of time under room temperature.

Uses. Production of bean flour is appealing for rural and urban communities alike. As blended flour, it improves food self-sufficiency and promotes business development. Equipment requirements for both small and large milling are widely available and simple to install or build. Milled bean flour presents opportunities to improve existing supply chains and open up trade in new areas since it increases markets to producers, offers savings on transportation costs and provides manufacturers opportunity to create new food products.

Composition. Smaller manually-operated equipment is used in cottage level production of bean flour, whereas larger automated systems are employed for industrial-scale processing. Manufacturing bean flour through the wet procedure requires soaking baths, solar dryers, hot air furnaces, boiler plates and steaming vessels. The malting and germination step occurs by placing whole beans inside moist cloths that are rinsed daily with water to prevent mold formation. Dehulling soaked beans involves abrasive rolling by hand or within a motorized friction chamber. Flour mills have a canister fitted with stainless steel blades that operate at high frequency to strike and grind the whole beans. Meshes placed within the mill determine the particle size of flour, and prevent excessive grinding. A water cooling system inside the mill ensures that the bean product is not overheated due to friction while being processed.

A high-quality bean flour manufactured in Burundi

Application. Bean flour produced through either wet or dry milling can be used in a wide range of products and foods. It is an all-purpose, gluten-free flour suitable for composite blends with cereal flour to prepare bread, pastry or porridge. Pure bean flour serves as a texturing ingredient for crisps and pasta, as thickener for soups, sauces and beverages, and as protein replacement in meat analogues.

Commercialization and Start-up Requirements. Bean flour and processed food products are already manufactured and sold in a number of African countries. Equipment for small-scale production of bean flour is available locally while large-scale industrial milling systems must be custom built or imported. The following steps are needed for enterprise development around bean flour and its widespread replication: 1) Raise awareness with farmers, agri-food companies and investors on the economic benefits of the technology, 2) Formulate appropriate product standards, packaging sizes and prices based on consumer demand, 3) Identify profitable, durable and equitable strategies for taking bean flour products to local, regional and international markets, 4) Establish reliable supply of beans to processing plants through contracted farming, 5) Set up equipment and production lines that make efficient use of energy and labor, and 6) Train operators and workers on safety and quality adherence throughout the manufacturing process.

Production costs. Prices of whole beans and the costs of labor and equipment for processing and packaging determine the overall investment. Small motorized bean dehullers that can process 50 kg hour^{-1} have a base cost of US $370, while machines with a capacity of 2 ton hour^{-1} are sold for US $3,000. Soaking tanks of 500 liter cost about US $1,500 and those with a capacity of 5,000 liter cost US $8,800. Mills with a capacity of 300 kg hour^{-1} start in price from US $2,000. Large industrial-scale milling setups with a capacity of several ton per hour have to be built on-site and cost upwards from US $100,000.

Customer Segmentation and Potential Profitability. Bean flour and processed foods have a large and diverse customer base which ranges from rural poor communities to middle-class urbanites. Currently, the market is served by few local and regional processors. In Nigeria bean flour is sold at about US $4 per kilogram while the wholesale price of beans is US $2, thus creating a sufficient margin to repay capital and operational investments.

Licensing Requirements. Producers of bean flour and flour products must comply with food safety regulations depending on the target country and market. Most of the simple cottage style machinery and equipment can be fabricated free of license, while industrial systems fall under intellectual property protection. Knowhow about bean flour processing is a Public Good, and ABC and its partners are responsible for disseminating this knowledge in Africa.

Make TAAT Your Technology Broker of Choice

TAAT offers its services toward the advancement of modernized agriculture. It brokers a wide range of needed technologies and bundles them through a process of co-design into winning solutions. It recognizes that modernized agriculture must serve as the main engine for economic growth in Africa and operates accordingly. Change is intended to achieve not only food and nutritional security but also to meet obligations under climate agreements allowing collaborative efforts to better combine global, national and community-level interests. TAAT operates from a unique perspective to mobilize innovative solutions through better partnering that includes honest technology brokerage and effective, scalable skills development through five key mechanisms.

- ☑ **Unique understanding:** Expertise is offered in the areas of site characterization and problem identification.
- ☑ **Innovative solutions:** Leadership is provided in technology brokerage and solution bundling based upon a dynamic portfolio of candidate technologies.
- ☑ **Better partnering:** Assistance is offered in the better co-design and management of projects prompting agricultural transformation.
- ☑ **Replicable approaches**: Assistance is available to advance skill sets in technology brokerage and project management through customized Training of Trainers activities.
- ☑ **Honest brokerage:** An independent capacity for impact assessment and constructive learning is achieved through standardized monitoring and evaluation.

These partnership mechanisms are applied to the technologies featured in this catalogue as follows:

1. **Improved Varieties.** The latest elite varieties of common bean are provided by TAAT to national agencies for testing and approval, and upon release assistance is provided in the design of seed systems that accelerate community-based seed production. *These services are arranged by TAAT with its partner the Alliance of Bioversity International and the International Center for Tropical Agriculture (ABC).*
2. **Nitrogen Fixation.** Managing biological nitrogen fixation is a climate-friendly means to reduce fertilizer required by beans and its companion crops. The ABC Bean Program offers its expertise in this area. *Services or offered through TAAT to assist the private sector in producing and marketing legume inoculants in Africa*.
3. **Fertilizer Management.** Special fertilizer blends for beans and other grain legumes are now available that increase return on investment and reduce overall fertilizer requirements of these crops. *TAAT and its partner International Fertilizer Development Center assist in the design and marketing of specialized fertilizer blends.*
4. **Pest, Disease and Weed Management.** Beans are quite susceptible to pests, diseases and weeds but integrated management strategies are available to overcome these constraints. *TAAT and ABC assist national programs in the design of these integrated management systems.*
5. **Value Addition.** Bean are now regarded as more that a subsistence food crop but also as an exciting area for value-added processing and investment in modernized food systems. *The TAAT Clearinghouse is ready to assist in the design of national food system projects prepared for development banks, including the African Development Bank.*

Be assured that TAAT is prepared to partner with development investors, national projects and the private sector in a demand-driven manner.

Conclusions

This catalogue provides a wide variety of options for modernizing bean production in Africa. It identifies improved varieties that are high yielding and biofortified, alongside with good practices related to use of beneficial microorganisms, inorganic fertilizers, and integrated techniques to control insects, diseases and weeds to address challenges on production, nutrition and resilience of food systems. The toolkit also features solutions linked to post-harvest handling and value addition that reduce storage losses and increase profit margins from the farm all the way to the processor. With this set of proven technologies, it is possible for bean growing communities in Africa to access the high-end of the value chain and global market place, which can boost incomes of households and agribusinesses alike.

This catalogue was prepared with a variety of users in mind whether they be producers, agents of agricultural development, extension supervisors or private sector investors. Farmers can use many of these catalogue items as production guidelines. Those from the public sector can utilize the catalogue as a whole and design agricultural projects involving common beans around this toolkit of modernizing technologies. Members of the private sector, including seed producers, input manufacturers, processors and investors also benefit from the contents of this catalogue. Indeed, the Technologies for African Agricultural Transformation Program's Clearinghouse welcomes feedback on its contents.

Information Sources

Biofortification of Common Bean for Higher Iron Concentration. Stephen Beebe. Alliance Bioversity International and CIAT. Frontiers in Sustainable Food Systems 4, 2020.

Bean Production Problems in the Tropics (Second edition). Edited by Howard F. Schwartz and Marcial A. Pastor-Corrale. 1989. 750 pages. CIAT.

Beans Training Manual for Extension workers in Uganda. Ministry of Agriculture, Animal Industry and Fisheries. 2019. Entebbe-Uganda.

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Technologies for African Agricultural Transformation (TAAT) and its Clearinghouse Office

The development objective of TAAT is to rapidly expand access of smallholder farmers to high yielding agricultural technologies that improve their food production, assure food security and raise rural incomes. This goal is achieved by delivering regional public goods for rapidly scaling up agricultural technologies across similar agro-ecological zones. This result is achieved through three principal mechanisms; 1) creating an enabling environment for technology adoption by farmers, 2) facilitating effective delivery of these technologies to farmers through a structured Regional Technology Delivery Infrastructure and 3) raising agricultural production and productivity through strategic interventions that include improved crop varieties and animal breeds, accompanying good management practices and vigorous farmer outreach campaigns at the Regional Member Country level. The important roles of sound policies, empowering women and youth, strengthening extension systems and engaging with the private sector is implicit within this strategy. The Clearinghouse is the body within TAAT that decides which technologies should be disseminated. Moreover, it is tasked with the responsibility to guide the deployment of proven agricultural technologies to scale in a commercially sustainable fashion through the establishment of partnerships that provide access to expertise required to design, implement, and monitor the progress of technology dissemination campaigns. In this way, the Clearinghouse is essentially an agricultural transformation incubation platform, aimed at facilitating partnerships and strengthening national agricultural development programs to reach millions of farmers with appropriate agricultural technologies.

Dr. Innocent Musabyimana, Head of the TAAT Clearinghouse

Back cover photos: Shopkeeper in Burundi posing with packaged high-iron bean flour at a sales outlet. Photographic credit: Alliance – Biodiversity International and CIAT.

Bean Technology Toolkit Catalogue

In collaboration with