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Enhancing the nutrient-rich yam bean *(Pachyrhizus spp.)* storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

FINAL REPORT

WRITTEN BY: Wolfgang J. Grüneberg
SUBMITTED TO: Belgian Development Agency
SUBMITTED BY: International Potato Center

CIP
INTERNATIONAL POTATO CENTER
A CGIAR RESEARCH CENTER

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ACRONYMS

AFLP	Amplified fragment length polymorphism
CIP	International Potato Center
DM	Dry matter
DRC	Democratic Republic of the Congo
fwb	free weight basis
INERA	Institut National pour l'Etude et la Recherche Agronomique
INIA	Instituto Nacional de Innovacion Agraria
INRAB	Institut National des Recherches Agricoles du Benin
ISABU	Institut des sciences agronomiques du Burundi
METs	Multi-environmental trials
NaCRRI	National Crops Resources Research Institute
NARO	National Agricultural Research Organization
NARS	National agriculture research systems
NGO	Nongovernmental organization
OFSP	Orange-fleshed sweetpotato
R&D	Research and development
R&T	Root and tuber
RAB	Rwanda Agricultural Board
SHIS	Social and Health Sciences and Innovation Systems
UCL	Université Catholique de Louvain

FINAL TECHNICAL REPORT: THE YAM BEAN CENTRAL AND WEST AFRICA PROJECT

Name of the Project:

"Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Date Range of Activities Reported: July 2009–June 2014

Organization Name: International Potato Center (CIP)

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Overall Goal of the Project:

To provide proof of concept that the underutilized yam bean (*Pachyrhizus* spp.) can lead to greater food availability, improved food quality (especially for children and women of reproductive age), more sustainable farming systems, and new options for generating income and improving the livelihood of the rural and urban poor in Central and West Africa.

Specific Objectives of the Project:

- Improve the availability of yam bean germplasm
- Identify adapted high-yielding yam beans for Central Africa
- Develop yam bean storage root products for Central Africa
- Improve processing of yam bean storage root products in West Africa
- Develop marketing strategies for yam bean products and promote their use in West Africa
- Provide new diversity to use yam bean seed for human consumption
- Make available evidence of livelihood impacts associated with increasing yam bean production in Central and West Africa
- Promote awareness, communication, training, and capacity building.

Locations and Partners of the Project:

- **Peru:** CIP, Instituto Nacional de Innovacion Agraria (INIA)
- **Belgium:** Université Catholique de Louvain (UCL)
- **Benin:** Institut National des Recherches Agricoles du Benin (INRAB); and Børnefonden (BØRNEfonden-Bénin), a nongovernmental organization (NGO)
- **Rwanda:** Institut des Science Agronomique du Rwanda; new name is Rwanda Agricultural Board (RAB)
- **Burundi:** Institut des sciences agronomiques du Burundi (ISABU)
- **Democratic Republic of the Congo (DRC):** Institut National pour l'Etude et la Recherche Agronomique (INERA)
- **Uganda:** Makerere University, CIP.

1. OVERALL STATUS OF THE PROJECT AND STRUCTURE OF REPORT

The project is phased out. Six objectives (1–5 and 8) were fully achieved; two were partially achieved: objective 6 (Provide new diversity to use yam bean seed for human consumption) and objective 7 (Make available evidence of livelihood impacts associated with increasing yam bean production in Central and West Africa). For objective 6, a concept note has been written (see Appendix 8) to search for further funding; the International Atomic Energy Agency/Austria is a potential donor). Objective 7 has been taken up by Social and Health Sciences and Innovation Systems (SHIS) at CIP to finalize impact estimates from increasing yam bean cultivation in Central and West Africa. The work of SHIS on yam bean is carried out in the context of the project "Enhancing nutrition, food security and income through sustainable system intensification with roots and tubers crops in Asia and Sub-Saharan Africa," a new activity being funded by Consortium Research Program PIM (Policies, Institutions and Markets, led by the International Food Policy Research Institute). According to the project proposal the first target country in 2015 is Benin. Furthermore, the yam bean has been taken up by two other projects: "Improved Soil Fertility Management for Sustainable Intensification in Potato Based Systems" in Kenya and Ethiopia (BMZ funded), and "Developing Optimal Soil Fertility Management and Sustainable Intercropping Systems with Sweet Potato" in Mozambique (funded by the Reaching Agents of Change). The latter project includes a PhD thesis with the working title "Soil fertility Improvement in Sweetpotato/Yam Bean Rotation and Intercropping."

1.1 BASELINE FOR THE PROJECT

At the beginning of the project, the yam bean was never investigated for its potential in the CGIAR. It is a close relative of the soybean and the small genus *Pachyrhizus* in the sub-tribe *Gycininae* comprises three cultivated yam bean species: Mexican yam bean (*P. erosus*), Andean yam bean (*P. ahipa*), and Amazonian yam bean (*P. tuberosus*). It was reported that all yam beans are exclusively used for their storage roots, although the seed yields are high. The crop has an extreme diversity with respect to local given names—for example, ahipa, Ashipa, Chuin (Peru); jicama (Mexico); bunga (Philippines); mishrikand, ram-kaseru, sankalu, sankeh alu, bangkoewang (Indonesia); dòushǔ or liáng shǔ (China). At the beginning of the project we gathered a list of 28 names for yam bean which already might reflect a very wide adaptation of the crop. It was commonly understood that yam bean storage roots, with exception of some Amazonian yam beans from Peru, are all low in storage root dry matter (DM) and are consumed raw as a root fruit/vegetable for its refreshing taste (Sørensen et al. 1997). However, there was no access to high DM yam beans on a clear legal basis. It was known that yam beans are high in protein and iron in storage roots, that the root system fixes a considerable amount of nitrogen, and that it is efficient in phosphor uptake due to mycorhiza association. It has been estimated that the yam bean (*P. erosus*) is fixing about 200 kg of N/ha (Woomer 1979), with a range 160–260 kg of N/ha in *P. ahipa* (Rodríguez-Navarro 2009). It has been also been reported that the crop can adapt well to drought-prone areas in West Africa (Zanklan et al. 2007). *P. erosus* requires 850 L of water for 1 kg of seed production, plus 0.56 kg of storage root dry yield production, as calculated across 16 accessions on basis of yields and water supply form Zanklan et al. (ibid.). This compares quite favorably with soybean, which requires 2,000 L of water for 1 kg of seed production (Pimentel et al. 2004). Before starting this project, only the low DM Mexican yam bean (*P. erosus*) has made its way out of the area of origin. *P. erosus* became known until the end of the 20th century across nearly all of Asia, where low DM yam bean nowadays reaches about 5% of the cultivation area of sweetpotato as root fruit/vegetable. High DM yam bean never became known in Asia. In Africa that crop was never cultivated on farm, and in Central Africa it was not known for research and development (R&D) at all until the start of this project. Furthermore, there was very limited knowledge about yam bean and its (1) seed in addition to storage roots (these seeds are not eaten because of toxic compounds); (2) high storage root DM contents (these so-called

Chuin types of *P. tuberosus* are cooked and processed to flour); and (3) options to be processed as food products (in this project, we focused on food products made traditionally in Africa). However, the overall major limitation to work with yam bean was access to germplasm and a genebank professional managing the yam bean genetic resources.

1.2 OVERVIEW OF ACHIEVEMENTS UNTIL END OF THE PROJECT

The project made it possible for CIP to establish a collection of cultivated yam beans covering the key attributes the crop. Most important might be that the project made a fraction of high DM accessions and high DM breeding populations available for R&D with permission of Peruvian authorities. It must be noted that yam beans do not belong to the Annex 1 crops of the international convention on rights on genetic resources. For this reason, national rights have to be considered in germplasm dissemination and exchange of *Pachyrhizus* spp. Yet this holds true for nearly all other neglected and/or underutilized crops. Our approach to work with the yam bean can serve as a model.

During the past five years of the project we have shown the following:

- That crosses among low DM and high DM yam beans (*P. ahipa, P. tuberosus*, and *P. erosus*) result in fertile interspecific hybrids and high DM breeding population can be easily developed (the three cultivated yam bean species have no crossing barriers and frequencies of successful interspecific recombination is high).
- The crop is adapted to Central Africa and high-yielding low DM types have been selected in Central Africa (medium- to high-yielding high DM yams are available through CIP's genebank and/or still in segregating selection through Makerere University, Uganda).
- Various traditional food products in Central Africa can be made with yam bean storage roots such as *fufu*, *ugali*, *atapa*, porridge, and fritters.
- In Benin/West Africa, it was confirmed that yam bean can be used to process *gari*—a major food product in West Africa eaten by millions every day (NB: the conversion rate to *gari* is very different among yam beans, ranging from 4.8% in low DM genotypes to 19% in high DM genotypes).
- The yam bean juice obtained during food processing—especially in *gari* processing—is a much more valuable product as expected for food industry and smallholder income generation (in *gari* from cassava the juice is usually treated as waste).
- The storage root and processed products have higher iron contents than other traditional root crops and the iron bioavailability in yam bean raw or derived food products is very high (studies carried out with Raymond Glahn, 2014, Cornell University, Ithaca, New York).
- There is genetic variation for the toxic compounds (rotenone and derivatives), which make the yam bean seed so far unavailable for human consumption; there is now one accession available with no actuate toxicity, based on animal studies.
- Yam bean storage roots yields are remarkably high in Africa (up to more than 80 t/ha were reported in Rwanda). In 75 villages in Benin, for 101 producers, the storage root yields averaged 24 t/ha. A first analysis of the dissemination and adoption of yam bean in six of the eight agro-ecological zones of Benin showed an adoption rate of 47% compared with an adoption rate of 31% for orange-fleshed sweetpotato (OFSP).

At the end of the project, we unfortunately cannot say that we sustainably introduced yam bean in Africa, and we still need to finalize impact estimates from increasing yam bean cultivation in Central and West Africa.

1.3 STRUCTURE OF THE PROJECT REPORT

This report is structured by the objectives of the original project proposal. These are to (1) improve the availability of yam bean germplasm; (2) identify adapted high-yielding yam beans for Central Africa; (3) develop yam bean storage root products for Central Africa; (4) improve processing of yam bean storage root products in West Africa; (5) develop marketing strategies for yam bean products and promote their use in West Africa; (6) provide new diversity to use yam bean seed for human consumption; (7) make available evidence of livelihood impacts associated with increasing yam bean production in Central and West Africa; and (8) promote awareness, communication, training, and capacity. Within objectives, the report is structured, where applicable, by the final reports of project partners. These are provided as appendices:

- **Appendix 1**—Final Report INIA (Peru)
- **Appendix 2**—Final Report CIP to INIA (Peru)
- **Appendix 3**—Final Report RAB (Rwanda)
- **Appendix 4**—Final Report INERA (DR Congo)
- **Appendix 5**—Final Report ISABU (Burundi)
- **Appendix 6**—Final Report INRAB (Benin)
- **Appendix 7**—Final Report BØRNEfonden (Benin)
- **Appendix 8**—Final Report UCL (Belgium)
- **Appendix 9**—Final Report Makerere University (Uganda)
- Photo galleries are provided as appendices for three countries: "**Appendix 10**—YB Photo Gallery Peru," "**Appendix 11**—YB Photo Gallery Uganda," and "**Appendix 12**—YB Photo Gallery Benin." Photo galleries for the other countries are still incomplete.

1.4 LITERATURE USED

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Rodríguez-Navarro, D.N., M. Camacho, F. Temprano, C. Santamaria, and E.O. Leidi. 2009. Assessment of nitrogen fixation potential in Ahipa (*Pachyrhizus ahipa*) and its effect on root and seed yield. *Expl Agric*. 45: 177–188.

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Zanklan, A.S., S. Ahouangonou, H.C. Becker, E. Pawelzik, and W.J. Grüneberg. 2007. Evaluation of the Storage-Root-Forming Legume Yam bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Sci*. 47: 1934–1946.

2. OBJECTIVE 1: IMPROVE THE AVAILABILITY OF YAM BEAN GERMPLASM

The availability of yam bean germplasm has been improved. Greater diversity of cultivated yam beans is now available through CIP for R&D than in the past (about 100 accessions in 2014 compared with 15 accessions in 2009 are now maintained in CIP's genebank). This diversity comprises (1) low storage root DM accessions for use as root vegetable and raw consumption (traditional use in Asia, Mexico, and the US); (2) high storage root DM accessions for processing (a new way to use yam beans); and (3) segregating breeding populations comprising high DM yam bean bulks (about 18 segregating populations are maintained in CIP's genebank). These populations are in Uganda and Rwanda as part of two PhD studies, and promising high DM breeding lines have been selected. Our work eased the bottleneck of the availability of high DM germplasm in the yam bean gene pool. This enabled abundant material for both yam bean types (low DM for traditional use and high DM for processing use) to be introduced into Benin, Ghana, Uganda, Rwanda, Burundi, and DRC (in this project), as well as into Kenya, Mozambique, and Cameroon, through seed requests of other projects, nongovernmental organizations (NGOs), and national agricultural research systems (NARS). Finally, there is now one yam bean accession available (CIP-209054) that has no acute toxicity in animal studies, and one accession with high potential not to be toxic (CIP-209038). But this does not mean that we have made the yam bean gene pool available for seed consumption.

On the basis of the results of the project in West and Central Africa, the project partners have chosen a set of yam bean accessions for demonstration trials (Table 1). These accessions might be of interest to new projects with the yam bean across all tropical and subtropical regions of the world, and reflect a major portion of genetic diversity among yam beans.

Table 1 Yam bean accessions and breeding lines recommended for demonstration trails in tropical and subtropical regions of the world

Accession	Genotype	Selected Characteristics
CIP 209013	*P. tuberous* Chuin	Farmer variety, low to medium yields, high DM, 55 ppm Fe (dry weight basis, or dwb), storage root taste close to cassava
CIP 209017	*P. erosus*	Farmer variety, high yields across many countries, very low DM, raw consumption, and good porridge quality (Uganda)
CIP 209018	*P. erosus*	Farmer variety, high yields across many countries, very low DM, 45 ppm Fe dwb, and good porridge quality (Uganda)
CIP 209035	*P. ahipa*	Farmer variety, good yields in East-DRC, low DM, and good porridge quality (DRC)
CIP 209036	*P. ahipa*	Farmer variety, good yields in East-DRC, low DM, and good porridge quality (DRC)
CIP 209037	*P. ahipa* x *P. tuberous*	Breeding line, Chuin Hybrid – good yields in Peru and Ghana, 35% DM, 32 ppm Fe dwb, offspring of high DM parent CIP-209008, *P. tuberous* Chuin
CIP 209039	*P. ahipa* x *P. tuberous*	Breeding line, Chuin Hybrid – good yields in Peru and Ghana, 32% DM, 29 ppm Fe dwb, offspring of high DM parent CIP 209015 *P. tuberous* Chuin
CIP 209041	*P. ahipa* x *P. tuberous*	Breeding line, Chuin Hybrid – good yields in Peru and Ghana, 28% DM, 29 ppm Fe dwb, offspring of high DM parent CIP-209014 *P. tuberous* Chuin
CIP 209054	*P. tuberosus*	Farmer variety, low DM – low rotenone and pachyrrhizine contents, and no 12-hydroxypachyrrhizone detected in seed (not acute toxic at 0.7g/200 g in animal studies) – seed use only for potential animal research studies

2.1 GERMPLASM ACQUISITION AND COLLECTION

To date, there are about 100 yam bean accessions at CIP; all are under international trust status. There are 13 *P. erosus*, 28 *P. tuberosus,* and 22 *P. ahipa* farmer accessions (accessions that trace back to collections), 9 breeding accessions (accessions that trace back to crossings by breeding), and 18 breeding populations in breeding stage F2.

Thirty-one new *P. tuberosus* accessions were collected in the Amazon region of Peru, of which 15 were high DM Chuin types. The national partner in Peru, INIA, participated in all collections and evaluated collected material independently (see Appendix 1). The activities to obtain collection permits in indigenous communities of the Peruvian Amazon region, yam demonstration trials, and seed fairs for indigenous communities are given in Appendix 2. (The collections in the Amazon area of Peru are documented with photos in Appendix 10.) However, so far, it was not possible to find any *P. ahipa* accessions in Peru. The farthest area north where *P. ahipa* has been found recently is the area around the city of Apolo in Bolivia, which is less than 50 km from the Peruvian border. However, CIP staff can be faulted for not traveling into the area of southern Peru, where the same indigenous language, Aymara, is spoken in Bolivia.

One of the project's major successes was obtaining permission from Peruvian authorities, including those that represent indigenous communities from the Amazonian lowlands of Peru. Known as the "Permiso para distribuir Ahipa: permiso para distribución de 11 accesiones y híbridos de *P. tubersosus,*" this permit made high DM yam beans available for international R&D. This success has so far not been exploited much by CIP, INIA, CGIAR, and the Belgium embassy in Peru. The background is that Peru has national rights on the known high DM yam bean accessions because the yam bean is not among the "Annex 1 Crops" of the International Treaty on Plant Genetic Resources," and high DM yam beans are relatively new collections, so that this treaty applies to all found high DM accessions and derivatives. CIP is now allowed to use four high DM accessions from Peru for R&D, including derivatives and cross population with these high dry DM accessions. However, the situation applies to nearly all neglected/underutilized crops and new germplasm acquisitions and collections for these crops, so our approach and agreements can serve as a model for others. Critical voices articulate that under current international conventions, it is nearly impossible to work on a legal basis with neglected crops and their genetic resources. Yet we have demonstrated in this project that it is possible. In addition, making available high DM yam beans and breeding populations is certainly a clear step forward to broaden the use of yam beans, because high DM genotypes are more suitable for processing.

Note that seven *P. erosus* accessions and eight *P. tuberous* accessions at CIP's genebank were obtained by germplasm exchange from CATIE/Costa Rica. All are low DM yam beans.

2.2 GERMPLASM DISSEMINATION

2.2.1 FIRST BATCH OF SEED DISSEMINATION FROM CIP–PERU TO AFRICA (2009–2010)

In 2009–2010 we provided yam bean seed to the following organizations:

UCL obtained 300 seed samples for rotenone determination in yam bean seeds. These 300 samples have been used to develop precise methods to determine rotenone and pachyrrhizine in yam bean seed and extend calibrations of the fast through-put near-infrared reflectance spectroscopy (NIRS) method for rotenone determination in yam bean seeds.

CIP–Benin and INRAB (Benin) have obtained two *P. erosus* accessions—209018 from China and 209019 from Mexico—in larger quantity (200 seeds per accession) in 2009; followed by a second shipment comprising five *P. ahipa* (209003, 209004, 209006, 209007, and 209021) and two *P. erosus* (209016 and 209017) accessions in smaller quantity (20 seeds per accession). In 2010 Benin obtained six high DM *P. tuberosus x P. ahipa* hybrids (209037, 209039, 209040, 209041, 209044, and 209045). But soon after this shipment we had to inform INRAB that none of the accessions should be used and must be destroyed, because CIP had not yet received all required permissions for this shipment. From CIP-Benin the material was introduced into Ghana via CIP-Ghana.

CIP–Uganda has obtained 11 *P. erosus* accessions (209016, 209017, 209018, 209019, 209046, 209047, 209048, 209049, 209050, 209051, and 209052); 20 *P. ahipa* accessions (209003, 209004, 209006, 209007, 209021, 209022, 209023, 209024, 209025, 209026, 209027, 209028, 209029, 209030, 209031, 209032, 209033, 209034, 209035, and 209036); and 11 *P. tuberosus* accessions (209013, 209014, 209015, 209054, 209055, 209056, 209057, 209058, 209059, 209060, and 209061) from CIP-Lima (each accession with 20–40 seeds). Also in the case of Uganda we had to inform them that accessions 209013, 209014, and 209015 had to be destroyed because their presence in Uganda was illegal. At CIP-Uganda through the project the material was multiplied and quarantine conditions and introduced to Rwanda, Burundi, and DRC, as well as into Kenya. Project partners in each country multiplied in a first step again under quarantine conditions, and national authorities inspected the material for pest and diseases before accessions were moved into preliminary field trials and field multiplications.

2.2.2 SECOND BATCH OF SEED DISSEMINATION FROM CIP–PERU TO AFRICA (2012)

Owing to the "Permiso para distribuir Ahipa: permiso para distribución de 11 accesiones y híbridos de *P. tubersosus,*" it was possible to start disseminating high DM yam beans in 2012. Six African countries and one country out of Africa received high DM yam beans (Table 2). Germany obtained seed to verify our virus test procedure for yam bean seed dissemination. In addition to this seed dissemination, Makerere University obtained nine cross populations of *P. erosus* x *P. tuberosus* Chuin for a PhD thesis in Uganda, and nine cross populations of *P. ahipa* x *P. tuberosus* Chuin for a PhD thesis in Rwanda as F1 seed (see objective 8: Promote awareness, communication, training, and capacity building). CIP–Mozambique obtained *P. erosus* accession for demonstration trials.

Table 2 Yam bean seed dissemination from CIP's genebank to six African countries in 2012 with emphasis on high DM accessions with amount of seeds introduced by country

Accession	Number	Rwanda	Uganda	Ghana	Benin	Cameroon	Nigeria	Germany
CIP 209004	AC 524							150
CIP 209007	AC 525							150
CIP 209016	EC 041					50	25	200
CIP 209018	EC 533					50	25	
CIP 209019	EC Kew						25	200
CIP 209023	AC 102 153	50	150	50	50			
CIP 209028	AC 524 164	50	150	50	50			
CIP 209031	AC 525 170	50	150	50	50			
High DM species Chuin								
CIP 209013	TC 354	50	150	50	50		25	250
CIP 209014	TC 355	50	150	50	50		25	
CIP 209015	TC 361	50	150	50	50		25	250
Hybrids with one Chuin parent deriving from previous breeding efforts								
CIP 209037	AC 102 153x TC 353	50	75	25	25	25	25	25
CIP 209038	AC 102 153x TC 355	50	75	25	25		25	
CIP 209039	AC 102 153x TC 361	50	75	25	25	25	25	25
CIP 209040	AC 524 164x TC 353	50	75	25	25		25	
CIP 209041	AC 524 164x TC 355	50	75	25	25		25	
CIP 209042	AC 254 164x TC 361	50	75	25	25		25	
CIP 209044	AC 525 170x TC 355	50	75	25	25		25	
CIP 209045	AC 525 170x TC 361	50	75	25	25		25	

2.3 GERMPLASM EVALUATIONS

The germplasm evaluation at CIP–Peru comprised three studies: (1) yield and quality evaluation of the yam bean germplasm held in trust at CIP; (2) a germplasm diversity study of the yam bean material held in trust at CIP by amplified fragment length polymorphism (AFLP) markers (this work was linked to the MSc study of Monica Santayana); and (3) an evaluation of the compatibility among yam bean species and testing the frequency of successful interspecific hybridization among *P. ahipa*, *P. tuberosus*, and *P. erosus*.

2.3.1 GERMPLASM YIELD AND QUALITY EVALUATION

In total, 41 accessions of *P. ahipa, P. erosus, P. tuberosus*, and *P. ahipa* x *P. tuberosus* hybrids were evaluated for agronomic performance—that is, yield potential, nematode tolerance, desirable growth, and storage root composition (protein, DM content, iron, zinc, and starch) at two environments in Peru (Table 3).

Table 3 Germplasm evaluation of *Pachyrhizus* spp. across two environments at San Ramón and two plot replications comprising means and minimum and maximum accession value

Species	Trait	Mean across Accessions	Minimum Accession Value	Maximum Accession Value
P. ahipa (N=20)	Yield (t/ha)	4.9	1.4	13.6
	DM (%)	19.1	17.2	20.5
	Protein (%)	7.7	6.3	9.4
	Starch (%)	53.4	37.9	62.9
	Fe (mg/kg)	24.1	19.0	31.0
	Zn (mg/kg)	9.9	7.6	14.0
P. erosus (N= 5)	Yield (t/ha)	31.8	24.4	39.6
	DM (%)	13.7	11.4	16.1
	Protein (%)	8.3	6.6	10.4
	Starch (%)	35.3	20.7	50.5
	Fe (mg/kg)	21.8	19.0	23.5
	Zn (mg/kg)	11.2	10.0	13.5
P. tuberosus (N= 8)	Yield (t/ha)	25.4	4.9	49.2
	DM (%)	26.5	13.2	38.0
	Protein (%)	6.4	4.7	8.9
	Starch (%)	59.4	24.4	78.0
	Fe (mg/kg)	37.0	21.5	52.0
	Zn (mg/kg)	7.4	5.7	11.4
P. tuberosus x *P. ahipa hybrids* (N = 8)	Yield (t/ha)	15.0	7.0	21.5
	DM (%)	30.7	27.0	37.2
	Protein (%)	7.2	4.7	11.4
	Starch (%)	68.7	51.1	78.8
	Fe (mg/kg)	33.6	24.0	49.5
	Zn (mg/kg)	8.9	6.1	11.7

The range for quality traits in the yam bean gene pool is remarkable. *P. ahipa* and *P. erosus* are clearly two yam bean species with low DM storage root contents (Table 2). However, starch contents on a DM basis of up to 60% can be found in these two species. An unexpected observation was that in both species the iron storage root contents are not higher than 31 ppm on DM basis. In contrast, *P. tuberous* and *P. tuberosus* Chuin x *P. ahipa* hybrids exhibit high storage root DM (up to 38%), high starch content on storage root DM basis (up to 78%), and high iron content on storage root DM basis (up to 52 ppm). The high DM and starch contents in *P. tuberosus* and hybrids are similar or slightly higher than the average found in cassava germplasm, and the high iron content corresponds to the average found in *Phaseolus vulgaris* germplasm. The extreme wide range of DM and starch in *P. tuberosus* can be explained by the fact that low DM *P. tuberosus* Ashipa accessions were evaluated together with high DM *P. tuberosus* Chuin accessions.

2.3.2 GERMPLASM DIVERSITY STUDY

In this study, 58 accessions of the three cultivated *Pachyrhizus* species were characterized by AFLP molecular markers in order to estimate genetic diversity and interspecific relationships. Shannon's diversity indices for each species were 1.04 (*P. ahipa*), 1.07 (*P. tuberosus*), and 2.42 (*P. erosus*), while the total diversity index was 2.45. Phylogenetic analysis, principal coordinate analysis, and analysis of molecular variance (FST = 0.796) all showed significant species differentiation. All accessions were diploid (2n = 2x = 22), which is characteristic of the tribe *Phaseoleae* and the sub-tribe *Gycininae*. The species *P. tuberosus* and *P. ahipa* are more closely related compared with *P. erosus*. Within *P. tuberosus*, low DM Ashipa types and high DM Chuin types form separate groups within the species at high levels. The eight *P. tuberosus* Chuin x *P. ahipa* hybrid breeding lines in later breeding stages used in this study appear to be clearly hybrids between these species. Moreover, one *P. ahipa* accession was found to be a *P. ahipa* x *P. tuberosus* hybrid, one *P. tuberosus* accession was found to be a *P. tuberosus* x *P. erosus* hybrid, and in all three species accessions were found containing 2–20% genome from another yam bean species. This indicates that all three cultivated yam bean species are very closely related and exchange in nature and/or cultivation genes by open pollination.

The study has been published as:

Santayana, M., G. Rossel, J. Núñez, M. Sørensen, M. Delêtre, R. Robles, V. Fernández, W.J. Grüneberg, and B. Heider. 2014. Molecular Characterization of Cultivated Species of the Genus *Pachyrhizus* Rich. ex DC. by AFLP Markers: Calling for More Data. *Tropical Plant Biology* 7: 121–132.

2.3.3 COMPATIBILITY STUDY AMONG YAM BEAN SPECIES

Our germplasm diversity study shows that hybridizations among yam bean species can trace back to controlled crossings and might occur in nature by open pollination and in germplasm management. Previous findings already reported the possibility of *P. ahipa* and *P. tuberosus* hybridization:

Grüneberg, W.J., P. Freynhagen-Leopold, and O. Delgado-Váquez. 2003. A new yam bean (*Pachyrhizus* spp.) interspecific hybrid. *Genetic Resources and Crop Evolution* 50: 757–766.

For this reason, we studied the recombination and frequency of successful crosses (pod and seed formation) among three *P. ahipa*, three *P. tuberosus* Chuin, and three *P. erosus* accessions (see Table 4). *P. ahipa* (AC) x *P. tuberosus* (TC) interspecific hybridization do not appear to be much different with respect to the success rate of crossings from intraspecific crosses *P. ahipa* (AC) x *P. ahipa* (AC) and *P. tuberosus* (TC) x *P. tuberosus* (TC). However, *P. erosus* (EC) x *P. tuberosus* (TC) interspecific hybridization do not appear much different with respect to the success rate of crossings from intraspecific crosses of the type *P. tuberosus* (TC) x *P. tuberosus* (TC). But they do differ with respect to intraspecific crosses of the type *P. erosus* (EC) x *P. erosus* (EC), as the frequency of successful recombination is 16.1% for *P. erosus* (EC) x *P. erosus* (EC) versus 6.2% and 4.7% for *P. erosus* (EC) x *P. tuberosus* (TC) and the reciprocal cross *P. tuberosus* (TC) x *P. erosus,* respectively.

Our results show that the success of recombining among yam bean species can be much higher than reported in previous studies (Grüneberg et al. 2003). The success of crossing yam beans might strongly depend on environment and technical skills of labor as in many other crops. As expected, we observed that all yam bean species can be considered as one primary breeding, which means that an incorporation of high DM attributes from *P. tuberosus* Chuin into *P. ahipa* and *P. erosus* is relatively easy. Even a complete introgression of the three species and development of "one new hybrid yam bean species" appear to be possible. On the basis of our results, taxonomy even could consider to merge *P. ahipa* and *P. tuberosus* into one species. However, recombination success within *P. erosus* appears to be different from that of the interspecific *P. erosus* x *P. tuberosus* recombination. Note: The opinion of whether to merge *P. ahipa* and *P. tuberosus* into one species is also shared by Marc Deletre based on Simple Sequence Repeat marker studies in yam beans (personal communication, 2015).

A manuscript for this study is available: Heider, B., E. Romero, R. Eyzaguirre, and W.J. Grüneberg. Interspecific hybridization between three species of cultivated American yam bean (*Pachyrhizus* sp. DC).

Table 4 Recombination among *P. ahipa* (AC), *P. tuberosus* Chuin (TC), and *P. erosus* (EC) and frequency of successful intraspecific and interspecific hybridization

Groups	Cross Combinations	No. of Flowers Crossed	No. of Pods Obtained	Success Rate (%)
1st Experiment (2010)				
1	AC x AC	323	26	8.0
2	TC x TC	389	43	11.1
3	AC x TC	876	72	8.2
4	TC x AC	410	39	9.5
2nd Experiment (2011)				
1	EC x EC	1710	275	16.1
2	TC x TC	1869	89	4.8
3	EC x TC	4051	250	6.2
4	TC x EC	1796	84	4.7

3. OBJECTIVE 2: IDENTIFY ADAPTED, HIGH-YIELDING YAM BEANS FOR CENTRAL AFRICA

A total of 38 yam bean accessions were made available in Central Africa in 2010/11 through CIP–Uganda (see Section 2.2.1 above). All accessions were low DM *Pachyrhizus* accessions comprising 11 *P. erosus*, 20 *P. ahipa*, and 7 *P. tuberosus* Ashipa accessions. This set of accessions was considered to be sufficient to study the yield and adaptation potential of yam beans in Central Africa. Three strategies were applied to identify adapted, high-yielding yam beans for Central Africa. The first was multi-environmental trials (METs) across Central Africa (Uganda, Rwanda, and East DRC) organized by CIP–Uganda in cooperation with the project partners in Central Africa under supervision of Silver Tumwegamire. The second strategy was independent on-station and on-farm trials/selections by the partners RAB (Rwanda) under supervision of Jean Ndirigue, ISABU (Burundi) under supervision of Astère Bararyenya, and INERA (DRC) under supervision of Georges Bouwe. The third strategy was yield and adaptation studies in the MSc and PhD studies at Makerere University under supervision of Phinehas Tukamuhabwa (see also Section 9 below and Appendix 9).

3.1 MULTI-ENVIRONMENTAL TRIALS

METs with the abovementioned material (32 out of 38 accessions, complete design) were established in:

- **Uganda:** Namulonge (forest zone, 1,150 masl, 1,500 mm); Serere (savanna zone, 1,140 masl, 900–1,300 mm); and Kabale (highland zone, 2,150 masl, 1,750 mm)
- **Rwanda:** Rubona (highland zone, 1,650 masl, 926 mm) and Musanze (highland zone, 1,850 masl, 900.6 mm)

- **DRC:** Mulungu (highland zone, 1,700 masl, 1,200–1,700 mm) and Ruzizi Valley (savanna zone, 900 masl, 800–950 mm)
- **Burundi:** Bjumbura (savanna zone, 830 masl, 900–1,000 mm); Mpalambo (900 masl, 900–1,000 mm); and Imbo (900 masl, 800–950 mm).

The MET locations ranged from 830 masl (Bjumbura) to 2,150 masl (Kabale), with an annual rainfall from 798 mm (Bjumbura) to 1,750 mm (Kabale). The METs at Mvuazi in the Bas-Congo province and in Southern DRC close to the Zambia border at Kipopo were not planted. However, at both locations, observation trials for yam beans were planted (see Appendix 4). All seeds for these METs are provided by a seed multiplication under quarantine conditions at CIP-Kampala at Namulonge to ensure that all partners are working with the same material. For more detail on the accessions used in the METs, see the annual report for the current project (CIP 2011). With respect to yield estimates, it must be taken into account that at Namulonge and Serere two harvests per year were achieved with the yam bean (i.e., Naulonge 2011a and 2011b, 2012a and 2012b; Serere 2011a and 2011b, and 2012a and 2012b). For cassava, only one harvest per year can be achieved at these locations.

Average yam bean fresh storage root yields of up to 23.6 t/ha (CIP-209019) across the Central African environments in the MET study were observed (Table 5). Most high-yielding accessions were *P. erosus*; but high yields across Central Africa for *P. tuberosus* and *P. ahipa* can also be found, with average yields up to 12.3 t/ha (CIP-209055) and 9.5 t/ha (CIP-209024), respectively. The study shows that the Amazonian yam bean can also be well adapted to Central Africa at relative high altitudes (i.e., CIP-209055, CIP-209060, and CIP-209058). This agrees with the findings of *P. tuberosus* up to 1,800 masl in Bolivia (Ørting et al. 1996).

Table 5 Average fresh storage root yields of 32 yam bean accessions across Central African environments used in the MET study

Yam Bean Accession	Species	No. of Environments in Central Africa	Average Fresh Storage Root Yield (t/ha)
CIP-209019	*P. erosus*	7	23.6
CIP-209017	*P. erosus*	12	22.8
CIP-209018	*P. erosus*	13	21.8
CIP-209051	*P. erosus*	11	19.6
CIP-209016	*P. erosus*	12	19.0
CIP-209052	*P. erosus*	12	16.3
CIP-209050	*P. erosus*	11	14.8
CIP-209055	*P. tuberosus*	12	12.3
CIP-209046	*P. erosus*	12	11.9
CIP-209060	*P. tuberosus*	12	10.5
CIP-209024	*P. ahipa*	11	9.5
CIP-209035	*P. ahipa*	12	8.7
CIP-209023	*P. ahipa*	11	8.4
CIP-209058	*P. tuberosus*	10	8.3
CIP-209032	*P. ahipa*	12	8.2
CIP-209029	*P. ahipa*	10	7.9
CIP-209036	*P. ahipa*	12	7.8
CIP-209031	*P. ahipa*	12	7.3
CIP-209033	*P. ahipa*	12	6.5
CIP-209030	*P. ahipa*	11	6.4
CIP-209007	*P. ahipa*	12	6.0

Yam Bean Accession	Species	No. of Environments in Central Africa	Average Fresh Storage Root Yield (t/ha)
CIP-209003	*P. ahipa*	12	5.7
CIP-209025	*P. ahipa*	11	5.6
CIP-209022	*P. ahipa*	11	5.1
CIP-209004	*P. ahipa*	11	5.0
CIP-209006	*P. ahipa*	12	4.8
CIP-209034	*P. ahipa*	11	4.7
CIP-209025	*P. ahipa*	11	4.5
CIP-209028	*P. ahipa*	11	4.5
CIP-209027	*P. ahipa*	10	3.8
CIP-209054	*P. tuberosus*	12	3.3
CIP-209059	*P. tuberosus*	11	2.9

The highest average yam bean fresh storage root yields across season were observed at Bjumbura in Burundi with 57.9 t/ha (CIP-209019) (Table 5). Considering annual storage root yields across two growing season, similar yields were observed at Namulonge and Serere in Uganda. The results are consistent with yields in experimental trials reported by Zanklan et al. (2007), with 44.8 t/ha across 14 accessions of *P. erosus* and two environments in Benin. For *P. tuberosus* and *P. ahipa*, storage root yields up to 15.8 and 21.2 t/ha were observed at Namulonge and Rubona, respectively. The upper limit of yam bean cultivation in Central Africa appears to be around 2,100 masl (see yields at Kabale in Uganda, Table 6). At the elevated altitudes of Rubona in Rwanda and Mulungu in Eastern DRC we observed that more *P. ahipa* accessions were among the top 10 yielding accessions compared with Namulonge and Serere. A striking result is that *P. ahipa* is not surpassing *P. erosus* yields at higher altitudes. However, note that *P. ahipa* does not need much more than 120 days from sowing to harvest, whereas *P. erosus* needs around 150 days.

Table 6 Top 10 yielding yam bean accessions in Central Africa by locations across seasons used in the MET study (fresh storage root yields in t/ha given in brackets)

Location	Top 10 Yielding Yam Bean Accessions in Central Africa*
Namulonge, Uganda† 1,150 masl	EC CIP-209016 (28.9), EC CIP-209017 (27.9), EC CIP-209018 (26.5), EC CIP-209051 (26.1), EC CIP-209019 (23.4), EC CIP-209050 (19.2), EC CIP-209052 (17.3), EC CIP-209046 (17.1), AC CIP-209024 (15.8), and TC CIP-209055 (15.8).
Serere, Uganda† 1,140 masl	EC CIP-209017 (23.2), EC CIP-209052 (17.1), EC CIP-209051 (16.8), TC CIP-209055 (15.7), EC CIP-209016 (15.1), EC CIP-209050 (14.5), EC CIP-209018 (14.3), EC CIP-209019 (11.5), TC CIP-209060 (11.2), and TC CIP-209058 (9.3).
Kabale/Kachwekano, Uganda 2,150 masl	EC CIP-209016 (6.2), EC CIP-209017 (5.8), EC CIP-209046 (5.7), TC CIP-209055 (5.1), EC CIP-209018 (5.0), EC CIP-209050 (4.9), AC CIP-209036 (5.5), AC CIP-209035 (4.3), AC CIP-209030 (3.5), and AC CIP-209032 (3.5).
Rubona, Rwanda 1,650 masl	EC CIP-209019 (30.0), EC CIP-209018 (28.5), EC CIP-209052 (23.3), AC CIP-209029 (21.2), EC CIP-209050 (12.9), TC CIP-209055 (12.3), AC CIP-209032 (12.0), AC CIP-209023 (11.9), EC CIP-209016 (11.8), and AC CIP-209024 (11.3).
Mulungo, DRC 1,700 masl	EC CIP-209017 (31.1), EC CIP-209051 (21.4), EC CIP-209016 (21.3), AC CIP-209052 (19.5), AC CIP-209035 (17.7), EC CIP-209018 (17.6), AC CIP-209032 (17.4), EC CIP-209050 (17.3), EC CIP-209046 (14.8), and AC CIP-209022 (14.5).
Bujumbura, Burundi 830 masl	EC CIP-209019 (57.9), EC CIP-209018 (46.5), EC CIP-209017 (37.0), AC CIP-209051 (19.5), AC CIP-209023 (26.8), AC CIP-209036 (23.2), EC CIP-209052 (22.2), AC CIP-209032 (19.7), AC CIP-209031 (19.3), and AC CIP-209007 (15.4).

* EC, *P. erosus*; TC, *P. tuberosus*; AC, *P. ahipa*.
† Two growing seasons/year demonstrated; yields are given per growing season.

High-yielding accessions (yields larger than the general mean) with low genotype by environment interaction (low deviations from the zero PC1 line) were observed in our METs in Central Africa (Fig. 1) (i.e., EC CIP-209017, EC CIP-209051, EC CIP-209052, EC CIP-209050, TC CIP-209055, and AC CIP-209029). Such accessions can be labeled as high yielding and widely adapted in Central Africa. However, among *P. erosus* there appears also a specific adaptation (i.e., EC CIP-209019 and EC CIP-209018 at Bjumbura and EC CIP-209016 at Serere). Among *P. ahipa* accessions there is a more pronounced adaptation to the elevated locations of Rubona and Mulungu (i.e., AC CIP-209029, AC CIP-209023, AC CIP-209032, AC CIP-209024, and AC CIP-209036). As mentioned before though, *P. ahipa* accessions are not surpassing *P. erosus* accessions at higher altitudes as long as days from sowing to harvest are taken into account. We expect that early harvest (120 days after sowing) leads to yields in *P. ahipa* compared with *P. erosus* at higher altitudes.

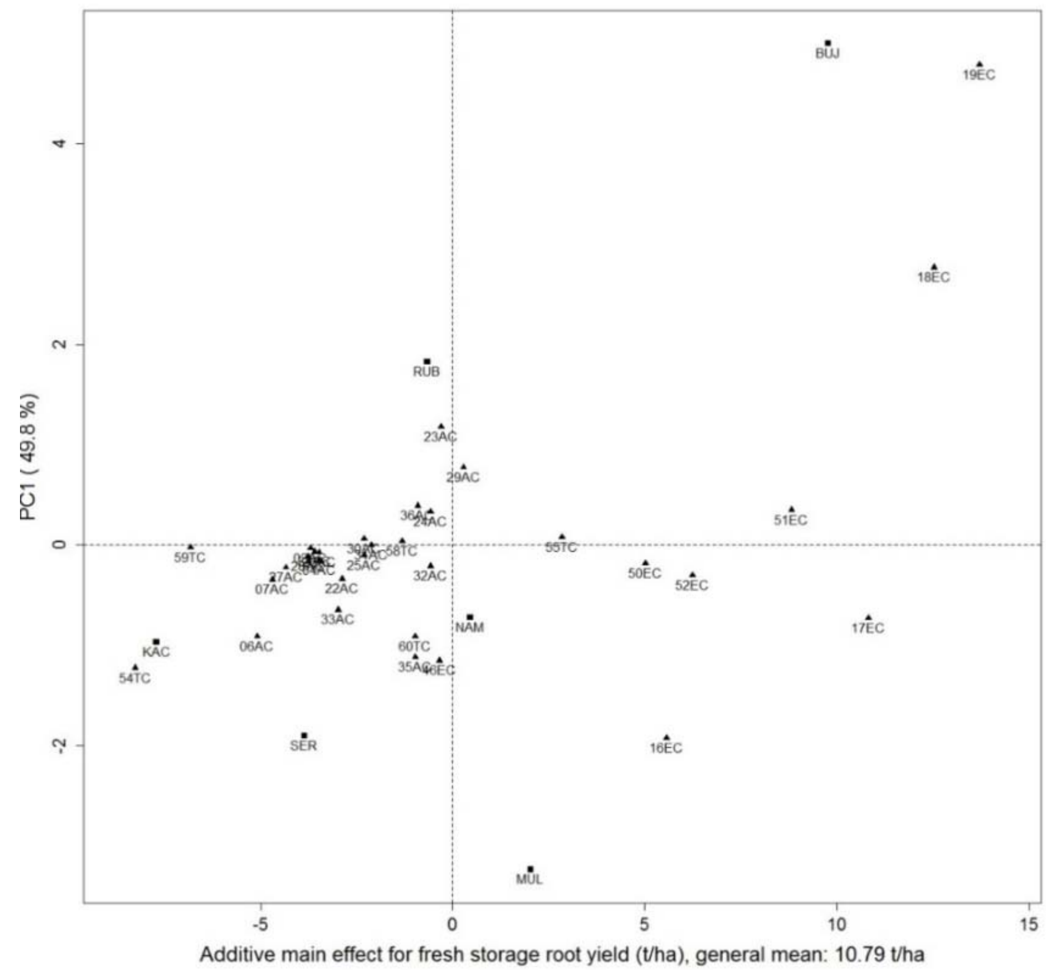


Figure 1. Adaptation of 32 yam bean accessions to Central African growing environments with respect to storage root yield illustrated by an AMMI bi-plot. Only the two last digits of CIP accession numbers are given: AC, *P. ahipa;* EC, *P. erosus*; TC, *P. tuberosus*; NAM, Namulonge (Uganda); SER, Serere (Uganda); KAC, Kachwekano/ Kabale (Uganda); Rubona (Rwanda); MUL, Mulungu (DRC); BUJ, Bujumbura (Burundi).

A limitation of the MET in 2012–2013 is that only low DM yam beans were used, because high DM yam beans were not available in Africa before 2012 and were multiplied in 2013. However, in 2014 yields and DM content of some high DM yam bean accessions relative to high-yielding low DM yam beans were evaluated in observation trials by CIP–Kumasi in Ghana (Table 7). With respect to fresh storage root yields, high DM yam beans yield up to 45% (i.e., CIP-209041) of extreme high-yielding low DM accessions (i.e., CIP-209018 and CIP-209019). With respect to relative storage root DM yields, high DM accessions can surpass yields of low DM yam beans (i.e., CIP-209014, CIP-209015, CIP-209037, and CIP-209041 compared with the checks CIP-209018 and CIP-209019). High-yielding high DM yam beans exhibit starch content on fresh weight basis in the range of 21–30% (i.e., CIP-209013, CIP-209014, CIP-209015, CIP-209037, CIP-209040, and CIP-209041). Given the background of trace mineral deficiency in Africa, especially iron, it is worth noting that 100 g of fresh, high DM yam beans contain 0.83–1.74 mg of iron, which is twice as high as the average iron contents of sweetpotato as reported by Tumwegamire et al. (2011) in East Africa.

Table 7 Relative yields and quality attributes of high DM yam beans compared with high-yielding, low DM yam beans evaluated in observation trials by CIP-Kumasi in Ghana

				Storage Root Contents (fwb)			
Accession	**Relative Storage Root Yield***	**DM (%)**	**Relative Storage Root DM Yield**	**Protein (%)**	**Iron (mg/100g)**	**Zinc (mg/100g)**	**Starch (%)**
High DM yam beans							
CIP-209013	35.7	31.5	11.3	3.1	1.74	0.21	22.4
CIP-209014	36.5	36.9	13.5	2.9	1.44	0.32	30.0
CIP-209015	32.8	37.8	12.4	3.7	1.30	0.40	29.8
CIP-209037	36.9	35.7	13.2	3.1	1.15	0.33	27.6
CIP-209038	10.4	36.9	3.8	3.0	1.07	0.37	30.0
CIP-209039	20.0	32.4	6.5	3.0	0.90	0.26	25.8
CIP-209040	30.4	34.8	10.6	3.0	1.02	0.30	26.5
CIP-209041	44.1	28.5	12.6	2.1	0.83	0.20	21.5
CIP-209042	22.3	28.3	6.3	2.2	0.77	0.20	21.3
CIP-209044	17.2	35.0	6.0	2.9	1.31	0.27	26.9
CIP-209045	23.2	39.8	9.2	3.4	1.35	0.35	31.9
Low DM yam beans used as checks							
CIP-209018	100	11.1	11.1	1.0	0.51	0.11	3.5
CIP-209019	100	11.6	11.6	1.2	0.46	0.14	3.9

* Average yield across CIP-209018 and CIP-209019 used as checks and representing to high yielding widely adapted accessions in West Africa.

Furthermore, high DM yam beans have been generated by our interspecific crossing program among *P. erosus* x *P. tuberosus* (Chuin) and *P. ahipa* x *P. tuberosus* (Chuin) (see previous section). The derived 18 breeding populations were evaluated in Uganda and Rwanda as part of the PhD thesis by Rolland Agaba (in Uganda) and Jean Ndirigue (in Rwanda). This high DM material has been developed until F2 in F3 and is used to measure the response to selection for high-yielding, widely adapted high DM yam beans in Uganda (*P. erosus* x *P. tuberosus* [Chuin] populations) and short crop duration, high DM yam beans with acceptable yields in Rwanda (*P. ahipa* x *P. tuberosus* [Chuin] populations). We plan to get from both students their top selections into the genebank at CIP–Peru.

Literature Used:

Ørting, B., W.J. Grüneberg, and M. Sørensen. 1996. Ahipa (*Pachyrhizus ahipa* (Wedd.) Parodi) in Bolivia. *Genetic Resources and Crop Evolution* 43: 435–446.

Tumwegamire, S., R. Kapinga, P.R. Rubaihayo, D.R. LaBonte, W.J. Grüneberg, G. Burgos, T. zum Felde, R. Carpio, E. Pawelzik, and R.O.M. Mwanga. 2011. Evaluation of Dry Matter, Protein, Starch, Sucrose, b-carotene, Iron, Zinc, Calcium, and Magnesium in East African Sweetpotato [*Ipomoea batatas* (L.) Lam] Germplasm. *HortScience* 46 (3): 348–357.

Zanklan, A.S., S. Ahouangonou, H.C. Becker, E. Pawelzik, and W.J. Grüneberg. 2007. Evaluation of the Storage-Root-Forming Legume Yam bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Science* 47: 1934–1946.

3.2 ON-STATION AND ON-FARM TRIALS/SELECTIONS BY PROJECT PARTNERS

The National Agricultural Research Organization (NARO) in Uganda was not a partner in this project. All activities in Uganda for the project were conducted with the Makerere University (see next section 3.3. for objective 2, as well as the section for objective 8 of the project, and Appendix 9. However, CIP and NARO/NaCRRI (National Crops Resources Research Institute) are working very closely together in Uganda with respect to our sweetpotato activities, and the yam bean activities of CIP and Makerere University at Namulonge were known to NARO/NaCRRI. At the end of the project, a discussion started at NARO/NaCRRI to make the yam bean a medium-term research priority crop, but so far no decision has been made.

RAB in Rwanda observed in their on-station trials even higher yields as in our METs (see above), especially at the location Karama (1,471 masl) to the northwest from Rubona (1,650 masl, 926 mm) (see Appendix 3 for details). Adaptability trials with farmers' participation showed that in Rwanda the best performing genotypes are the *P. erosus* accession CIP-209018 and the *P. ahipa* accessions CIP-209032, CIP-209033, and CIP-209035. RAB put more emphasis on *P. ahipa* selection, as would have been expected, based on the METs alone. This has to do with the shorter crop duration of *P. ahipa* compared with *P. erosus*.

INERA in DRC evaluated at many more locations as it appears from the MET and the MSc thesis by Kilongo Bulambo (see section 9 for objective 8 and Appendix 9). Yam beans were evaluated on station at eight locations and on-farm at five locations (Table 8). Accessions were selected within all three yam bean species. The best yielding accessions were two for *P. ahipa* (CIP-209035 and CIP- 209036), two for *P. erosus* (CIP-209017 and CIP-209018), and two for *P. tuberosus* (CIP-209054 and CIP-209055). Storage root yields reported for *P. ahipa*, *P. erosus*, and *P. tuberosus* were up 18.5, 31.1, and 22.0 t/ha, respectively. For further details see Appendix 5.

Table 8 Overview of on-station and on-farm trials conducted in DRC (2012/2013)

Type of Trials	Experiment	Locations	No. of Accessions
On-station	Evaluation of accessions in context of METs across countries in Central Africa	Mulungu	11
		Mulungu	34
		Ruzizi Valley	34
	Local trials	Mvuazi	13
		Kipopo	9
		Tshirumbi	9
On-farm	Evaluation of selected yam bean accessions	Runingu	4
		Kakondo	4
		Cibinda	4
	Agronomy trials	Bushuma	2
		Runingu	2

ISABU in Burundi reported storage root yields across accessions and environments of 22 t/ha under pruning (no seed production allowed) and 10.3 t/ha without pruning. It concluded that most yam bean genotypes are well adapted to Burundi (see Appendix 5). The highest yielding accession was 209019, with a storage root yield across environments of 57.9 t/ha. ISABU moved with two selected *P. erosus* accessions (209019 and 209017); three selected *P. tuberosus* accessions (209013, 209054, and 209060); and one *P. ahipa* accession in on-farm trials and processing studies. Note that 209013 was moved into the study very late in 2013; however, it was valued for its near-similar taste to cassava.

3.3 YIELD AND ADAPTATION STUDIES IN MSC AND PHD STUDIES

One MSc study and the first manuscripts of the PhD studies emphasized yield and adaptation across a larger range of yam bean accessions.

Students	Thesis	Discipline	Supervisor
Jean Ndirigue	PhD	Plant breeding	Prof. P Rubaihayo, Dr. P. Tukamuhabwa
Rolland Agaba	PhD	Plant breeding	Dr. P. Tukamuhabwa, Prof. P. Rubaihayo
Charles Andiku	MSc	Agronomy	Dr. James Ssebuliba, Dr. Hebert Talwana

Jean Ndirigue completed all the field trails for the genotype by environment interaction study in Rwanda, comprising 22 accessions and six environments. The data have been completely analyzed for yield, yield stability, and adaptation. The results are consistent and publishable, but so far no manuscript is available.

Rolland Agaba completed all the field trails for variance component estimations of yield and quality traits in Uganda, comprising 26 accessions at Namulonge and Serere. The manuscript is soon to be submitted.

Genetic variability for yield and nutritional quality in yam bean (*Pachyrhizus* spp.) evaluated in Uganda by Rolland Agaba

Abstract

Information on the nature and magnitude of genetic variation in breeding populations is critical for designing effective improvement programs. This study aimed at estimating genetic variability for storage root yield and quality among 26 yam bean accessions in Uganda for potential improvement through selection. A randomized complete block design was used with two replications across two eco-geographical locations and seasons during 2012A and 2013A. Near-infrared reflectance spectroscopy (NIRS) technology was used to determine quality of root samples. The results showed that yam bean genotypes are significantly different in all the traits studied except protein, zinc and phosphorous while genotypic (σ^2_G) variance components were significant for storage root fresh yield, storage root dry matter, storage root dry yield, vine yield, fresh biomass yield, starch and iron contents. In addition, moderate to high broad sense heritability estimates (h^2_b) were recorded for harvest index, iron, vine yield, potassium, starch content and storage root dry yield, storage root fresh yield and storage root dry matter ranging from 26% to 78.2%. Phenotypic and genotypic coefficients of variation were high for storage root fresh yield (66%, 56.7%), storage root dry matter (22.6%, 20.0%), storage root dry yield (53.3%, 40.8%), fresh biomass yield (63%, 53.9%), vine yields (85.3%, 55.0%), fresh biomass yield (63.0%, 53.9%), starch (16.2%,12.4%) and iron (28.0%, 17.9%) respectively. There were significant positive correlations between storage root fresh yield and both storage root dry yield (r = 0.926) and fresh biomass yield (r = 0.962), as well between protein content and potassium (r=0.303), iron(r=0.499), phosphorus (r = 0.70) and zinc (r = 0.756). The current study demonstrates the presence of substantial genetic variation in yam bean to permit trait improvement for SRFY, SRDY, SRDM, VNY, FBY, HI, starch, iron and potassium with potential for rapid genetic progress through selection.

Charles Andiku completed his MSc thesis and prepared a manuscript. However, the manuscript still needs to be completely revised.

Evaluation of the American Yam Bean (*Pachyrhizus* spp.) for Storage Root Yield across Varying Ecogeographic Conditions in Uganda by Charles Andiku

Abstract

The yam bean (*Pachyrhizus* spp.) is a legume crop that is exclusively used for its storage roots. The seeds are inedible due to presence of toxic compounds. It produces high storage root yields comparable of major root crops like cassava or sweetpotato and flower pruning more than doubles its root yield performance. Using twenty five yam bean accessions, the current study aimed to determine root yield stability and adaptability, and presence of yam bean production mega environments in Uganda. Trials were planted at three stations, Namulonge, Serere, and Kachwekano during two consecutive seasons of 2011. Fresh storage root yields were significantly different ($p<0.05$) across locations with the ideal location being Namulonge (storage root fresh yield of 10.05 tha^{-1}), followed by Serere (8.0 tha^{-1}), and Kachwekano (3.08 tha^{-1}) respectively. Results of AMMI analysis indicated the presence of genotype-by-environment interaction for storage root fresh yield. Through AMMI estimates and GGE visual assessment, genotype 209017 was the highest yielding with mean yield of 20.68 t/ha. Genotype 209018 with mean yield of 15.48t/ha was the most stable and adapted accession in the entire discriminating environment in Uganda. From the environmental focusing plot, the six environments were grouped into two putative mega environments for yam bean production.

For further details see Appendix 9.

4. OBJECTIVE 3: DEVELOP YAM BEAN STORAGE ROOT PRODUCTS FOR CENTRAL AFRICA

Yam bean storage root products have been developed for Central Africa and include local products made from traditional root crops. The target was to demonstrate the development of at least two local food products from the yam bean.

INERA reported the development of porridge, fufu, and fritters. The products fufu and porridge were developed based on two formulations: (1) up to 100 % with yam bean and (2) in combination with maize flour (50:50). The product fritters, made with wheat and yam bean flour (50:50), had the highest scores for appearance, taste, and consistency of consumer acceptance studies. The second highest score was for porridge made 100% from yam bean. The results and recipes are presented in Appendix 4; INERA has also printed a small manual about yam bean processing.

RAB demonstrated the processing of yam bean storage roots to ugali, weaning food with mixed flour, and juice. Selected famers from on-farm trials participated in taste tests for each product. Remarkable is the scoring of yam bean juice. A consumer preference assessment of yam bean juice was conducted by 30 panelists, who scored the samples of juice based on sensory attributes given. Pineapple juice was used as a control. **The results showed that most of the panelists preferred yam bean juice (from low DM yam beans) over pineapple juice.** A yam bean juice protocol was developed where a clear and stable juice was created (see Appendix 3). It is worth noting that yam bean juice was also among the most favorable products developed reported from Benin. Juice and processing of different food products should go hand-in-hand with yam bean processing.

ISABU reported the testing of chips, salad, and *katogo* preparation from yam bean (see Appendix 5). Selected famers from on-farm trials participated in taste tests of each product. Yam bean salad and katogo protocols were developed; more focus was put on *katogo* and salad. **Remarkable is the scoring**

of yam bean chips from the high DM accession CIP-209013 (Fig. 2), for which ISABU reported tastes comparable to cassava.

Figures 2a and 2b. Yam bean chips prepared in Burundi from high DM accession *P. tuberosus* Chuin CIP-209013 (which tastes comparable to cassava).

The development of storage root products in Central Africa was linked with a training component for one MSc student from Uganda. The student, Ms. Lydia Nakagiri, was among the best students and leading the group of "yam bean students" at Makerere University. Unfortunately, she was the only MSc student who did not complete her thesis—she simply "disappeared" and is no longer responding to e-mails. There are rumors that she is now living in Ghana. Some of the processing work with women's groups in Uganda can be seen in Appendix 11. Favorite products were *ugali*, made from composite flour 50% yam bean and 50% maize; pancakes from dough made from ripe dessert banana and yam bean flour; porridge made from composite flour 50% yam bean and 50% maize; and *atap* made from yam bean, cassava, sweetpotato, and sorghum. (Fortunately, there is a good draft of Ms. Nakagiri's thesis available and from which the recipes of the food products she developed with women's groups can be extracted.) We will meet with Silver Tuwegamire in July 2015 (since 2013 he has been working for the International Institute of Tropical Agriculture) to extract the recipes from Ms. Nakagiri's thesis draft and to merge these with the recipe manual for yam bean developed by INERA. We also note that the BSc thesis of James Muhangi (see abstract below) is of such good quality that we still want to revise it with an editor and print it with ISBN number.

Cost Benefit Analysis of Processing Yam Bean into Flour used to make Atap/Ugali Food Product in Serere and Luwero Districts

Abstract

A benefit/cost analysis (BCA) was conducted to determine the viability of processing yam bean introduced by International Potato Centre (CIP) in Uganda. The analysis was found important to determine if the expenditure on production and processing is economically viable for the target communities in the Serere and Luwero districts. Both qualitative and quantitative data was collected using a pre-tested questionnaire. The data included costs and benefits (direct and indirect) met by farmers in undertaking the production and processing activities. The major study respondents were individual farmers who participate in growing and processing of yam bean. In addition, focus group discussions were employed to capture vital qualitative information regarding yam bean production and processing. Results of the benefit cost analysis show that yam bean processing and production are financially viable enterprises in the target area with regard to selling of flour and fresh yam bean roots. As expected, for every Ugandan shilling invested in production of yam bean, farmers obtain 1.32 and 1.37 shillings for both Luwero and Serere respectively. For every one Ugandan shilling invested in

processing, a 1.41 and 1.56 Ugandan shilling is obtained for both Luwero and Serere respectively. These results imply that commercial production and processing of yam bean into flour used to make *Atap* and *Ugali* or porridge is viable and worthwhile to farmers. 90% of the farmers in Luwero district preferred consumption of processed yam bean because of various uses when processed, whereas 62.5% of the farmers in Serere preferred consumption of fresh yam bean because of the fresh taste involved with it and the low dry matter content.

Based on the findings, the following conclusions were made:

i) Processing of yam bean into flour is viable whether homegrown or purchased roots are used.
ii) Yam bean has the potential of improving household incomes of rural people and can hence be instrumental in fighting rural poverty due to the viability of both production and processing.
iii) Yam bean has the potential of improving the nutritional status of citizens in Uganda due to its nutrient content base.

Finally, two yam bean demonstration processing units were constructed: one at Namulonge in Uganda and the second at Gisozi research station in Burundi. These processing units will also be used for sweetpotato and cassava processing. In West Africa, especially Nigeria and Benin, such units were and are still used successfully to market cassava, and today are found throughout rural areas. In contrast, they are rarely found in rural areas in Central Africa.

5. OBJECTIVE 4: IMPROVE PROCESSING OF YAM BEAN STORAGE ROOT PRODUCTS IN WEST AFRICA

This part of the project was very successful. Processing of yam bean storage root products in West Africa has been significantly improved. We even can state that the project might have led to a fundamental change in how the yam bean is considered to be used. In the past, yam bean was only considered as a fruit/root vegetable to be eaten raw. The project has developed a wide array of products based on yam bean that, so far, has driven the success of adoption of the crop in Benin.

In 2000 the yam bean was introduced into Benin/West Africa for scientific purposes. This led to a paper that emphasized storage root and seed yields of the crop under West African growing conditions (Zanklan et al. 2007). However, the paper already reported demonstration of processing yam bean storage roots to *gari*. *Gari* is the most important root crop food product in West Africa and eaten by millions on a daily basis. In the project we demonstrated not only improved processing from yam bean to *gari*; we also developed and tested a multitude of products and most promising products were compiled into a marketing strategy, which was linked with dissemination efforts.

In a first step it was reconfirmed that *gari* processed from yam beans can indeed be addressed as *gari*. This was done in cooperation with Department of Agrotechnology and Food Sciences of Wageningen University, The Netherlands. The work was integrated into the MSc study of Ms. Renee Wassens (Wassens 2011). However, only low DM yam beans were used in this study, because high DM yam beans were not available at that project stage, as mentioned above in the discussion on Peru's national rights on high DM *P. tuberosus* Chuin and its derivatives. The results were very positive, except that the conversion rate of the storage roots to *gari* of about 4.5% from low DM yam beans was very low. It was reconfirmed that yam bean storage roots can be processed to produce *gari*. However, *gari* prepared from yam bean with the traditional cassava procedures was at first much browner than cassava *gari*. But protein, calcium, iron, and zinc levels in yam bean *gari* were three to four times higher than those in cassava *gari*. Moreover, organoleptic quality of yam bean *gari* was judged as very good by 53%, good by 27%, and quite good by 20% of the consumers. Ms. Wassens developed a new *gari* processing technology for yam bean storage roots in collaboration with CIP-Benin by adapting the traditional *gari*-making process (for cassava) to yam beans. She reported 8.9 g of protein, 4.6 mg of iron, and 1.2 mg of zinc in 100 g of yam bean *gari*. But the low conversion rate from low DM storage roots to *gari* of about 4.5% appeared to be a "no-go decision" for marketing.

Ms. Wassens work has been published and/or is available through the University of Wageningen:

Wassens, R. 2011. "Assessment of the suitability of yam bean for the production of Gari." MSc Thesis. Product Design and Quality Management, Department of Agrotechnology and Food Sciences, Wageningen University, Wageningen, The Netherlands. 61 p. & annexes.

In a second step, two strategies were applied: (1) INRAB in Benin was searching/testing for other products from yam bean storage roots that are economically more attractive, and (2) CIP-Peru was emphasizing the demonstration of the difference between conversion rates from low and high DM yam beans to *gari*.

5.1 PROCESSING AT INRAB

In Benin 14 low DM yam bean accessions were available in 2010, of which two high-yielding *P. erosus* accessions were multiplied on a large scale to provide seeds for on-farm activities and farmer participatory processing studies; two vitamin A-rich OFSP were also disseminated. On the basis of this material, INRAB has shown that yam beans can be processed into a very wide range of products (e.g., juice, soups and stew, *gari*, *gari* in mixtures, starch, chips, snacks, and even yogurt and alcohol). For *gari* processing aiming at a product in mixtures with traditional cassava *gari*, see Padonou et al. (2013). Most important was linking of juice processing and *gari* processing to get an economically viable processing chain. The juice can be used directly or pasteurized as a bottle refreshment; it was valued highly in a taste test at weddings. And the pulp can be easily processed within the flexible *gari* processing chain around cassava, which is well established in Benin and other West African countries. Alcohol distillation was also mentioned as an economically very attractive product from yam bean juice, because usually palm wine is used in Benin for alcohol production, which is very expensive. Our aim, however, was certainly not to support alcohol production in Benin.

The product development was mainly driven by Wilfrid Padonou from INRAB. We are still compiling all recipes from Benin together into a processing manual (including those developed in Peru). The range of products processed and tested is only illustrated in Appendix 12, but here we report juice and *gari* processing for mixtures.

5.1.1 JUICE FROM MEXICAN YAM BEAN (P. EROSUS) AS BOTTLE REFRESHMENT

The juice obtained in processing yam beans after grading and pressing is an important product with monetary value (Fig. 3). The process to obtain bottle refreshments for markets is as follows:

Ingredients

Amount	Ingredients
250 g	Sugar
10 ml	Aroma
10 kg	Yam bean

Procedure

- Peel, wash, and grate yam bean.
- Put the mash into a woven bag and press under a screw press to extract the effluent.

- Filter the effluent and retrieve the supernatant.
- Heat the supernatant until 80–90°C and remove the foam.
- Cool down and filter the liquid, fill, and cap tightly cleaned and sterilized bottles.
- Pasteurize by heating the filled bottles in water at 80°C for 20–30 min.

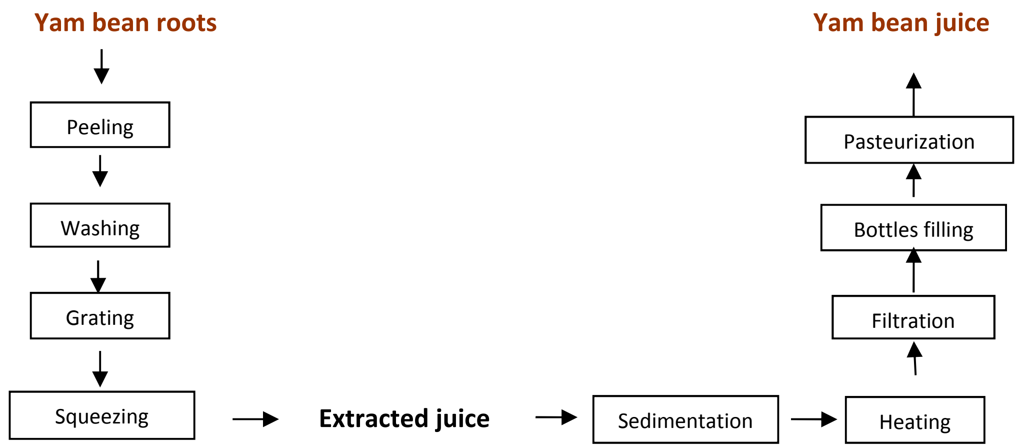


Figure 3. Juice from Mexican yam bean in bottles after pasteurization, Benin (photo by Wilfrid Padonou, 2012).

5.1.2 YAM BEAN-FORTIFIED GARI FROM MEXICAN YAM BEAN (P. EROSUS)

The pulp of yam bean after grading and pressing can be processed into various products, one of which is called "yam bean-fortified *gari*" (Padonou et al. 2013) (Fig. 4).

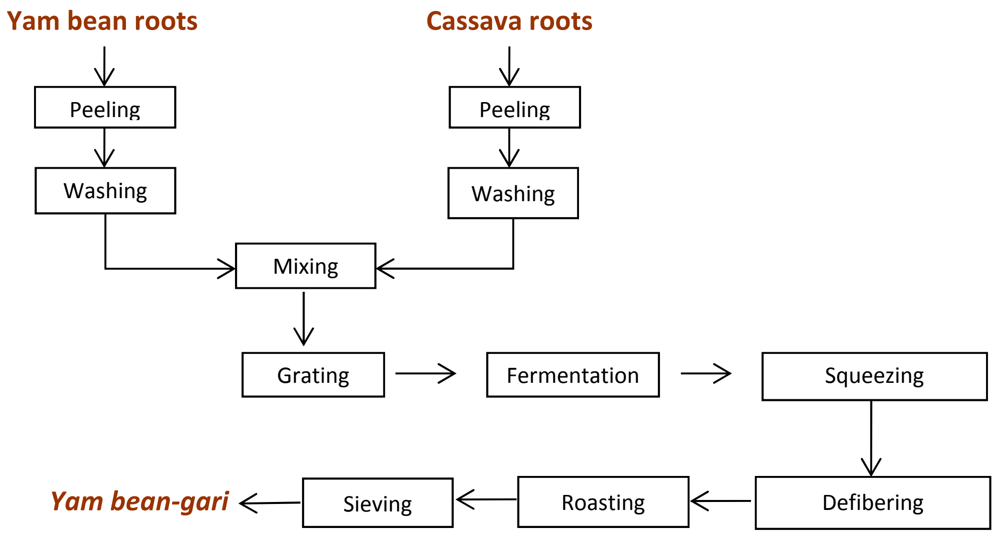
Ingredients

Amount	**Ingredients**
5 kg	Raw yam bean storage roots
5 kg	Raw cassava roots

Procedure

- Peel and wash separately yam bean roots and cassava roots.
- Mix the two kinds of roots.
- Rasp together the peeled roots.

- Put the mash in a basket to allow a part of the effluent to escape.
- Put the mash into a woven bag and press under a screw press to remove liquid up to ~40% water content.
- Crumble the block obtained after pressing.
- Reduce the fiber by sieving through a vegetable sieve.
- Toast in pan with constant hand-turning until 10–12% water content.
- Sieve to grade and pack in plastic bags or buckets.



Figures 4. Gari from Mexican yam bean (*P. erosus*) during toasting (*left*) and in buckets (*right*), Benin (photo by Wilfrid Padonou, 2010).

The work has been published:

Padonou, S.W., et al. 2013. Yam bean (*Pachyrhizus erosus*) tuber processing in Benin: production and evaluation of the quality of yam bean-*gari* and yam bean fortified *gari*. *Int. J. Biol. Chem. Sci.* 791: 247–259.

5.2 PROCESSING AT CIP IN PERU

The processing at CIP-Peru mainly sought to:

- Determine conversion rates of high DM yam beans to *gari*, because this yam bean type could not be made available for the project in Africa until 2012.

- Process under controlled conditions to determine true plant-iron concentration in fresh yam beans, yam bean products, and bioavailability studies of plant-iron in yam beans and yam bean products, in cooperation with Cornell University, Ithaca, New York.

Furthermore, a product was developed, *Mazamorra,* which is typical for Latin America, including the Amazonian zone of Peru. The yam bean *Mazamorra* also uses OFSP to get an iron and pro-vitamin A-enriched product. It can be considered as a ready-to-eat breakfast to be prepared in 5 min.

5.2.1 DETERMINATION OF CONVERSION RATES OF HIGH DM YAM BEANS TO GARI

Two high DM yam bean, accessions CIP-209013 (TC354) and CIP-209020 (TC362), and two low DM accessions, CIP-209016 (EC041) and CIP-209018 (EC533), were used for conversion rate studies. The materials were grown at two locations—that is, San Ramon and Oxapampa (both in Peru and the humid tropics) in two plot replications.

Harvest index of roots after peeling was around 89% and 75% in low and high DM yam beans, respectively. With respect to the three products (i.e., juice, sieved and dry *gari* and remaining fiber), the harvest index from peeled storage roots was around 50%, 4.5%, and 0.1% in low DM yam bean and about 25%, 19%, and 0.4% in high DM bean, respectively. The results show that conversion rates to *gari* are about four to five times higher in high DM yam beans than in low DM yam beans. Moreover, in both processing cases juice was obtained in significant amounts to justify further use and/or processing and treatment of this part of the harvest. Differences in peeling and remains between low and high DM yam beans are due to shape and damage of storage roots. The low DM yam beans in this study have very high yields, have a pronounced round shape, and are easy to peel.

5.2.2 NUTRIENT CONTENT OF YAM BEAN AND YAM BEAN PRODUCTS, INCLUDING IRON BIOAVAILABILITY

The nutrient contents of two yam accessions (one low DM and one high DM) and yam bean products are given in Table 9.

Table 9. Nutrient content of yam bean storage roots and two yam bean products

	Raw storage root		Juice		Gari	
	Low DM CIP-209018 (200 g)	**High DM** CIP-209013 (200 g)	**Low DM** CIP-209018 (200 g)	**High DM** CIP-209013 (200 g)	**Low DM** CIP-209018 (200 g)	**High DM** CIP-209013 (200 g)
Water (%)	88.2	72.0	95.9	87.0	7.5	5.5
Protein (g)	2.9	5.4	1.3	9.3	16.4	11.3
Starch (g)	5.2	42.5	0.4	16.0	47.0	131.7
Sucrose (g)	3.5	7.6	5.2	17.2	22.2	9.5
Glucose (g)	6.5	2.0	9.6	1.0	23.1	1.9
Fructose (g)	5.6	2.4	6.7	3.3	18.5	2.6
Iron (mg)	0.59	1.9	0.59	3.2	5.6	3.9
Zinc (mg)	0.53	0.7	0.58	1.2	3.7	1.3

Note: Storage roots and products estimates are on fwb, and all samples were tested for non-plant iron contamination.

Processing yam beans to *gari* results in (1) the product *yam bean gari*, which has high protein (5.6–8.2%) and high iron content (2–2.8 mg/100g), and (2) additionally in the product juice, which has high protein (0.65–4.65g/100 ml) and iron content (0.3–1.6 mg/100 ml). Consuming yam beans raw, as juice, and/or as processed products such as *gari* can improve the nutrient status of vulnerable populations, especially in the case of pronounced iron deficiency in the population (the iron bio-availability in yam beans and the yam bean product *gari* is very good; see section 5.2.3). **Eating raw yam beans and drinking yam bean juice might contribute significantly to iron intake in food supply**. The *yam bean gari* certainly contains 3.9–5.6 mg of iron in 200 g (Table 9)— an iron-dense plant food product that easily can be developed with on-farm technologies in developing countries. With respect to protein and iron content, there are pronounced differences if juice is obtained from low DM yam beans (i.e., CIP-209018) or high DM yam beans (CIP-209013), which are due to clear differences in iron content among low and high DM yam beans. We still do not know why low and high DM yam beans are different with respect to iron content in storage roots. However, with respect to *yam bean gari* developed from low and high DM yam beans, the differences in iron content are less pronounced and show a cross-over in ranking. As a result, the iron content of *yam bean gari* from low DM yam beans is higher than that of *yam bean gari* from high DM yam beans (Table 9). (NB: All our samples were checked for non-plant iron contamination by determination of aluminum concentrations in samples.) We assume that our protein, iron, and zinc results for *gari* will be principally similar for some other yam bean products, such as yam bean porridge. Moreover, we note that, according to the Food and Nutrition Board (2001), the recommended daily allowance of iron is 11 mg for infants (6–12 months), 7 mg for children (1–3 years), 27 mg for pregnant women, and 18 mg for non-pregnant women. To get more than 10 mg iron into the food supply on a daily basis is extremely difficult without using animal food products. And usually the iron bio-availability in plant food products is relatively low compared with iron bio-availability in animal food products.

In collaboration with Cornell University, we obtained iron bio-availability estimates for the yam bean measured by in-vitro digestion/Caco-2 cell culture. For accession CIP-209018, Cornell estimated iron content of 12.2 µg/g (1.22 mg/100 g dwb) and corresponding Caco-2 ferritin/mg protein was 11.9. For CIP-209013, an iron content of 23.6 µg/g (2.36 mg/100 g dwb) was estimated; the corresponding Caco-2 ferritin/mg protein was 16.7. Also for the product *yam bean gari*, Caco-2 ferritin/mg protein was very high. These results for yam beans are much better (often by a factor of 10 or more) compared with ratios for iron content and ferritin values in different types of common beans (Ariza 2007). The reason for this might be the low phytate and high vitamin C concentrations in raw yam bean. Vitamin C reduces tremendously after processing, so that bio-availability of iron in processed yam bean products reduces but still remains high because of low phytate concentrations. We think yam beans have the potential to help alleviate iron deficiency in children and women, especially in populations where there is very low consumption of animal products. Certainly it merits further investigation to quantify potential and contributions to alleviate iron deficiency in human food supply by increasing yam bean consumption (fresh as well processed). Anecdotally, we report here rural knowledge from Sumatra/Indonesia (an area with traditionally very high production of yam beans), which says that pregnant women should consume yam bean for well-being (personal communication, Abidin Putri Ernawati, 2013). Independently, consumers in Benin and Uganda said that consuming yam bean makes them more active. We have speculated that these effects could be related to more iron and very good iron bio-availability through yam bean in food of populations where prevalence of anemia is high.

Literature used:

Ariza, M. 2007. Screening of iron bioavailability patterns in eight bean (*Phaseolus vulgaris*) genotypes using the Caco-2 cell in-vitro. *Journal Agriculture and Food Chemistry* 55: 7950–7956.

Food and Nutrition Board. 2001. Institute of Medicine. Iron. Dietary reference intakes for vitamin A, vitamin K, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press, pp. 290–393.

5.2.3 MAZAMORRA MADE WITH SWEETPOTATO GARI AND YAM BEAN GARI (30:70)

Mazamorra (from Spanish, "Moor's dough") is a traditional Latin American food that originally was a maize porridge. In Peru, *mazamorra* is traditionally made with a local type of maize, *maiz morado*, rich in anthocyanin that gives the porridge a deep purple color. The Peruvian *mazamorra* is often served to guests and in restaurants by cooking the maize with pineapple, cinnamon, and sweetpotato flour. Our idea was to make a micronutrient-enhanced *mazamorra*, which was derived from comments of teachers in the “Instituto de Educación Superior Tecnológico Publico “Ashaninka” (IESTP”A”) at Puerto Ocopa, Peru, where most Amazonian children have only a glass of “masato de yucca” (a drink made from cassava) as food before school. As an alternative we wanted to create a traditional and ready-to-eat breakfast based on pro-vitamin A-rich sweetpotato and iron-rich yam bean. For sweetpotato we used in the *mazamorra* preparation—the OFSP variety ‘Sumy’, which was recently launched as a new variety in the area of the Amazonian Peru (areas around the rivers Ucayali, Tambo, and Ene). For yam bean in the *mazamorra* we used the accessions CIP-209018 and CIP-209013. Figure 5 illustrates the preparation of yam bean x sweetpotato *mazamorra*. Our *mazamorra* can be prepared in the morning within minutes, and is a mixture of 30% sweetpotato sieving (similar to *gari*) and 70% yam bean sieving (similar to *gari*).

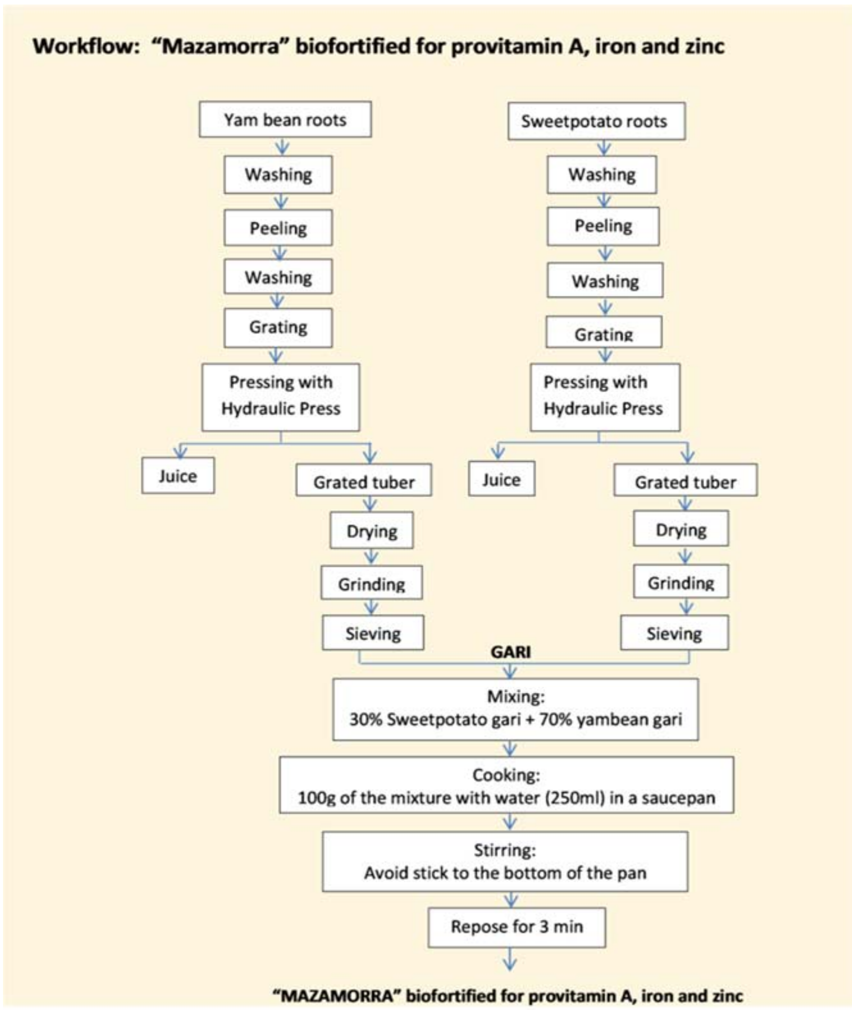


Figure 5. Illustration of the preparation of the ready-to-eat breakfast yam bean x sweetpotato *mazamorra*.

It became obvious that through food processing and a simple formula, the micronutrient density in traditional food products can be enhanced (Table 10). The yam bean x sweetpotato *mazamorra* contains in 200 g (mixture of 30% sweetpotato and 70% yam bean) 5.7–7.3% protein, 0.9 mg of pro-vitamin A, 1.9–2.8 mg of iron, and 0.8–2.0 mg of zinc, depending on the yam bean type used.

Table 10 Nutrient content of *mazamorra* prepared from 30% OFSP 'Sumy' and 70% yam bean accessions 209018 and 209013

	Sweetpotato (30%) x Yam Bean (70%) *mazamorra*	
	Low DM CIP-209018 in 200-g mixture	**High DM** CIP-209013 in 200-g mixture
Water (%)	7.6	6.3
Protein (g)	14.6	11.4
Starch (g)	57.3	122.2
Sucrose (g)	22.3	19.1
Glucose (g)	18.6	8.6
Fructose (g)	16.0	6.7
Pro-vitamin A (mg)	0.9	0.9
Iron (mg)	2.8	1.9
Zinc (mg)	2.0	0.8

5.3 YAM BEAN USED AS ANIMAL FEED

We have not tested the use of yam beans as animal feed, except for the feeding of giant African snails (considered a delicacy and sold in gourmet restaurants in Benin). A contact for these studies is Charles Pomalegni (animal production scientist at INRAB/Benin). These snails are relatively easy to raise and feed at a very small pace, and are considered a source of protein as well as on-farm income.

See also: Adapting Ahipa in Africa: http://cipotato.org/wp-content/uploads/Cipnewsletter/CIP-Newsletter-March-2012.pdf

From Uganda we have heard that yam bean is tested as pig feed, and from Thailand that it is used to feed elephants. However, peelings and remains of processed yam beans are generally given to animals such as chickens and goats.

6. OBJECTIVE 5: DEVELOP MARKETING STRATEGIES FOR YAM BEAN PRODUCTS AND PROMOTE YAM BEAN USE IN WEST AFRICA

The marketing strategy had two goals. One was to convince farmers and consumers that the yam bean is a desired product. The second goal was to establish the yam bean on farm and on markets in Benin in order to (1) generate more income among famers and food processors; (2) achieve greater food security; (3) increase the nutrient density in food supply; and (4) manage farm resources and farming systems more sustainably, with respect to the soil nutrient cycle and water consumption.

The strategy for objective 5 in this project was to enable the yam bean (and the benefits discussed above) to penetrate Benin's existing, cassava-dominated root and tuber (R&T) market.

6.1 BASELINE STUDY

In the first year of the project, we carried out a baseline study to evaluate the present situation in Benin for (1) farming systems, (2) processing and food systems, and (3) marketing systems that are based on R&T crops. The results for production, consumption, and marketing systems of the baseline study were:

- **Production systems**. The main systems were characterized for seven sites by (1) soils and association to particular production systems; (2) gender roles in production, with the result that women are marginalized due to limited right to access land; (3) the principal R&T crop, which is nearly always cassava (except for one village producing mainly sweetpotatoes); and (4) the production constraints of R&T crops, which were priorities by farmers as to lack of labor, land, and capital.

- **Consumption systems**. Populations in the surveyed villages mainly consume maize and cassava processed into maize stiff porridge, maize x cassava stiff porridge, *gari*, and *akassa* (made from maize). Malnutrition levels in the surveyed villages observed through anthropometry are critical in children under 5 years old. More than 50% of the population is grouped into underweight or severely underweight. Malnutrition in children under 5 was positively associated with the frequency of consumption of manioc and maize and negatively associated with consumption of vegetables. Most people eat three meals per day; during the "hunger period" the number of meals drops to 2.6 per day; in one village about 60% of the people consumed only two meals per day during the hunger period. About 70% of the households consume R&T-based products every day.
- **Marketing systems.** Four types of local R&T markets exist in Benin: (1) quartier (area in a village/town), (2) local, (3) regional, and (4) outside of Benin borders (i.e., Nigeria). Most of the processors/traders are female with little or no education. They can be further grouped into semi-wholesalers (44.4 %), wholesalers (25.9 %), and retailers (29.6 %). A large majority (72%) of the quantity of R&T crops is sold by only 20% of the traders. Primary constraints to accessing R&T products in Benin are lack of capital and difficulties of getting the products from production facilities to markets and transportation.

6.2 CONSUMER PREFERENCES FOR R&T PRODUCTS IN BENIN

Ms. Monica Opuku, a student from the University Wageningen's Department of Marketing and Consumer Behaviour, was working on her thesis ("Consumer preferences for R&T products in Benin and Ghana"). She was working together with INRAB in the three focus villages [Boussouvi (CRA-Sud), Paouignan (CIP), and Gbanlin (CRA-Centre)] for the yam bean project and compared these rural communities with urban communities with respect to R&T consumption. The survey revealed several factors that stakeholders consider prior to adopting a new product. These are:

- **Price**. Consumers are price sensitive; they will adopt a new product if it is cheaper than the food they are currently eating.
- **Diversified uses**. Adoption is facilitated if the product can be used in different ways and in many dishes.
- **Ease of cooking**. Adoption is facilitated if the product can be readily consumed without any major preparation/cooking (such as *gari*) so that even children can prepare it when parents are not at home.
- **Health implications**. Adoption is facilitated if the product does not have any ill and/or health implications.

We concluded that consumers will be motivated to adopt a new product if (1) the price is lower and/or it tastes better than existing products; (2) the texture can be the same as or better than the existing one; (3) the new product is of better quality than the existing one; (4) the on-farm trial outcome is the same as the one given by researchers; and (5) the crop has a long shelf life and the taste does not change during storage.

6.3 ORIGINALLY PLANNED AND IMPLEMENTED COMMUNICATION/PROMOTION STRATEGIES

To facilitate the diffusion of the new product yam bean, the project deployed three communication strategies: (1) word-of-mouth, (2) megaphone by town crier, and (3) multimedia (radio/TV) campaigns in urban areas.

During the first two project years, it turned out that of these strategies for a completely new product in rural areas of an entire sub-region, word-of-mouth might likely be the most effective to start in focus villages, compared with a town crier or multimedia (radio/TV). However, these latter two strategies can become more effective when they have been shown to be successful in focus villages. Moreover, this information can be used later in communication by town crier and multimedia campaigns, an approach that makes them more reliable and effective.

For these reasons, Wilfrid Padonou created a road show on how to use—especially how to process—the yam bean in locally known and/or desired products. It appears that whenever yam bean was introduced during the second and (especially) the third and fourth years of the project by someone using a word-of-mouth strategy, other processors learn how to prepare it mainly as a group. When there appears to be an advantage of the crop, people test it and, when the advantage is shown, they soon recommend the product to others.

Direct marketing of yam bean storage roots was not of interest as a marketing strategy until the end of the project, because buyers/traders do not know the crop and are searching for crops that they can sell and trade without too much risk. We learned that the word-of-mouth strategy should be the focus in village groups. It should demonstrate directly how to plant the yam bean and how to use and process the yam bean storage root into locally known food production and/or food products that are in demand, such as juice. (For details, see chapter 5 and objective 4 of the project.) For example, yam bean juice was quickly in high demand for weddings in rural areas because it is tasty, easy to obtain/produce in rural areas, and relatively cheap.

The health benefits of the crop (i.e., its high iron content and high bio-availability) appeared not to be a key factor in the first steps of marketing the yam bean in rural areas; however, these nutritional facts are welcomed. Most likely this is because micronutrient deficiency and anemia—in other words, "hidden hunger" —are to a certain extent abstract. After testing the crop and consuming yam beans more regularly, such information becomes more important because it is promoted as "the crops make you stronger." Anecdotally, we can report that the notion that "the crop makes sexually more active" spread among men. Direct marketing of yam bean storage roots during the project was only of interest in a few cases, such as close to supermarkets in the main city of Benin Cotonou. Very high prices were realized, comparable to those in the supermarkets of Mexico and the United States. This could change, however, with sustainable establishment of the crop in Benin and when buyers and traders would most likely start to search for the crop in rural areas.

In addition to word-of-mouth, megaphone by town crier, and multimedia campaigns, the project relied on agriculture fairs and/or field days as a communication and promotion strategy. (But from our experience, these venues do not reach many famers or rural community groups with the results of testing a new product or crop.) Such fairs, however, appeared to be important to inform and lobby among farmers with large landholdings (although they do not farm by themselves) as well as policymakers about the new crop yam bean. These fairs are considered in section 9, "Promote awareness, communication, training, and capacity building," or objective 8 of the project.

Photo documentation of the on-farm work with road shows by INRAB and BØRNEfonden (Benin) appears in Appendix 12.

6.4 OUTPUT OF THE IMPLEMENTED COMMUNICATION/PROMOTION STRATEGY

On-farm yam bean promotion in Benin started in 2011. By the end of 2013, at road shows about 300 farmers were supplied with seed and shown how to grow and process yam beans in six of the eight agro-ecological zones of Benin. In 2013–14 surveys were carried out in 75 villages across 19 communes of seven departments in Benin to document the dissemination status of the new crop, its yields, and prices fetched from the sales of yam bean products. For details, see Appendix 6: Final Report INRAB (Benin) and Appendix 7: Final Report BØRNEfonden (Benin).

A total of 101 producers were surveyed in 2013–2014. Across six agro-ecological zones of Benin so far, we estimate an adoption rate of 47% for the yam bean compared with an adoption rate of 31% for OFSP. The baseline of OFSP production in Benin is close to zero, and was therefore used as a reference with respect to adoption rate comparisons. The West-Atacora zone of Benin appeared to present the best yield average for yam bean grain production (true yam bean seed), with 301 kg/1,000m^2. The best average storage root yields of yam bean were recorded in the Cotton zone of Center-Benin, with 3,566 kg/1,000m^2. In contrast, the best average storage root yield for OFSP was recorded in the zone of "*terres de barre,"* with 1,050 kg/1,000m^2. Both crops (yam bean and OFSP) need about 4–6 months until harvest, whereas cassava needs about 10–11 months.

The surveys in 2013–14 revealed the following information: The average sales price of fresh yam bean storage roots (without processing) was relatively low, with 20 Fcfa/kg (about 3.4 cents and about US $338 for a 10-t harvest[1]). However, the processed storage root to flour and/or *gari* had average sales prices of 1,630 Fcfa/kg (about $2.73/kg). In contrast, the average sales price of raw OFSP storage roots was 105 Fcfa/kg (processed OFSP sells on average for 160 Fcfa 160/kg). The main advantages of cultivating the new crop, as reported by farmers, were high storage root yields in combination with high grain yields, which facilitates rapid propagation and dissemination (the yam bean is propagated by true seed), as well as various options for small-scale storage root processing (e.g., *gari*, juice, yogurt, alcohol, snacks, and flour). The main constraints related to the cultivation of yam bean are its laborious cropping operations, tedious tilling, and limited knowledge of planting techniques.

Until the end of 2014, there was information from CIP-Ghana that the yam bean is already used by at least 1,000 farmers in Benin. INRAB-Benin concluded in their report (Appendix 6) that yam bean can become an integral part of farming systems in Benin.

The NGO BØRNEfonden-Benin has been working with the project for about two years (2012–2014) and the yam bean in their intervention areas in Benin (in Bonou, Adjohoun, Dangbo, and Zakpota; southern part of Benin, northeast of Cotonou, and northwest of Porto Novo—about 100 km from Lagos, Nigeria). In total 71 farmers have reported their harvests. The storage roots yields of the crop were remarkably high: 25.0, 16.7, 15.8, and 14.6 t/ha across farms in the area of Bonou, Adjohoun, Dangbo, and Zakpota, respectively. Awareness campaigns were undertaken by BØRNEfonden-Benin in conjunction with INRAB-Benin to promote processed food products from yam beans via road shows (see Appendix 7). The major advantage of the new root crop—apart from yield, processing options, and nutritional quality—is certainly the relative ease of supply of seed to farmers that made success on-farm possible. That is, during the project period, BØRNEfonden-Benin could supply only 8 farmers with OFSP planting material compared with 80 farmers who were supplied with yam bean seed for 500m^2 per farm.

For the area of yam bean dissemination covered by BØRNEfonden-Benin, detailed questionnaire records are available, which as of the writing of this report have not been analyzed. In 2015 BØRNEfonden-Benin continued to work with the yam bean based on its own funds. The NGO stated that it believed that the

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[1] Conversion rate (2.7.2015): Fcfa/USD = 591.93.

yam bean would need only two years of moderate investments (about $10,000–20,000/year) to "really take off" in the southeastern part of Benin, close to the border with Nigeria. For this reason, we suggest this particular area of Benin as a medium- to long-term post-project study area of yam bean adoption in Benin.

Furthermore, we want to report that the yam bean entered Nigeria via Benin through the support of National Root Crops Research Institute of Nigeria. However, we have no information about the size of on-farm yam bean cultivation in Nigeria. There is some additional yam bean cultivation around Kumasi, Ghana, and in North Ghana, both of which trace back to introductions from CIP-Ghana. Yet nor can we give information about the size of on-farm yam bean cultivation in Ghana.

7. OBJECTIVE 6: PROVIDE NEW DIVERSITY TO USE YAM BEAN SEED FOR HUMAN CONSUMPTION

The project wanted to develop a set of at least two genotypes to demonstrate that yam bean seeds can be used for human consumption and to have a group of parents to open a pre-breeding population for this target. This target was not met, although one genotype was found that appears to have no acute seed toxicity—namely, CIP-209054 (*P. tuberosus*). And the crop continues to be an untapped source for seed consumption. It can be discussed whether the reason for this failure is lack of commitment to screen among the thousands of mutation lines generated in the project. CIP-209054 was found in the yam bean germplasm by screening about 100 accessions; we therefore hypothesize that our inducted mutation lines are full of yam bean mutants with no actuate seed toxicity.

The background is that flowered, unpruned yam beans (as a production technique, flower pruning is usually done to increase storage root yields in yam beans, which results in no seed yields) have very high seed yields of 5.2 t/ha (based on estimates across 14 *P. erosus* accessions across two locations in Benin; Zanklan et al. 2007). In case no pruning is done, seed yields are not much reduced by drought stress (5.7 t/ha with no drought and up to 4.7 t/ha with drought stress). This is an exception among legume grain crops and is an attribute that might be due to the reserves of the yam bean storage roots. Grüneberg et al. (1999) have shown that yam bean seed protein and oil contents are similar to those of soybean. We have calculated that 1 kg of *P. erosus* seed requires about 850 L of water and that 0.56 kg of dry storage root yield is produced. This compares quite favorably with soybean, which requires 2,000 L of water for 1 kg of seed production (Pimentel et al. 2004). We think that the yam bean would have already been a much more important crop if its seed were not toxic.

The major challenge with respect to this objective of the project became obvious in 2012. That is, the toxicity in yam bean seeds is not only due to rotenone and pachyrrhizine as commonly referred to in the literature. Indeed, all references that rotenone causes yam been seed toxicity can be traced back to Santos et al. (1996).

In the first steps of the project at UCL, precise and fast screening methods for rotenone and pachyrrhizine were developed and the acute and chronic toxicity levels in yam bean seed for safe consumption were determined (for details, see Appendix 8). The range of rotenone in yam bean seeds is usually 1–3 mg/g, which corresponds to 1,000–3,000 ppm, or 0.1–0.3%. This is only one-third of the magnitude reported by Santos et al. (1996) based on fewer accessions and less-precise methods. With respect to rotenone, an intake by humans of more than 0.015 mg/kg/day—this corresponds to a rotenone intake of more than 0.75 mg of rotenone/day in adults—can provoke acute toxicity. Chronic toxicity effects may occur if the rotenone intake is higher than 0.0004 mg/ kg/day (this corresponds to a rotenone intake of more than 0.02 mg/day for adults). The working group at UCL began to doubt whether a fatal case of yam bean and rotenone toxicity (Narongchai 2005) is correct, based on intakes reported. In an animal study, standard feed was provided to Wistar female rats in group 1. It contained twice the rotenone concentration as did yam bean seed; in group 2 the rats were fed with yam bean seed flour. Wistar female rats consuming feed with twice the rotenone concentration as in yam bean survived, whereas those consuming yam bean seed flour died. There are many plant compounds that can result in such toxicity in legumes, including rare amino acids. In 2013–2014 of the project, activities at UCL were nearly completely devoted to finding out what makes the yam bean seed toxic.

The toxicity of yam bean seed is mainly located in its lipidic fraction. In-vivo tests of yam bean seed clearly showed that their toxicity is not only due to rotenone and pachyrrhizine, but also at least to one or more additional lipophilic compound(s). Fractionations followed by in-vivo toxicity tests allowed UCL to identify these potential compounds as (1) 12-hydroxypachyrrhizone, (2) munduserone, (3) 12-hydroxydolineone, and (4) dehydroneotenone. The toxic activity of 12-hydroxypachyrrhizone and 12-hydroxydolineone on inhibition of in-vitro respiration has been compared with the activity of rotenone by Nath et al (1980). It was observed that at weak concentrations ($0,5.10^{-7}$ M), these compounds (12-hydroxypachyrrhizone and 12-hydroxydolineone) were less toxic than rotenone (12-hydroxypachyrrhizone being more toxic than 12-hydroxydolineone), whereas at higher concentration (1.10^{-6} M), the compounds are more toxic active on NADH-oxydoreductase than rotenone. It has been reported that the rotenoid metabolism is essentially oxidative and hydroxyled rotenoids are detoxified more slowly. Munduserone has been reported to be less toxic active than rotenone (Crombie et al. 1992). No information was found on dehydroneotenone's toxicity. From literature data it seems that the six toxic compounds are also biosynthetically linked (Fig. 6). It is hypothesized that there are close genetic correlations among these compounds in yam beans; however, so far it has been shown that rotenone and pachyrrhizine concentrations in yam bean seed are correlated (Lautié et al. 2013).

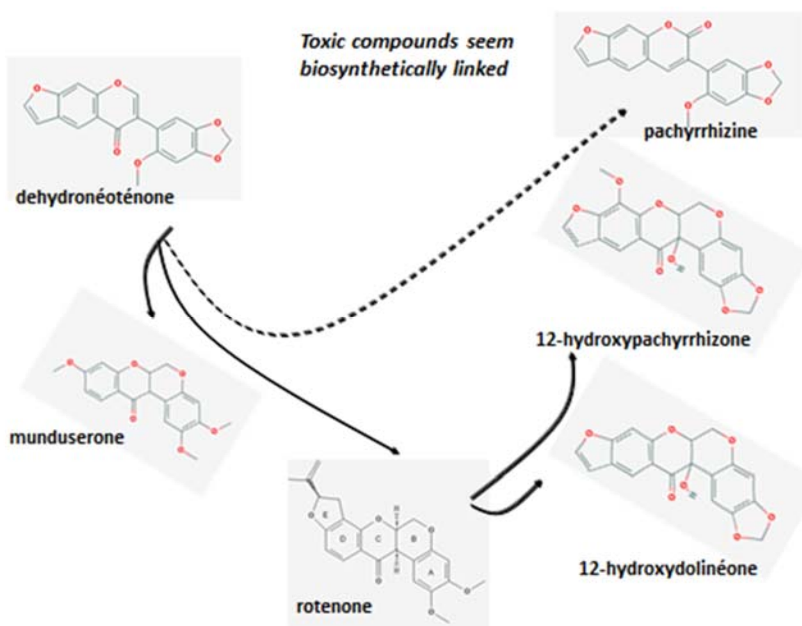

Figure 6. Current hypothesis of biosynthetical pathway of potentially toxic rotenoids in yam bean seeds.

UCL observed that the accession *P. tuberosus* (CIP-209054) has very low rotenone content and did not contain any 12-hydroxypachyrrhizone. The accession was not toxic when it was tested in vivo on Wistar rats at the dose where other samples were toxic. No toxicity was either detected for the same accession dried 7 h at 100°C. One further interesting accession is CIP-209038 (*P. ahipa*), which was found to have a quantity of rotenone lower than the lower limit of quantification; but the accession was not tested in vivo or in animal studies. The results show that (1) there is one accession (CIP-209054) with low rotenone content and no acute toxicity (chronic toxicity should be tested further) as well one accession (CIP-209038) with high potential of having no acute toxicity; (2) the biosynthetical pathway can be interrupted without damaging the plant and without an accumulation of rotenone if it is indeed one of the precursors of the other toxic compounds; and (3) there is clearly genetic variation in the yam bean genepool for toxicity without inducing mutations.

Other procedures to reduce toxicity in yam bean seed and young pods. As mentioned above, the toxicity of yam bean seed is mainly located in its lipidic fraction, so the protein content of the seed could still be valorized after the extraction of the toxic fraction. For example, UCL was able to extract more than 70% of rotenone from yam bean seed flour with a local alcohol. UCL also tested different thermic/cooking processes to lower rotenone content, as this compound is sensitive to temperature. Drying and roasting of whole seeds seem to be the more effective processes, allowing a degradation of up to 70% of the initial content of rotenone. Moreover, it was observed that the toxicity (in vitro and in vivo) decreased with rotenone content. Young yam bean pods are reported to be eaten occasionally in Asia. For pods and leaves, rotenone contents lower than in seeds were observed. **Leaves contain between 0.3mg/g and up to 1.6 mg/g rotenone, whereas young pods contain levels so low that they were often under the limit of detection, although levels of up to 0.8 mg/g rotenone were also observed**. Rotenone content increased with the maturity level of the pods. Surprisingly, sun drying did not lower the rotenone content in the leaves.

The studies resulted in several publication:

Lautié, E., E. Rozet, P. Hubert, and J. Quetin Leclercq. 2012. Validated SPE HPLC-UV quantification of rotenone in seeds of different yam bean (*Pachyrhizus* sp.). *Food Chemistry* 131(4): 1531–1538.

Lautié, E., C. Rasse, E. Rozet, C. Mourgues., J.P. Vanhelleputte, and J. Quetin Leclercq. 2013. Fast microwave assisted extraction of rotenone for its quantification in seeds of yam bean (*Pachyrhizus* sp.). *Journal of Separation Science* 36: 758–763.

Lautié, E., E. Rozet, P. Hubert, N. Vandelaer, F. Billard, T. zum Felde, W.J. Grüneberg, and J. Quetin-Leclercq. 2013. Fast method for the simultaneous quantification of toxic polyphenols applied to the selection of genotypes of yam bean (*Pachyrhizus* sp.) seeds. *Talanta* 117: 94–101.

Catteau, L., E. Lautié, O. Koné, M. Coppé, K. Hell, C.B. Pomalegni, and J. Quetin-Leclercq. 2013. Degradation of rotenone in yam bean seeds (*Pachyrhizus* sp.) through food processing. *Journal of Agricultural and Food Chemistry* 61(46): 11173–11179.

At CIP-Lima, NIRS calibration was developed to determine rotenone and pachyrrhizine in fast through-put screening. Based on the samples analyzed by the reference laboratory method (see work at UCL), the calibration of the NIRS equipment was initiated at CIP-Lima. So far, NIRS achieved in a first batch (N = 60) the results of a significant correlation between reference laboratory values and NIRS of r = 0.61, which appears to be low. The reason for this low correlation might be that 60 samples are still very low for good NIRS calibrations. Usually NIRS calibration developments start with 100–120 samples. Another reason for the low correlation can be that the range of rotenone content in yam bean seed (1,000–3,000 ppm to be considered generally as large) is not large enough to discriminate well by NIRS among genotypes with high, medium, and low rotenone contents. However, we think that NIRS wavelengths respond well to rotenone, and samples with very low contents should be detectable as outliers with our currently available calibrations.

Moreover, CIP-Peru determined the optimal mutagenic treatment of yam bean to induce mutations with no or low toxic compounds. Three mutagenic compounds were tested: N-nitrozo-n-methylourea

(MNUA), sodium azide (SA), and ethyl methanesulphonate (EMS). In total 2,400 seeds were treated (six accessions, nine treatments, and one control). All compounds are useful to develop fertile M1 plants with high frequencies of mutations. The optimal concentrations are 0.5% EMS, 2mM MNUA, and 4mM SA. M1 plants have been evaluated to find an optimal mutagenic treatment. Seeds from M1 plants were harvested. These M2 seeds from M1 plants were developed into M2 plants and M2 lines in M3. In total, there are now about 5,000 M2 lines in M3 available at CIP to be screened for the six toxic compounds and additionally 20,000 M2 seeds. Certainly, a part of this material could have been screened by NIRS with the rotenone and pachyrrhizine calibrations available—especially the M2 lines in M3—since an assistant was allocated to this work for four years, but not during the phasing-out component of the project. The material would have been screened if the phasing-out component would have been two years and not one, and the funding for this component would have been €750,000 as originally expected.

Literature used:

Crombie, Leslie, Jonathan L. Josephs, Jane Cayley, John Larkin, and John B. Weston. 1992. The rotenoid core structure: modifications to define the requirements of the toxophore. *Bioorganic & Medicinal Chemistry Letters* 2(1): 13–16.

Grüneberg, W.J., F.D. Goffman, and L. Velasco. 1999. Characterization of yam bean (*Pachyrhizus* spp.) seeds as potential sources of high palmitic acid oil. *JAOCS* 76: 1309–1312.

Narongchai, P., S. Narongchai, and S. Thampituk. 2005. The first fatal case of yam bean and rotenone toxicity in Thailand. *J. Med Assoc. Thai* 88(7): 984–986.

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Zanklan A.S, S. Ahouangonou, H.C. Becker, E. Pawelzik, and W.J. Grüneberg. 2007. Evaluation of the Storage Root-forming legume Yam Bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Science* 47: 1934–1946.

8. OBJECTIVE 7: MAKE AVAILABLE EVIDENCE OF LIVELIHOOD IMPACTS ASSOCIATED WITH INCREASING YAM BEAN PRODUCTION IN CENTRAL AND WEST AFRICA

Evidence of livelihood impacts associated with increasing yam bean production in Central and West Africa was made available. However, impact assessments remain incomplete.

- Owing to propagation as true seed, the yam bean creates considerably lower costs in maintaining germplasm and disseminating germplasm to national agricultural research systems and among farmer groups compared with traditional R&T crops. This attribute was well noticed in this project during the dissemination efforts of INRAB and BØRNE-fonden-Benin, and could be compared to OFSP, which was disseminated simultaneously.
- True seed propagation makes the yam bean crop easy to handle by farmers from one to the next growing season. Planting can be made timely (using growing/rainy seasons properly) without delays as they often occur with sweetpotato, cassava, or potato cultivation.

- Owing to true seed propagation, virus-related yield declines are expected to be much lower in yam beans than with sweetpotato, cassava, and potato.
- Yam bean gets 150–200 kg of nitrogen into the farming system. The crop has the capacity to improve the phosphor nutrient cycle in the farming system due to an intensive mycorrhiza association; this must be seen against the background that fertilizers in Africa are 85% more expensive than in Southeast Asian countries such as Thailand. And the world's supply of phosphate fertilizer is expected to become soon—within the next decades—much more limited. We can report that we never observed in our trials (on-station and on-farm) problems that could have been related to nutrient deficiency.
- Yield estimates on-farm are 20–25 t per growing season for low DM yam beans (i.e., CIP-209017 and CIP-209018 estimated on large scale); for high DM yam beans (i.e., CIP-209013 and CIP-209041) yield estimates are supposed to be 8–12 t per growing season. Certainly for high DM yam beans, there is still more room for genetic improvement compared with low DM yam beans, because the latter have been bred by farmers for many centuries. Yield estimates for yam beans have to consider that they can be grown in many locations twice per year. This is a clear yield advantage compared with cassava, which can only be grown once per year.
- Yam bean harvest is easy to store for a long time (easily for 3–4 months) and has a much longer shelf-life than cassava and sweetpotato. This makes yam bean flexible in processing chain into which it can enter when there is no fresh cassava available, which usually needs to be directly processed and cannot be stored.
- Cost/benefit ratios for yam bean cultivation are currently estimated as 1:1.4 in Uganda with high-yielding, widely adapted low DM yam beans (i.e., CIP-209017 and CIP-209018). This requires processing to food products such as *gari*, atap, or other traditional products. So far, the exploitation of juice as an additional product in food processing, which is valued as good or even better as pineapple, is not considered. Cost/benefit ratios are estimated similar to cassava in Benin, but these estimates currently are based on the difficulty of finding buyers for yam bean harvests. The estimates might change in favor of the yam bean when the crop and processing knowledge become more widely known among buyers and traders. Note that farmers consider it a weakness of the yam bean that "pruning" cultivation is laborious. On the other hand, farmers consider it as a strength that two harvests per year are possible, that harvests are easy to store, and that yam bean has more options (fresh consumption and various processing options) than cassava production. This is particularly true with the processing of juice from yam bean, which has to be valued and considered in cost/benefit estimates.
- With high-yielding medium to high DM yam beans, different scenarios of cost/benefit ratios must be taken into account where processing is emphasized (i.e., on juice or on *gari*). For example, conversion rates to *gari* from high DM types (i.e., CIP 209013 and CIP 209041) are 14–22%, but this results in less juice production.
- The market strategy developed in Benin shows that processing is needed for the yam bean at the current stage in Africa to enter on the market; there are still no markets and buyers for the fresh yam bean storage roots. In the future this could change if the crop is better established and more widely known among traders.
- Processing root crops in West Africa is mainly women's work. Women might have more opportunities to enter into market niches with the yam bean, because the crop has more options in processing than cassava and yam bean products such as *gari* have clearly higher nutrient density than cassava.

- Yam bean is a crop that can be made easily available in rural areas. It can be eaten raw in larger quantities than any other root crop, and can be processed in very different traditional food products. These attributes, together with extreme good bio-availability of iron in yam beans, can be used to reduce iron deficiency in people exposed to prevalence of high anemia. (NB: Prevalence of anemia in Africa is estimated to be 68% among pre-school age children, 57% among pregnant women, and 48% among non-pregnant women.) The positive dietary iron attributes of the yam bean include:
  - 200 g of fresh yam bean is estimated to provide 0.7–2 mg of iron, depending on the yam bean type (low or high DM types)
  - 0.333 ml of yam bean juice is estimated to contain 0.9–3.5 mg of iron, depending on the yam bean type used in processing
  - 200 g of *gari*—and most likely other processed food products such as yam bean porridge—is estimated to contain 4.0–5.5 mg of iron, depending on the yam bean type used in processing.
- Certainly this iron nutritional aspect of yam bean merits further investigation, and must be considered in impact assessment estimates. So far, this attribute of the crop, combined with the good iron bio-availability, is not well known.

  With respect to potential genetic improvement in the medium and long term, the crop is easy to breed (abundant flowering and easy pollination). This potential of the yam bean can be summarized as follow: (1) high-yielding, widely adapted low DM types can directly enter into variety release; (2) high-yielding, widely adapted high DM types are available, but much better genotypes are possible if investments were made in a small-scale breeding program (which can be made quite cheap through farmer participation but must last at least three years); and (3) in the long term, the crop offers a huge potential through its high seed yields, which could be made available for human consumption if a "genetic block" can be generated to avoid the production of the toxic compounds in yam bean seed. (For details see previous chapter and objective 6.) Yam bean seed yields are surpassing soybean yields in the tropics and subtropics, and yam beans appear to need much less water than soybeans. This suggests that the yam bean would already be a major food crop if seeds were not toxic.

CIP and INRAB collaborated for social science research on constraints and opportunities in *gari* markets. This was done to understand the market potential that *gari* made partly or wholly from ahipa would face (Adegbola et al. 2013; Hibon et al. 2011). This work has been published:

Adegbola, Y.P., R.N. Yegbemey, N.I. Sedjro Djenontin, A.M. Hibon, K. Hell, G. Thiele, and O.D. Koudande. 2013. Les marchés du manioc et du « *gari* » dans le Sud et le Centre du Bénin: performances et principales contraintes à leur développement. *Cahiers Agricultures* 22(4): 293–302.

Hibon, A., P. Ygué Adegbola, K. Hell, and G. Thiele. 2011. Contraintes et opportunités pour l´introduction de nouveaux produits sur les marchés locaux des racines et tubercules au Bénin.Series Contraintes et opportunités pour l´introduction de nouveaux produits sur les marchés locaux des racines et tubercules au Bénin. Lima, CIP: 54 p.

For continuous learning and ex-post project reviews, information from questionnaires in farming communities in the area southwest of Benin are available (see Appendix 6 and Appendix 7). These communities in Benin can be easily monitored through the NGO BØRNEfonden-Benin. The SHIS unit in CIP has started work on yam bean in the context of the project "Enhancing nutrition, food security and income through sustainable system intensification with roots and tubers crops in Asia and Sub-Saharan

Africa," which is funded by CRP Policies, Institutions and Markets, led by the International Food Policy Research Institute. The first target country of the project in 2015 is Benin.

Literature used:

Food and Nutrition Board. 2001. Institute of Medicine. Iron. Dietary reference intakes for vitamin A, vitamin K, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press, pp. 290–393.

WHO. 2008. Worldwide Prevalence of Anaemia, 1993–2005. *WHO Global Database on Anaemia*. (Bruno de Benoist, Erin McLean, Ines Egli, and Mary Cogswell, eds). World Health Organization, New York.

9. OBJECTIVE 8 (PROMOTE AWARENESS, COMMUNICATION, TRAINING, AND CAPACITY BUILDING)

Awareness, communications, training, and capacity building have been promoted. The project has increased the visibility of the yam bean to potential donors such as the BMGF, BMZ, FAO, the International Atomic Energy Agency, and Syngenta. In addition to the CIP platforms in the sub-Saharan Africa region (Uganda, Ghana, Mozambique), the universities (UCL and MAK), and the NARS (INIA, INRAB, RAB, ISABU, and INERA) involved in this project, our work on the yam bean is being followed by other potential stakeholders, such as the International Institute of Tropical Agriculture and The World Vegetable Center; the University of Wageningen, the University of Gent, the University of Copenhagen, and the University La Agraria La Molina in Peru; and NARS in Ghana, Nigeria, Kenya, Cameroon, Mozambique, and Zambia.

Worth noting especially is the communication from FAO in which the yam bean was selected as the traditional crop of the month (see http://www.fao.org/traditional-crops/yambean/en/).

Further communications on the net were by the New Agriculturist, entitled "Partnership for yam bean" (see http://www.new-ag.info/en/developments/ devItem.php?a=2895:) and by CIP such as "Adapting Ahipa to Africa" (see http://cipotato/resources/publications/cip-newsletter/march-2012/adapting-ahipa-in-africa) and "Packing a Punch – Targeting Native Foods and Improving Nutrition and Health" (see http://www.cgiar.org/consortium-news/packing-a-punch-targeting-native-foods-and-improving-nutrition-and-health/). Finally a page was created where new findings will be posted (see http://ahipabreeder.com/).

Through the Makerere University in Uganda, the project had a very strong training and capacity-building component. It involved two PhD students in breeding, four MSc students in agronomy, two MSc students in food science/technology, one MSc and one BSc student in plant genetic resources, and two BSc students in agribusiness (see Appendix 9). Table 11 provides an overview of the work at the Makerere University—all BSc and MSc students completed their thesis, except for Lydia Nakagiri. For some details of her thesis work, see Section 4, objective 3: Develop Yam Bean Storage Root Products for Central Africa. The PhD students have completed their field trials and have written up the first manuscript (at Makerere University, two manuscripts accepted by peer-reviewed journals are required for the PhD). The theses are available on request via the university and/or CIP. We still intend to publish some of the theses as CIP working papers—for example, the thesis of James Muhangi—to make them available for citation with an IBSN number.

So far, only one publication done as part of the yam bean program at Makerere University has been published:

Kisambira A., J. H. Muyonga, Y.B. Byaruhanga, P. Tukamuhabwa, S. Tumwegamire, W. Grüneberg. 2014. Physicochemical Characteristics of Yam Bean (Pachyrhizus erosus) Seed Proteins. Journal of Food Research Vol. 3 No. 6. 168-178.

Table 11 Name, country of origin, program, thesis title, and supervisor of the training and capacity-building component supported by the yam bean project at the Makerere University)

Name	Country	Program	Title	Supervisors
Jean Ndirigue	Rwanda	PhD Plant Breeding	Adaptation and genetic analysis for earliness and yield of yam bean (*Pachyrhizus* spp.) through *P. ahipa* x *P. tuberosus* interspecific hybrids in Rwanda	Prof. P Rubaihayo, Dr. P. Tukamuhabwa
Rolland Agaba	Uganda	PhD Plant Breeding	Genetic improvement of yam bean (*Pachyrhizus* spp.) for storage root dry matter, starch and protein through *P. erosus* x *P. tuberosus* interspecific hybrids in Uganda	Dr. P. Tukamuhabwa, Prof. P. Rubaihayo
Charles Andiku	Uganda	MSc Agronomy	Evaluation of yam bean (*Pachyrhizus* spp.) accessions for root yield and nutritional quality under growing conditions of Uganda	Dr. James Ssebuliba, Dr. Hebert Talwana
David Onyuta	Uganda	MSc Agronomy	Farmer participatory evaluation of storage root forming legume yam bean (*Pachyrhizus* spp.) in selected areas of Uganda	Dr. James Ssebuliba, Dr. Jenifer Bisikwa
Ernest Vyizigiro	Burundi	MSc Agronomy	Effect of different plant populations and manure application levels on the yield of yam bean (*Pachyrhizus* spp.) in Burundi	Dr. Hebert Talwana, Prof. David Osiru
Kilongo Bulambo	DRC	MSc Agronomy	Effect of agronomic practices on growth and yield of yam bean in Eastern DRC	Dr. Hebert Talwana, Dr. James Ssebuliba
Lydia Nakagiri	Uganda	MSc Food Science and Technology	Participatory development of nutrient enriched yam bean *(Pachyrhizus sp.)* products and recipes in Uganda	Prof. John Muyonga, Dr. Agnes Namutebi
Abbas Kisambira	Uganda	MSc Food Science and Technology	Physico-Chemical Characteristics of Yam Bean (Pachyrhizus) Seed Flour and Protein	Prof. John Muyonga, Dr. Yusuf Byaruhanda
Godwin Nkwasibwe	Uganda	MSc Plant Genetic Resources	Morphological Characterization of Legume Root Crop Germplasm for Utilization and Conservation in Uganda	Dr. P. Tukamuhabwa, Prof. Elly Sabiiti
Gloria Asingwire	Uganda	BSc Agriculture	Consumer acceptability of yam bean salads in Kampala	Ms. Harriet Kyomugisha
Elias Oyesigye	Uganda	BSc Agriculture	Morphological diversity of African yam bean (*Sphenostylis stenocarpa*) Winged bean (*Psophocarpus Tetragonolobus*) and other legume forming tubers	Dr. Phinehas Tukamuhabwa
James Muhangi	Uganda	BSc Agriculture	Cost Benefit Analysis Of Processing Yam Bean Into Flour Used To Make *Atap* / *Ugali* Food Products In Serere and Luwero Districts	Ms. Elizabeth Balirwa

Worth noting is that, as part of the project, Makerere University also supported an M.Sc. thesis entitled "Morphological Characterization of Legume Root Crop Germplasm for Utilization and Conservation in Uganda" (summarized in Appendix 9). With exception of the yam bean, only a very limited number of accessions became available for other legume root crops. This reflects the fact that the availability of cultivated legume root crops such as *Sphenostylis stenocarpa*, *Psophocarpus tetragonolobus*, and wild storage root-forming *Vigna vexillata* are only very limited—accessible to agricultural research—which is clearly insufficient for a comprehensive germplasm evaluation and/or breeding. No accessions were obtained for the wild storage root-forming legumes *Tylosema esculentum* (origin southern Africa), *V. lobatifolia* (origin southern Africa), *Pueraria* (origin India), *Flemingia* (origin India), *Apios* (origin North America), and *Psoralea* (Australia and North America).

Furthermore, one MSc student, Reneé Wassens, in food science/technology was supported through the University of Wageningen in the Netherlands; thesis title "Assessment of the suitability of yam bean for the production of *gari*." One M.Sc. student in plant genetic resources, Mónica Lucía Santayanna Rivera, received support from University Agraria La Molina in Peru, with the thesis title "Caracterización citogenética y molecular de las epecies cultivadas del género Pachyrhizus Richard ex DC." Moreover, the project supported two post-docs: Emmanuelle Lautié at UCL in Belgium, and Bettina Heider at CIP-Lima.

The work of the project was presented at agriculture fairs in Benin and Uganda and four other venues: (1) the ACSS conference, 10–13 Oct. 2011, Maputo, Mozambique (two presentations); (2) the CIALCA conference, 22–28 Oct. 2011, Kigali, Rwanda (two presentations); (3) the ISTRC symposium, 24–28 Sept. 2012, Abeokuta, Nigeria (four presentations); and (4) the ISTRC-African Branch symposium, 30 Sept.–5 Oct. 2013, Accra, Ghana (four presentations). The stakeholders of the project met each year in a workshop to revise planning and exchange results. A final overview of the project results will be presented at the ISTRC symposium in China in Oct. 2015, with the title "Introduction of the root crop *Pachyrhizus* spp. into Africa."

10. CHALLENGES

Although the "Permiso para distribuir Ahipa: permiso para distribución de 11 accesiones y híbridos de *P. tubersosus,*" successfully made high DM yam beans available for R&D, it delayed studies with the high DM yam bean in Africa. These delays could not be fully compensated for until the end of the project. This was especially true for the processing and market studies in Benin with high DM yam beans, and the PhD studies on high DM x low DM breeding populations in Uganda and Rwanda.

Two staff departures affected the project: Kerstin Hell (Benin) in 2012, and Silver Tumwegamire (Uganda) to the International Institute of Tropical Agriculture at the beginning of 2013. Mr. Tumwegamire was an excellent assistant for the project and highly interested in the crop, which could not be compensated for later in 2013–14. Moreover, we want to note that work with a neglected crop has a trade-off, which can be seen in staff commitment. The result is that as soon as work and/or opportunities with major crops arise, the priority is given in the direction of the major crop. This is a general perspective and does not hold true in individual cases (e.g., the work of Wilfrid Padonou at INRAB in Benin with respect to processing and his very innovative road shows in farmer communities about how to use and process the crop, as well as the work of Nestor Alokpaï at BØRNEfonden-Benin in selected farmer communities 50 km north of Porto-Novo; the farmer groups are recommended for further ex-post project reviews). Project actors at BØRNEfonden-Benin believe that with quite moderate funding for two more years, yam bean would have really taken off in southwest Benin. Even so, the NGO continued to work with the crop out of their own funds.

The phasing-out component of the project, which lasted only one year, was quite short for such a complex project involving so many partners.

APPENDIX 1

FINAL REPORT INIA (PERÚ)

FINAL TECHNICAL
REPORT FOR PROJECT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: INIA—Re-collection, evaluation, and conservation of genetic resources of *Pachyrhizus spp.* (*P. tuberosus and P. ahipa*) in Peru

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA DIRECCIÓN DE INVESTIGACIÓN AGRARIA SUBDIRECCIÓN DE RECURSOS GENÉTICOS Y BIOTECNOLOGÍA

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FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: La Molina, 18 of December 2013

Re-collection, evaluation and conservation of genetic resources of *Pachyrhizus spp.* in Perú (INIA)/Peru under AHIPA project

On behalf of INIA

Authors:
Ing. Agripina Roldán Chávez
Plant Genetic Resources Specialist
Pachyrhizus project coordinator

SUDIRGEB-INIA

Submitted to:
Bettina Heider
(post-doc in the Yam Bean Project based at CIP-Peru)

Translation and editing by:
Raul Eyzaguirre and Wolfgang Grüneberg

CONTENTS

ABSTRACT

The project "Re-collection, evaluation, and conservation of genetic resources of *Pachyrhizus* spp. (*P. tuberosus* and *P. ahipa*) in Peru" was carried out in Anexo Campo Verde in EEA Pucallpa. The objectives of this subcomponent of the larger yam bean project were to broaden the genetic base of *Pachyrhizus spp*. conserved in genebanks, and to create a database for the crop (passport data, plant attributes, traditional management, environmental favorable characteristics, etc.), with collected material in the lowland central forest of Peru.

Three collecting missions were conducted: (1) in the Ucayali river basin (Alto Ucayali); (2) in the central forest (Route San Ramón – Oxapampa, Ciudad Constitución); and (3) in the Tambo river basin. A genebank with 30 ahipa accessions has been established in Anexo Campo Verde and 19 accessions were evaluated and characterized. The field characterization data was documented in Excel data sheets. For storage root yield, accession BEH05A stood out, with a yield of 36 t/ha. Biochemical characterization was also performed with 27 ahipa accessions coming from INIA-Pucallpa and the International Potato Center—namely, dry matter, reducing sugars, raw fiber, vitamin C, protein, iron, and starch contents of storage roots. October 2013, 29 accessions were sown in the field to be characterized in the 2013–2014 campaign. A copy of the genetic material was kept in the seed bank of SUDIRGEB at headquarters at the end of the harvest. The proper management and conservation of the collected germplasm strengthened and increased the national collection of tropical roots and tubers at INIA.

1. PLACE AND DATE OF EXECUTION OF PROJECT ACTIVITIES

Country: Peru

Department: Ucayali

Province: C. Portillo

District: Campo Verde

Experimental field: Anexo Campo Verde

Agricultural experimental station (EEA): Pucallpa

Field stage: EEA Pucallpa

Laboratory stage: La Molina INIA/UNALM

Start/End Dates: October 2010–November 2013

2. TECHNICAL TEAM

Chief of "Subdirección de Recursos Genéticos & Biotecnología": Biol. Fredesvinda Carrillo Castillo

Field activities responsible: Eng. Wilfredo Felipe Guillén H.

Genetic Resources specialist at EEA Pucallpa-INIA

Laboratory activities responsible: Eng. Karla Peña Pineda

Agro-business characterization specialist

Laboratory activities collaborator: Eng. Fredy Quispe Jacobo

Nutritional science and characterization specialist

Project coordinator: Eng. Agripina Roldán Chávez

Headquarters plant genetic resources specialist.

3. INTRODUCTION

The neotropical genus *Pachyrhizus* DC. (yam beans) is a legume with edible storage roots. The *Pachyrhizus* species could be used as a new non-traditional source of flour and starch. The crop is native to South and Central America and the main cultivated species are *P. tuberosus*, the yam bean of the Amazon region and grown in Bolivia, Peru, Ecuador, and Brazil; *P. erosus*, the Mexican jacatupe or jícama and cultivated in Central America and the Caribbean; and *P. ahipa*, the Andean jícama or ahipa and found in the Bolivian Andes and northern parts of Argentina (Forsyth et al. 2002).

P. ahipa was cultivated by the Inca civilization, but its consumption and production decreased significantly with the collapse of indigenous cultures after the conquest of America. The indiscriminate use of natural resources and traditional practices contributed to a degradation of natural ecosystems as well as extinction and genetic erosion of species especially used as staple foods (e.g., native roots and tubers). In the case of ahipa (*P. tuberosus* and *P. ahipa*), there is an alarming decline in cultivation, which can result in extinction. These issues deserve the management, conservation, and sustainable use of valuable unknown crops, with the aim to rescuing germplasm by collecting genetic material across Peru. Efforts should also include botanical and agronomical characterization, and the documentation of this work in order to identify their agricultural and agro-industrial potential.

The main characteristics of the yam bean are the (1) accumulation of starch in the storage root, which is of industrial interest, and (2) presence of rotenone in seeds and leaves. The root is consumed raw as a fruit or cooked; the skin is very easily lifted from the inner fleshy portion, which is mostly white (Milanez and Dallaqua-Moraes 2003). The commonly accepted definition for functional foods refers to food or ingredients that provide a physiological benefit in addition to their contribution to basic nutrition concerns (Day et al. 2009). The roots and flour from yam bean may be considered as alternative foods because of its high starch content and its incorporation as an ingredient for gluten-free foods. Most valuable for processing is *Pachyrhizus* germplasm, with high dry matter (DM) in storage root—so far, only known in the Amazonian area of Peru. (NB: most often *Pachyrhizus* germplasm has low DM in storage root, so that the roots are consumed raw as fruit, root, and/or salads.) Although this high DM germplasm was found in the early 1990s, it is unavailable in the germplasm collections of national or international genebanks.

4. MATERIALS AND METHODS

4.1 MATERIAL AND ORIGIN

Collection sites: The sites where the genetic material from *Pachyrhizus spp*. was collected were selected based on field reports of the Facultad de Agronomia, Universidad Nacional de la Amazonia Peruana, Peru, and an analysis of the crop distribution sites through the use of geographic information system (GIS). Three locations were selected: Ucayali River Basin (upper Ucayali), central forest (Route San Ramón – Oxapampa, Ciudad Constitución), and the Tambo River area.

Location and ecological characteristics of the evaluation sites: The *P. spp.* accessions were collected in Anexo Campo Verde, EEA Pucallapa, located at Km 44 of the highway Federico Basadre, district of Campo Verde. This agro-ecological zone is very humid lowland forests at an altitude of 205 masl; south latitude 08° 31' 57.5", west longitude 74° 53' 19.7" (tropical climate with an average annual temperature of 25°C; annual rainfall of 1,560–1,777 mm, and relative humidity of 83%). **Soil:** The soil used in the EEA Pucallpa belongs to the height physiographic unit of the Ultisoles series, strongly acidic (pH 5.40 and 71% aluminum saturation), with sandy clay loam texture and with good drainage.

Genetic material: Twenty-nine accessions were collected during the three collection trips. The root samples of the collected *P. tuberosus* accessions came from the EEA Pucallpa INIA and the International Potato Center (CIP). The roots were received at the Laboratory of Molecular Biology and Genomics (INIA) and processed immediately. We proceeded to wash the roots with water to remove any solid residue after which they were dried at room temperature. For each of the analyzed components, a recommended method was used. For humidity, the AOAC (1990); for DM, the AOAC (1990) method; for **reducing sugars**, the spectrophotometric method (Wood and Col. 2013; Najmus and Whitney 2011); for row fiber, the NTP 205.003 (1980, revised 2011) method; for **vitamin C**, the AOAC. 967.21 (2012; chapter 45, ed. 19, pages 22–23); method; for **protein**, the AOAC. 920.152 (2012; chapter 37, ed. 19, page 10) method; and for **iron**, the AOAC. 975.03 (2012; chapter 3, ed. 19, pages 5–6) method. For **starch**, the gravimetric method was used, whereby fresh selected roots were peeled and cut into slices to a certain size. To determine starch by this method, 10–80 g of roots were triturated with water in a blender and the pulp obtained was sifted according sieves ASTM 200, 270, and 325 in order to remove fiber. Subsequently, after decanting the starch, it is recovered and dehydrated in a forced air oven to constant weight, and the results were expressed as a fraction over the initial amount of root used.

The number of accessions collected are listed in Tables 1 and 2. The accessions analyzed in the laboratory are provided Table 3.

Table 1. Number of accessions collected for the project, Pucallpa 2013

Collection Trip	Province/Area	Number of Accessions
November 2011	Ucayali river basin (Alto Ucayali)	12
August 2012	Central forest	7
June 2013	Ucayali river basin (Alto Ucayali)	10

Table 2. Accessions collected and preserved in the EEA Pucallpa for the project, Pucallpa 2013

Accession	Provenance/CCNN	Collection Date	Grain Color
CNNP01	Nuevo Paraíso	21-11-10	Red
CNNA02	Nuevo Ahuaypa	21-11-10	Black
CNPB05A	Puerto Belén	22-11-10	Marbled
CNPB05B	Puerto Belén	22-11-10	Black
CNAM06	Amaquiría	23-11-10	Black
CNCC07	Colonia de Caco	23-11-10	Black
CNCC08	Colonia de Caco	23-11-10	Marbled
CNSH10A	Shahuaya	25-11-10	Black
CNSH10B	Shahuaya	25-11-10	Black
CNTO13A	Toniromashi	26-11-10	Light brown
CNTO13B	Toniromashi	26-11-10	Black
CNBC14	Boca Cocani	27-11-10	Black
CNT01	Tsachopen	06-08-12	Red
CNT02	Tsachopen	07-08-12	Red
CNY03	Yarina	08-08-12	Red
CNY04	Yarina	08-08-12	Red
CNMP05	Mosquito Playa	09-08-12	Red
CNH06	Hanswaldt	11-08-12	Black
CNNP07	Nuevo Porvenir	11-08-12	Red
CNB01	Betania	11-06-13	Red
CNCH02	Cheni	12-06-13	Black
CNCH03	Cheni	12-06-13	Red
CNCH04	Cheni	12-06-13	Red
CNA05	Anapate	12-06-13	Black
CNO06	Oviría	13-06-13	Red
CNO07	Oviría	13-06-13	Red
CNO08	Oviría	13-06-13	Red
CNM09	Mazaroveni	14-06-13	Red
CNM010	Mazaroveni	14-06-13	Red

Table 3. Genetic material evaluated in laboratory

No.	ACCESIONES DE AHIPA	PROCEDENCIA
1	AC-209003	CIP
2	AC-209006	CIP
3	AC-209007	CIP
4	AC-209025	CIP
5	AC-209036	CIP
6	BEH01	INIA
7	BEH02	INIA
8	BEH05A	INIA
9	BEH05B-1*	INIA
10	BEH05B-2*	INIA
11	BEH10A	INIA
12	BEH13A	INIA
13	BEH13B	INIA
14	BEH14	INIA
15	CC003	INIA
16	CC004	INIA
17	CHI002	INIA
18	CNA005	INIA
19	CNP008	INIA
20	EC-209005	CIP
21	EVW20	INIA
22	EVW21	INIA
23	LM001	INIA
24	MO009	INIA
25	PLCH007	INIA
26	PLM006	INIA
27	TC-209058	CIP

CIP: Muestras proporcionadas por la Ing. Elisa Romero del CIP de la localidad de Chanchamayo.
INIA: Muestras proporcionadas por el Ing. Wilfredo Guillen del INIA
*Muestras correspondientes a la accesión BEH-05B cosechada en diferentes fechas

4.2 METHODOLOGY AND PARAMETERS EVALUATED IN THE FIELD

The project was carried out in three phases: (1) collection, (2) multiplication, and (3) morphological characterization and evaluation of storage root yields.

- **Collection phase**: In most accession collections, samples of pods and seeds of *Pachyrhizus spp.* were collected—in some cases, storage roots—in the Ucayali river basin (alto Ucayali), in the central forest (Route San Ramon - Oxapampa - Ciudad Constitucion), and in the Tambo River area.
- **Multiplication phase of the collected accessions**: Field preparation was mechanized, adding 20 t/ha of manure to the soil in localized form. Planting was carried out on three dates, according to the availability of the collected material during the collecting missions: 5 November 2010; 20 October 2011; and 22 October 2012. The distance was 2 m between rows and 1 m between plants. Cultural practices were conducted according to the requirements of the crop, with emphasis on pest control, especially in the control of nematodes and borers sheets (*Diabrotica sp.*). A mixture of Oncol with foliar fertilizer was applied at constant rate at a dose of 1 l/ha.
- **Characterization and evaluation of the accessions:** During the vegetative and reproductive cycles, especially during flowering and fruiting, morphological descriptors were used (see Annex A). The characterization data, descriptors, and root yield data at harvest are shown in the Tables 4.1–4.6 of Annex B.

4.3 METHODOLOGY AND PARAMETERS EVALUATED IN THE LABORATORY

The accessions, 27 *Pachyrhizus* spp., storage roots were obtained from the EEA Pucallpa INIA and CIP. The roots were received at the Laboratory of Molecular Biology and Genomics (INIA). For sample we analyzed for moisture content, DM, reducing sugars, fiber, vitamin C, protein, iron, and starch (methods used see above).

5. RESULTS AND DISCUSSION

We first present data of morphological characterization and yield evaluation of 19 accessions planted in 2013. The evaluated accessions are of a distinct growth type, with predominantly dark green stems (74%), dark green trifoliate pubescent leaves, central lobulated (58%) and oval lanceolate (42%), and the inflorescence is a raceme with simple white flowers (95%). The fruits have long pod shapes, smooth exocarp cream to dark-brown color at harvest time, and the grains are predominantly black (53%). The roots have irregular, elongated predominant shape (26%), white colored pulp (32%), and speckled (26%).

Root yield was evaluated with harvested samples 8 months after planting. Accession BEH05A had the highest storage root yield, 3.6 t/ha. This accession has mottled grains (cream with red) and yellow flesh. Moisture contents were between 73.1% and 92.7% for accessions BEH05B-1 and CNA005, respectively (see Annex B, Table 5). The average values of DM were between 7.3% and 26.9%, belonging to accessions CNA005 and BEH05B, respectively (see Annex B, Table 6). The results of crude fiber for the different accessions were among 0.4% and 2.3%. Accessions CC003 and BEH05A had higher values compared with the other accessions (see Annex B, Table 7). The content of reducing sugars evaluated according to the spectrophotometric method (Wood et al. 2013; Najmus and Whitney 2011) reveals that accession CNA005 has the highest value of reducing sugar content (4,122.3 mg/100 g per sample), whereas accessions BEH05B-1 and 2, and CC004, have the lowest values for the content of reducing sugars with 344.4, 253.4, and 170.6 mg/100 g per sample, respectively (see Annex B, Table 8). The analysis of vitamin C shows that accessions LM001, EC-209 005, BEH10A, TC-209 058, AC-209 036, AC-209 007, AC-209 025, 209 006, and AC-AC-9003 do not contain vitamin C, whereas accession BEH02 presents the highest value (12.3 mg/100 g per sample) (see Annex B, Table 9).

The evaluation of the protein content of the different accessions according to Kjeldalh (AOAC 920.152, 2012) produced results between 0.7% and 6.3% (see Annex B, Table 10). The evaluation of the iron content by atomic absorption spectroscopic method (AOAC 975.03, 2012) shows content between 1.7 and 28.1 mg/kg per sample for accessions BEH10A and BEH13B, respectively (see Annex B, Table 11). The evaluation of the content of starch using ASTM sieves of different mesh and gravimetric methods resulted in starch values between 15.7 and 0.3 g/100 per sample for accessions CC004 and BEH05A, respectively (see Annex B, Table 12).

Annex C displays various photos of collect yam bean accessions.

6. OUTPUTS

- All the accessions established (19 accessions) in the 2013 campaign were morphologically characterized and evaluated.
- Storage root yields were only up to 3.4 t/ha for accession BEH05A.
- 10 additional accessions were collected in the Tambo River area in the province of Satipo, Department of Junín.
- We are currently maintaining 29 accessions in the field for conservation and further characterization.
- Field data were entered into Excel spreadsheets for the respective statistical analysis.
- The national collection of tropical roots and tubers of INIA has been strengthened.

- The results of moisture on the yam bean samples were found to be between 73.1% and 92.7%, similar to those reported by other researchers (Ramos-de-la Pena et al. 2013).
- The DM contents for the yam bean accessions showed values between 7.3% and 26.9%, higher than those reported for *P. ahipa*, *P. tuberosus*, and *P. erosus* (Ramos-de-la Pena et al. 2013).
- Accession BEH05B-1 had the highest total protein content (6.3%), but lower than those reported by other researchers (Doporto et al. 2011; Ramos-de-la Pena et al. 2013).
- Accession BEH13B had the highest iron content (28.1 mg/kg per sample), similar to that presented by Norman et al. (2007) and lower than those reported by Leterme et al. (2006) and Ramos-de-la Pena et al (2013).
- The starch content reached 15.7% for accession CC004, higher than those reported by Forsyth and Shewry (2002) for *P. ahipa* (12.3%).
- Most important, we collected a larger number of high dry yam bean accessions and maintained them in the seed bank of INIA and CIP. This is the first time that such material became available to genebanks for research and development.

7. RECOMMENDATIONS

- Keep and maintain replicas of the collected germplasm in the seed bank of the SUDIRGEB for future studies.
- Collect more often in order to have greater representation of the genetic variability of *Pachyrhizus spp*. in the Amazonian area.
- Complete the morphological characterization of all accessions collected.
- Make more studies to find suitable processes for the production of flour and starch from yam bean roots.
- Complete the biochemical characterization of the National Germplasm Collection of yam bean at INIA. This effort will reveal the contents of rotenone on seeds and leaves, their functional properties, the content of essential amino acids, as well as suggest applications of the roots in the development of new products.
- Take into account the phenology of yam bean in order to have the roots for chemical analysis.

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ANNEX A: DESCRIPTORS FOR AHIPA CHARACTERIZATION

1. FASE VEGETATIVA

1.1 PORCENTAJE DE EMERGENCIA

Evaluar entre 8 a 40 días

1.2 HABITO DE CRECIMIENTO

1. Erecto
2. Semi erecto
3. Voluble trepador
4. Voluble rastrero

1.3 ASPECTO DE ENROSCAMIENTO

0. No enroscante
9. Enroscante

1.4 COLOR DE TALLO

1. Verde claro
2. Verde oscuro
3. Marrón claro
4. Marrón oscuro
5. Gris
6. Verde plateado

1.5 PRESENCIA DE ALETAS EN EL TALLO

0. Ausente
1. Leve
2. Moderado
3. Pronunciado

1.6 PUBESCENCIA DE TALLO

0. Ausente
1. Presente

1.7 COLOR DE HOJA

1. Verde claro
2. Verde oscuro
3. Verde morado
4. Morado
5. Otro

1.8 COLOR DE NERVADURA (ENVES DE HOJA)

1. Verde claro
2. Verde oscuro
3. Verde morado
4. Morado

1.9 PUBESCENCIA DE HOJAS

0. Ausente
1. Presente

1.10 TIPO DE HOJA

1. Simple
2. Bifoliados
3. Trifoliados
4. Digitada
5. Otros

1.11 FORMA DE HOJA

Registro de la forma predominante de la hoja

1. Deltada
2. Deltada partida
3. Ovada
4. Ovada lanceado
5. Lanceado
6. Romboide
7. Obovada
8. Redonda
9. Otro

1.12 TAMAÑO DE HOJA

Registro de longitud y ancho de 5 hojas en cm., tomados de la parte media de la planta.

1.13 COLOR DE PECIOLO

1. Verde claro
2. Verde oscuro
3. Verde morado
4. Morado

1.14 PUBESCENCIA DE PECIOLO

0. Ausente
1. Presente

1.15 COLOR DE PUBESCENCIA DE PECIOLO

1. Blanco/Crema
2. Amarillo
3. Marrón claro
4. Marrón oscuro
5. Morado
6. Rojo
7. Negro
8. Otro

1.16 ANTOCIANINA EN PECIOLO

0. Ausente
1. Presente

1.17 PRESENCIA DE ALETAS EN PECIOLO

0. Ausente
1. Presente

1.18 LONGITUD DE PECIOLO

Registro de longitud en cm., de 5 hojas del tercio medio de la planta.

2. INFLORESCENCIA – FRUTO – RAIZ

2.1 FLORACION

0. Ausente
1. Presente

2.2 TIPO DE INFLORESCENCIA - RACIMO

1. Simple
2. Compuesto

2.3 COLOR DE FLOR

1. Blanco
2. Amarillo
3. Lila
4. Morado
5. Verde claro

2.4 FRUTO ESTABLECIDO (Vainas)

0. Ausente
1. Presente

2.5 PUBESCENCIA DE FRUTO

Registro de pubescencia en frutos verdes (antes de la madurez fisiológica)

0. Ausente
1. Presente

2.6 EXOCARPO DEL FRUTO

3. Liso
7. Aspero

2.7 NUMERO DE VAINAS POR RACIMO

Registro de número de vainas de 5 racimos.

2.8 TAMAÑO DE FRUTO (Vainas)

Registro de longitud y ancho de 5 vainas secas, en cm.

2.9 COLOR DE VAINA SECA

1. Pardo
2. Crema
3. Marrón claro
4. Marrón oscuro
5. Morado
6. Negro
7. Otro

2.10 COLOR DE GRANO SECO

1. Blanco
2. Crema
3. Marrón claro
4. Marrón oscuro
5. Rojo
6. Negro
7. Morado
8. Jaspeado (Crema/rojo)
9. Otro

2.11 FORMACION DE RAIZ RESERVANTE (Aspecto)

1. Racimo cerrado
2. Racimo abierto
3. Disperso
4. Muy disperso
5. No desarrollado

2.12 LONGITUD DE PEDUNCULO DE RAIZ RESERVANTE

Registro de longitud en cm. de 05 pedúnculos de la raíz reservante.

0. Ausente
1. Muy corto: < 2 cm.
3. Corto: 2-5cm
5. Intermedio: 5-8 cm.
7. Largo: 9-12 cm.
9. muy largo: > 12 cm.

2.13 FORMA DE RAIZ RESERVANTE

Registro de la forma predominante de la raíz reservante.

1. Cónico

2. Cónico alargado
3. Redondo
4. Redondo irregular
5. Elíptico
6. Ovado
7. Oblongo
8. Largo elíptico
9. Largo irregular o curvado

2.14 COLOR EXTERNO DE RAIZ RESERVANTE

1. Blanco
2. Blanco cremoso
3. Amarillo
4. Café claro
5. Café oscuro
6. Morado
7. Gris

2.15 COLOR INTERNO DE RAIZ RESERVANTE

1. Blanco
2. Blanco cremoso
3. Amarillo
4. Lila
5. Morado

2.16. PRESENCIA DE RAICILLAS EN SUPERFICIE DE RAIZ

0. Ausente
1. Leve
2. Intermedio
3. Abundante

2.17. COLOR PULPA DE RAIZ RESERVANTE

1. Blanco
2. Crema
3. Amarillo
4. Lila
5. Morado
6. Jaspeado (Crema con puntos morados)

2.18. EVALUACION DE PLAGAS

0. Ausente
1. Cortador de brotes y hojas (Hormigas cortadoras)
2. Perforador de hojas (Diabrótica)
3. Chupadores de savia (Chinches y pulgones)
4. Coleópteros (Perforadores de vainas y granos)
5. Coleópteros (Perforador de raíz y tallo)

2.19. EVALUACION DE ENFERMEDADES

0. Ausente
1. Chupadera fungosa (Rhizoctonia)
2. Mustia hilachosa
3. Mancha foliar (Cercospora)
4. Virus
5. Bacterias

2.20. INCIDENCIA DE NEMATODES

0. Ausente
1. Leve
2. Moderado
3. Severo

2.21. NUMERO DE RAICES RESERVANTES POR PLANTA

Registro de 5 plantas

2.22 TAMAÑO DE RAIZ RESERVANTE

Registro de longitud y diámetro en cm. de la raíz predominante de 5 plantas.

2.23 PESO DE RAIZ RESERVANTE POR PLANTA

Registro de 05 Plantas en Kg.

2.24 RENDIMIENTO DE RAIZ RESERVANTE (t/ha)

2.25 DIAS A COSECHA

ANNEX B AHIPA DATA TABLES

Table 4.1 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Germina-tion	Growth type	Aspect	Color Stem	Aletas Tallo	Pubesc Stem	Color Leaf	Color Nerv	Pubesc Leaf	Type Leaf	Shape Leaf	Leaf length (cm)					
														1	2	3	4	5	Aver.
001	CNNP01	CCNN Nuevo Paraiso	68	3	9	1	0	1	2	1	1	3	1	13.1	15.4	11.3	13.4	14.4	**13.5**
002	CNNA02	CCNN Nuevo Ahuaypa	100	3	9	6	0	1	2	1	1	3	4	17.5	11.8	11.3	20.5	17.5	**15.7**
003	CNPB05A	CCNN Puerto Belén	90	3	9	6	0	1	2	1	1	3	4	22.7	20.2	17.7	22.1	23.5	**21.2**
004	CNPB05B	CCNN Puerto Belén	85	3	9	2	0	1	2	1	1	3	4	16.0	16.2	20.2	16.6	13.5	**16.5**
005	CNAM06	CCNN Amaquiria	30	3	9	2	0	1	2	1	1	3	4	16.7	17.2	16.5	21.7	19.5	**18.3**
006	CNCC07	CCNN Colonia del Caco 3	45	3	9	2	0	1	2	1	1	3	4	18.2	19.1	20.7	18.8	17.7	**18.9**
007	CNCC08	CCNN Colonia del caco 4	75	3	9	2	0	1	2	1	1	3	4	18.5	20.0	16.3	16.2	17.0	**17.6**
008	CNSH010A	CCNN Shahuaya 1	70	3	9	2	0	1	2	1	1	3	4	15.8	18.7	16.7	17.2	15.0	**16.7**
009	CNSH010B	CCNN Shahuaya 2	76	3	9	2	0	1	2	1	1	3	4	16.1	19.3	19.6	16.4	16.9	**17.7**
010	CNTO013B	CCNN Toniromashi 1	80	3	9	6	0	1	2	1	1	3	1	12.9	11.9	14.1	12.1	9.5	**12.1**
011	CNTO013	CCNN Toniromashi 2	65	3	9	6	0	1	2	1	1	3	1	11.2	12.3	11.6	14.4	11.5	**12.2**
012	CNBC014	CCNN Boca Cocani	65	3	9	6	0	1	2	1	1	3	1	9.2	13.3	11.0	9.2	15.4	**11.6**
013	CNT01	CCNN Tsachopen	17	3	9	1	0	1	2	1	1	3	1	11.3	8.8	11.2	11.5	14.2	**11.4**
014	CNT02	CCNN Tsachopen	67	3	9	2	0	1	2	1	1	3	1	11.1	12.5	11.5	15.9	11.4	**12.5**
015	CNY03	CCNN Yarina	80	3	9	2	0	1	2	1	1	3	1	13.0	11.3	12.3	12.2	11.5	**12.1**
016	CNY04	CCNN Yarina	40	3	9	2	0	1	2	1	1	3	1	10.6	10.2	12.0	12.0	17.1	**12.4**
017	CNMP05	CCNN Mosquito Playa	78	3	9	2	0	1	2	1	1	3	1	17.2	11.9	12.5	10.1	10.1	**12.4**
018	CNH06	CCNN Hanswaldt	85	3	9	6	0	1	2	1	1	3	1	17.0	13.2	15.4	13.0	13.4	**14.4**
019	CNNP07	CCNN Nuevo Porvenir	77	3	9	2	0	1	2	1	1	3	1	15.0	13.4	13.4	12.3	13.2	**13.5**

Prepared by Wilfredo Guillén. SUDIRGEB/INIA.

Table 4.2 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Leaf width (cm)						Color Peciolo	Pubesc Peciolo	Color Pubesc	Antoc Peciolo	Aletas Peciolo	Length of Peciolo (cm)					
			1	2	3	4	5	Aver.						1	2	3	4	5	Aver.
001	CNNP01	CCNN Nuevo Paraiso	15.3	17.8	15.0	15.8	18.7	**16.5**	1	1	1	0	0	14.1	11.9	14.5	16.1	13.2	**14.0**
002	CNNA02	CCNN Nuevo Ahuaypa	10.6	6.9	6.9	10.4	10.5	**9.1**	1	1	1	0	0	20.0	18.8	16.7	22.2	23.2	**20.2**
003	CNPB05A	CCNN Puerto Belén	11.5	10.2	9.4	12.2	14.4	**11.5**	1	1	1	0	0	19.3	16.3	22.1	20.6	24.6	**20.6**
004	CNPB05B	CCNN Puerto Belén	9.5	8.5	11.2	8.8	6.6	**8.9**	1	1	1	0	0	14.2	12.2	19.5	13.5	16.2	**15.1**
005	CNAM06	CCNN Amaquiria	7.1	9.3	8.5	10.4	8.7	**8.8**	1	1	1	0	0	21.1	20.2	30.7	24.2	17.5	**22.7**
006	CNCC07	CCNN Colonia del Caco 3	10.5	9.1	9.5	9.6	8.7	**9.5**	1	1	1	0	0	10.4	16.3	20.2	13.5	16.4	**15.4**
007	CNCC08	CCNN Colonia del caco 4	9.3	9.3	8.9	8.2	7.8	**8.7**	1	1	1	0	0	19.5	16.6	13.2	18.9	16.7	**17.0**
008	CNSH010A	CCNN Shahuaya 1	7.1	8.6	8.5	9.0	7.2	**8.1**	1	1	1	0	0	13.4	19.7	12.8	13.8	13.6	**14.7**
009	CNSH010B	CCNN Shahuaya 2	7.2	9.9	8.1	8.6	8.6	**8.5**	1	1	1	0	0	17.5	21.6	17.6	14.8	17.6	**17.8**
010	CNTO013B	CCNN Toniromashi 1	15.8	16.2	18.1	16.5	8.8	**15.1**	1	1	1	0	0	12.6	15.9	11.8	15.9	10.2	**13.3**
011	CNTO013	CCNN Toniromashi 2	13.9	12.5	15.5	16.0	14.5	**14.5**	1	1	1	0	0	9.6	12.4	21.8	19.3	12.5	**15.1**
012	CNBC014	CCNN Boca Cocani	12.4	12.6	12.3	13.9	19.8	**14.2**	1	1	1	0	0	14.6	14.5	12.6	15.4	13.1	**14.0**
013	CNT01	CCNN Tsachopen	14.8	10.1	12.8	15.9	18.8	**14.5**	1	1	1	0	0	15.8	8.3	12.6	14.9	16.5	**13.6**
014	CNT02	CCNN Tsachopen	16.1	14.5	15.7	20.6	14.9	**16.4**	1	1	1	0	0	9.9	14.3	9.1	11.9	12.8	**11.6**
015	CNY03	CCNN Yarina	13.3	12.5	12.8	9.2	13.1	**12.2**	1	1	1	0	0	20.1	14.9	20.0	12.1	13.8	**16.2**
016	CNY04	CCNN Yarina	12.3	14.6	15.3	16.5	19.2	**15.6**	1	1	1	0	0	20.1	14.2	12.1	14.1	17.8	**15.7**
017	CNMP05	CCNN Mosquito Playa	19.0	16.5	14.8	14.4	12.6	**15.5**	1	1	1	0	0	17.7	13.9	12.2	14.2	20.2	**15.6**
018	CNH06	CCNN Hanswaldt	20.6	17.9	20.3	15.2	19.8	**18.8**	1	1	1	0	0	19.4	11.4	22.6	17.2	19.6	**18.0**
019	CNNP07	CCNN Nuevo Porvenir	16.7	13.5	14.8	13.1	15.6	**14.7**	1	1	1	0	0	19.4	16.9	12.1	13.9	12.9	**15.0**

Prepared by Wilfredo Guillén. SUDIRGEB/INIA

Table 4.3 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Flower	Type Infloresence	Color Flower	Fruit Establ.	Pods	Exoc. Pods	Number of pods						Dry pod length (cm)					
									1	2	3	4	5	Aver.	1	2	3	4	5	Aver.
001	CNNP01	CCNN Nuevo Paraiso	1	1	1	1	1	3	2	6	4	2	3	3.4	15.0	13.0	14.0	13.3	14.2	**13.9**
002	CNNA02	CCNN Nuevo Ahuaypa	1	1	1	1	1	3	6	6	6	6	4	5.6	13.6	14.2	14.1	13.7	15.9	**14.3**
003	CNPB05A	CCNN Puerto Belén	1	1	1	1	1	3	4	7	5	5	3	4.8	18.5	18.1	16.2	18.9	16.0	**17.5**
004	CNPB05B	CCNN Puerto Belén	1	1	1	1	1	3	4	2	3	6	5	4.0	13.6	15.5	13.2	16.0	14.4	**14.5**
005	CNAM06	CCNN Amaquiria	1	1	1	1	1	3	5	3	4	6	2	4.0	19.5	15.9	20.9	15.0	19.0	**18.1**
006	CNCC07	CCNN Colonia del Caco 3	1	1	1	1	1	3	5	4	7	4	2	4.4	16.8	15.9	14.4	14.9	16.5	**15.7**
007	CNCC08	CCNN Colonia del caco 4	1	1	1	1	1	3	3	2	7	4	4	4.0	17.7	18.0	13.7	16.5	17.0	**16.6**
008	CNSH010A	CCNN Shahuaya 1	1	1	1	1	1	3	4	3	5	7	3	4.4	16.5	15.1	15.2	14.6	16.9	**15.7**
009	CNSH010B	CCNN Shahuaya 2	1	1	1	1	1	3	6	4	3	2	8	4.6	16.6	15.1	14.7	16.3	14.6	**15.5**
010	CNTO013B	CCNN Toniromashi 1	1	1	1	1	1	3	10	4	6	5	7	6.4	20.4	19.2	22.8	18.4	19.1	**20.0**
011	CNTO013	CCNN Toniromashi 2	1	1	1	1	1	3	3	3	3	5	7	4.2	20.8	20.7	18.1	20.2	21.1	**20.2**
012	CNBC014	CCNN Boca Cocani	1	1	1	1	1	3	4	5	6	4	7	5.2	20.6	21.4	23.4	20.8	21.7	**21.6**
013	CNT01	CCNN Tsachopen	1	1	1	1	1	3	3	2	2	4	5	3.2	16.5	17.6	15.9	14.5	15.3	**16.0**
014	CNT02	CCNN Tsachopen	1	1	1	1	1	3	2	3	2	5	5	3.4	16.1	20.1	17.3	16.1	19.1	**17.7**
015	CNY03	CCNN Yarina	1	1	1	1	1	3	3	6	3	4	2	3.6	22.7	20.3	22.4	20.0	20.8	**21.2**
016	CNY04	CCNN Yarina	1	1	1	1	1	3	5	2	1	2	3	2.6	19.5	22.2	19.6	22.6	18.1	**20.4**
017	CNMP05	CCNN Mosquito Playa	1	1	1	1	1	3	1	1	-	-	-	1.0	21.0	20.7	-	-	-	**20.9**
018	CNH06	CCNN Hanswaldt	1	1	1	1	1	3	5	6	2	3	5	4.2	22.3	21.6	21.1	20.0	19.9	**21.0**
019	CNNP07	CCNN Nuevo Porvenir	1	1	1	1	1	3	3	3	3	11	4	4.8	21.3	17.6	22.5	20.4	21.4	**20.6**

Prepared by Wilfredo Guillén. SUDIRGEB/INIA

Table 4.4 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Dry pod width (cm)						Color Pod	Color Grain	Format. Root	Dry pod length (cm)						Shape Root	Color Ext. Root	Color Int.Root
			1	2	3	4	5	Aver.				1	2	3	4	5	Aver.			
001	CNNP01	CCNN Nuevo Paraiso	1.8	1.6	1.5	1.6	1.7	**1.6**	2	5	3	4.2	3.7	14.3	8.2	13.5	**8.8**	8	2	2
002	CNNA02	CCNN Nuevo Ahuaypa	1.5	1.6	1.5	1.5	1.6	**1.5**	4		3	3.0	3.4	2.7	2.9	2.0	**2.8**	2	6	6
003	CNPB05A	CCNN Puerto Belén	1.8	1.8	1.7	1.9	1.8	**1.8**	4		3	7.0	3.5	2.3	4.5	3.9	**4.2**	1	2	2
004	CNPB05B	CCNN Puerto Belén	1.5	1.4	1.5	1.6	1.8	**1.6**	4	6	3	5.2	5.3	3.9	5.4	4.2	**4.8**	5	6	6
005	CNAM06	CCNN Amaquiria	1.9	1.5	1.9	1.5	1.8	**1.7**	4	6	3	3.0	3.8	3.9	4.2	3.7	**3.7**	9	6	6
006	CNCC07	CCNN Colonia del Caco 3	1.7	1.7	1.6	1.6	1.7	**1.7**	4	6	3	4.0	4.3	3.0	3.5	3.6	**3.7**	6	6	6
007	CNCC08	CCNN Colonia del Caco 4	1.9	1.7	1.7	1.8	1.9	**1.8**	4	8	3	3.8	10.5	4.5	2.8	4.8	**5.3**	5	2	2
008	CNSH010A	CCNN Shahuaya 1	1.6	1.5	1.5	1.7	1.8	**1.6**	4	6	3	1.8	4.0	3.6	2.2	2.0	**2.7**	6	6	6
009	CNSH010B	CCNN Shahuaya 2	1.6	1.5	1.5	1.6	1.6	**1.6**	4	6	3	2.0	3.0	1.5	2.9	1.3	**2.1**	9	6	6
010	CNTO013B	CCNN Toniromashi 1	2.1	2.1	2.0	1.9	1.9	**2.0**	2		2	26.4	5.5	7.2	18.4	15.7	**14.6**	9	2	2
011	CNTO013	CCNN Toniromashi 2	2.2	2.1	1.9	1.9	2.2	**2.1**	2		2	11.6	3.5	21.3	16.1	8.4	**12.2**	2	2	2
012	CNBC014	CCNN Boca Cocani	2.0	2.1	2.1	1.9	1.9	**2.0**	2		2	5.1	9.0	18.3	15.9	9.5	**11.6**	8	2	2
013	CNT01	CCNN Tsachopen	1.6	1.8	1.9	1.6	1.6	**1.7**	4		-	-	-	-	-	-		-	-	-
014	CNT02	CCNN Tsachopen	1.8	1.9	1.8	1.7	1.9	**1.8**	4		-	-	-	-	-	-		-	-	-
015	CNY03	CCNN Yarina	2.0	1.8	1.9	1.9	1.9	**1.9**	2		-	-	-	-	-	-		-	-	-
016	CNY04	CCNN Yarina	1.8	1.8	1.9	1.9	1.8	**1.8**	2		-	-	-	-	-	-		-	-	-
017	CNMP05	CCNN Mosquito Playa	2.0	2.1	-	-	-	**2.1**	2		-	-	-	-	-	-		-	-	-
018	CNH06	CCNN Hanswaldt	2.3	2.2	2.0	2.2	2.1	**2.2**	2		3	11.3	44.0	18.6	19.8	18.7	**22.5**	8	2	2
019	CNNP07	CCNN Nuevo Porvenir	1.9	1.8	2.0	2.0	1.9	**1.9**	2		3	15.0	20.8	18.0	14.9	17.5	**17.2**	9	2	2

Prepared by Wilfredo Guillén. SUDIRGEB/INIA

Table 4.5 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Roots	Color Flesh	Eval. Pests[1]	Eval. Disease[2]	Incid. Nemát.	Number of roots per plant						Root length (cm)					
								1	2	3	4	5	Aver.	1	2	3	4	5	Aver.
001	CNNP01	CCNN Nuevo Paraiso	0	1	2.4	3	2	3	3	4	4	6	**4.0**	17.6	14.8	13.9	20.6	14.4	**16.3**
002	CNNA02	CCNN Nuevo Ahuaypa	0	6	2.4	3	1	1	2	1	1	1	**1.2**	12.5	10.4	16.8	12.9	17.8	**14.1**
003	CNPB05A	CCNN Puerto Belén	0	3	2.4	3	1	1	2	1	1	-	**1.3**	16.0	16.6	12.8	17.0	15.3	**15.5**
004	CNPB05B	CCNN Puerto Belén	0	6	2.4	3	2	1	2	2	1	2	**1.6**	6.6	10.3	10.4	5.9	12.6	**9.2**
005	CNAM06	CCNN Amaquiria	3	6	2.4	**3**	2	1	3	1	1	3	**1.8**	24.9	10.6	24.9	22.1	15.8	**19.7**
006	CNCC07	CCNN Colonia del Caco 3	3	6	2.4	3	2	3	1	3	2	4	**2.6**	10.2	19.6	17.0	10.1	12.4	**13.9**
007	CNCC08	CCNN Colonia del Caco 4	0	2	2.4	3	2	1	1	2	4	1	**1.8**	13.3	12.6	6.6	9.0	12.3	**10.8**
008	CNSH010A	CCNN Shahuaya 1	2	6	2.4	3	3	2	2	0	0	1	**1.0**	8.7	11.9	14.0	51.4	12.6	**19.7**
009	CNSH010B	CCNN Shahuaya 2	0	6	2.4	3	3	1	1	1	1	1	**1.0**	10.7	4.9	9.5	5.5	7.0	**7.5**
010	CNTO013B	CCNN Toniromashi 1	0	1	2.4	**3**	2	2	2	2	2	3	**2.2**	13.1	18.6	29.8	21.1	15.8	**19.7**
011	CNTO013	CCNN Toniromashi 2	0	1	2.4	3	1	5	2	3	2	3	**3.0**	8.5	20.7	18.8	17.9	11.4	**15.5**
012	CNBC014	CCNN Boca Cocani	0	1	2.4	3	1	3	4	3	3	4	**3.4**	14.6	17.1	24.0	22.4	20.1	**19.6**
013	CNT01	CCNN Tsachopen	-	-	-	**3**	3	-	-	-	-	-	-	-	-	-	-	-	
014	CNT02	CCNN Tsachopen	-	-	2.4	3	3	-	-	-	-	-	-	-	-	-	-	-	
015	CNY03	CCNN Yarina	-	-	2.4	3	3	-	-	-	-	-	-	-	-	-	-	-	
016	CNY04	CCNN Yarina	-	-	2.4	3	3	-	-	-	-	-	-	-	-	-	-	-	
017	CNMP05	CCNN Mosquito Playa	-	-	2.4	3	3	-	-	-	-	-	-	-	-	-	-	-	
018	CNH06	CCNN Hanswaldt	0	1	2.4	3	1	4	2	1	1	3	**2.2**	23.3	28.5	30.0	19.9	35.8	**27.5**
019	CNNP07	CCNN Nuevo Porvenir	0	1	2.4	3	1	1	1	2	2	1	**1.4**	23.9	27.8	57.7	39.4	46.1	**39.0**

[1] Pests evaluation: 2 = perforation of leaves and 4 = Coleopteros

[2] Disease evaluation: 3 = Cercospora

Prepared by Wilfredo Guillén. SUDIRGEB/INIA

Table 4.6 Registration of Characterization Data – Ahipa Collection

SUDIRGEB-EEAP/CIP, 2013

Project: "Collection, evaluation and conservation of genetic resources of *Pachyrhizus spp*. (P. *tuberosus* and P. *ahipa*) in Perú"

Plot No.	Collection Code	Identification/ Common name	Root diameter (cm)						Root Weight per Plant (kg)						Root. Yield*	Days to harvest
			1	2	3	4	5	Aver.	1	2	3	4	5	Aver.		
001	CNNP01	CCNN Nuevo Paraiso	3.8	4.5	2.6	3.2	5.0	**3.8**	0.200	0.185	0.300	0.735	0.850	**0.454**	2.27	251
002	CNNA02	CCNN Nuevo Ahuaypa	4.4	3.4	4.7	5.1	2.5	**4.0**	0.200	0.200	0.100	0.100	0.165	**0.153**	0.77	174
003	CNPB05A	CCNN Puerto Belén	5.8	9.0	6.6	5.7	8.4	**7.1**	1.000	0.925	0.450	0.475	-	**0.713**	3.56	174
004	CNPB05B	CCNN Puerto Belén	2.8	2.6	4.3	2.4	6.0	**3.6**	0.235	0.080	0.080	0.100	0.160	**0.131**	0.66	265
005	CNAM06	CCNN Amaquiria	3.6	4.6	4.2	3.9	2.5	**3.8**	0.200	0.280	0.220	0.220	0.200	**0.224**	1.12	236
006	CNCC07	CCNN Colonia del Caco 3	2.8	3.9	6.1	3.9	2.8	**3.9**	0.210	0.100	0.190	0.110	0.510	**0.224**	1.12	236
007	CNCC08	CCNN Colonia del Caco 4	5.5	3.4	2.8	6.7	3.4	**4.4**	0.110	0.220	0.130	0.330	0.200	**0.198**	0.99	236
008	CNSH010A	CCNN Shahuaya 1	4.4	2.8	2.6	3.2	3.4	**3.3**	0.121	0.418	0.000	0.000	0.100	**0.128**	0.64	203
009	CNSH010B	CCNN Shahuaya 2	2.6	2.5	2.5	2.7	3.3	**2.7**	0.080	0.050	0.080	0.050	0.080	**0.068**	0.34	236
010	CNTO013B	CCNN Toniromashi 1	2.4	2.1	1.9	2.4	3.7	**2.5**	0.135	0.200	0.135	0.125	0.225	**0.164**	0.82	251
011	CNTO013	CCNN Toniromashi 2	4.2	3.5	6.0	4.3	3.8	**4.4**	1.000	0.225	0.575	0.175	0.200	**0.435**	2.18	251
012	CNBC014	CCNN Boca Cocani	4.8	5.7	3.5	3.4	3.5	**4.2**	0.400	0.265	0.225	0.575	0.400	**0.373**	1.87	265
013	CNT01	CCNN Tsachopen	-	-	-	-	-	-	-	-	-	-	-			
014	CNT02	CCNN Tsachopen	-	-	-	-	-		-	-	-	-	-			
015	CNY03	CCNN Yarina	-	-	-	-	-		-	-	-	-	-			
016	CNY04	CCNN Yarina	-	-	-	-	-		-	-	-	-	-			
017	CNMP05	CCNN Mosquito Playa	-	-	-	-	-		-	-	-	-	-			
018	CNH06	CCNN Hanswaldt	4.2	4.8	4.2	3.2	4.6	**4.2**	0.975	0.550	0.150	0.175	0.585	**0.487**	2.44	272
019	CNNP07	CCNN Nuevo Porvenir	3.3	3.0	4.6	3.3	4.1	**3.7**	0.750	0.425	0.725	0.250	0.175	**0.465**	2.33	272

*Storage root yield in t/ha

Table 5. Average root moisture content of collected yam bean accessions

Accesiones	Humedad (%)
CNA005	92,73
PLM006	89,87
PLCH007	89,72
CHI002	88,60
LM001	88,52
EVW20	88,23
CNP008	88,14
BEH13A	87,78
MO009*	87,51
BEH05A	86,59
BEH01	86,31
BEH13B	86,04
EVW21	85,44
BEH14	84,52
AC-209007	83,92
CC003	83,73
AC-209003	83,40
AC-209036	83,17
AC-209006	82,25
TC-209058*	81,19
BEH10A	78,90
EC-209005	78,09
BEH02	77,58
BEH05B-2*	77,28
AC-209025	76,95
CC004	74,47
BEH05B-1	73,10

Valores promedio de 3 repeticiones.

* Valores promedio obtenidos a partir de 2 repeticiones por falta de materia prima

Table 6. Average root dry matter content of collected yam bean accessions

Accesiones	Materia seca (%)
BEH05B-1	26,90
CC004	25,53
AC-209025	23,05
BEH05B-2*	22,72
BEH02	22,42
EC-209005	21,91
BEH10A	21,10
TC-209058*	18,81
AC-209006	17,75
AC-209036	16,83
AC-209003	16,60
CC003	16,27
AC-209007	16,08
BEH14	15,48
EVW21	14,56
BEH13B	13,96
BEH01	13,69
BEH05A	13,41
MO009*	12,49
BEH13A	12,22
CNP008	11,86
EVW20	11,77
LM001	11,48
CHI002	11,40
PLCH007	10,28
PLM006	10,13
CNA005	7,27

Valores promedio de 3 repeticiones.

* Valores promedio obtenidos a partir de 2 repeticiones por falta de materia prima

Table 7. Average fiber content of collected yam bean accessions

Accesiones	Fibra cruda (g/100 g de muestra)
BEH05A	2,25
CC003	2,21
BEH14	1,57
AC-209007	1,56
EVW21	1,24
BEH05B-1	1,18
AC-209006	1,14
MO009	1,12
CHI002	1,11
BEH02	1,06
PLM006	1,04
BEH05B-2	0,94
BEH10A	0,92
EVW20	0,89
CNP008	0,85
TC-209058	0,85
CC004	0,77
EC-209005	0,75
BEH01	0,70
BEH13A	0,69
AC-209003	0,62
CNA005	0,53
LM001	0,52
BEH13B	0,51
PLCH007	0,49
AC-209036	0,41
AC-209025	0,37

Valores promedio de 3 repeticiones.

Table 8. Average reducing sugars contents of collected yam bean accessions

Accesiones	Azúcares reductores (Equivalentes mg de glucosa/100 g de muestra)
CNA005	4122,28
AC-209025	3622,85
PLM006	3488,66
PLCH007	3428,87
TC-209058	3415,02
BEH05A	3087,19
AC-209036	2977,93
LM001	2964,41
BEH13B	2877,39
BEH01	2781,22
AC-209003	2747,77
AC-209007	2677,24
CC003	2534,84
CHI002	2514,25
BEH13A	2464,48
EVW20	2398,11
MO009	2386,99
CNP008	2163,29
EVW21	2155,52
BEH14	2057,09
AC-209006	2030,59
EC-209005	1578,62
BEH02	1342,91
BEH10A	638,10
BEH05B-1	344,35
BEH05B-2	253,39
CC004	170,58

Valores promedio de 3 repeticiones.

Table 9. Average vitamin C contents of collected yam bean accessions

Accesiones	Vitamina C (mg/100 g de muestra)
BEH02	12,31
EVW21	8,32
CC004	7,55
BEH05B-2	7,37
EVW20	6,95
CC003	6,48
BEH05A	5,72
BEH14	5,33
PLM006	4,28
MO009	4,04
BEH05B-1	3,60
BEH13A	2,86
CNP008	2,83
BEH01	2,77
PLCH007	2,41
CHI002	2,16
CNA005	1,52
BEH13B	1,43
LM001	0,25
EC-209005	0,00
BEH10A	0,00
TC-209058	0,00
AC-209036	0,00
AC-209007	0,00
AC-209025	0,00
AC-209006	0,00
AC-209003	0,00

Valores promedio de 3 repeticiones.

Table 10. Average protein contents of collected yam bean accessions

Accesiones	Proteína (g/100 g de muestra)
BEH05B-1	6,25
BEH10A	4,90
CC004	4,07
CC003	3,05
BEH05B-2	2,92
CNP008	2,61
EC-209005	2,36
PLM006	2,29
EVW21	2,08
BEH01	2,04
BEH02	2,01
LM001	1,98
BEH13A	1,82
EVW20	1,68
BEH14	1,65
TC-209058	1,37
BEH05A	1,21
PLCH007	1,14
BEH13B	1,14
AC-209007	1,13
MO009	1,09
AC-209006	1,05
AC-209003	0,95
AC-209036	0,94
CNA005	0,93
CHI002	0,93
AC-209025	0,74

Valores promedio de 3 repeticiones.

Table 11. Average storage root iron contents of collected yam bean accessions

Accesiones	Hierro (mg/kg de muestra)
BEH13B	28,13
CC003	25,49
BEH05B-2	25,05
MO009	24,16
BEH14	23,57
BEH05B-1	20,23
EC-209005	19,14
PLCH007	18,10
BEH01	17,92
BEH05A	17,42
EVW20	17,23
CNA005	17,13
CC004	16,80
PLM006	15,93
BEH02	15,68
LM001	15,59
CNP008	14,73
AC-209006	14,48
TC-209058	14,31
CHI002	14,26
AC-209025	13,98
AC-209003	11,91
BEH13A	10,06
EVW21	8,62
AC-209036	7,76
AC-209007	7,66
BEH10A	1,71

Valores promedio de 3 repeticiones.

Table 12. Average storage root starch contents of collected yam bean accessions

Accesiones	Almidón (g/100g de muestra)
CC004	15,67
TC-209058	10,98
AC-209025	10,49
BEH05B-2	9,10*
AC-209006	8,68
AC-209007	7,84
CC003	7,80
AC-209003	7,36
EVW21	7,34
AC-209036	7,05
EC-209005	6,97
BEH14	6,82
BEH13B	4,79
CNP008	3,95
CHI002	3,85
EVW20	3,79
BEH10A	3,69
BEH01	3,46
BEH13A	3,41
BEH05B-1	3,02
LM001	2,71
PLM006	2,46
MO009	2,39
CNA005	1,89
BEH02	0,79
PLCH007	0,45
BEH05A	0,27

Valores promedio de 2 repeticiones.
*Dato correspondiente a una repetición por falta de materia prima

ANNEX C: PHOTOS OF COLLECTED YAM BEAN ACCESSIONS


BEH-05B


BEH-02


BEH-14


CNA-005


BEH-13B


PLM006


PLCH-007


AC-209006


MO-009


BEH-05A


EVW-20


EVW-21

APPENDIX 2

FINAL REPORT CIP TO INIA (PERÚ)

FINAL TECHNICAL
REPORT FOR PROJECT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: Technical cooperation Project: Re-collection, evaluation, and conservation of genetic resources of *Pachyrhizus spp.* (*P. tuberosus and P. ahipa*) in Peru

SUBMITTED TO: INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA DIRECCIÓN DE INVESTIGACIÓN AGRARIA SUBDIRECCIÓN DE RECURSOS GENÉTICOS Y BIOTECNOLOGÍA

SUBMITTED BY: THE INTERNATIONAL POTATO CENTER

A U G U S T 2 0 1 3

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: San Ramón, August 27, 2013

Re-collection, evaluation, and conservation of genetic resources of *Pachyrhizus spp.* (*P. tuberosus and P. ahipa*) in Peru (INIA)/Peru under AHIPA project

On behalf of CIP

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ABSTRACT

The report provides information about the activities to obtain collection permissions in the Peruvian Amazon area and three field collection trips to collect *Pachyrhizus spp*. (*P. tuberosus* and *P. ahipa*) in Peru. Thirty-seven accessions were collected (target was 30) and most of the material could be multiplied and incorporated into the genebank at the International Potato Center (CIP). Among the material incorporated are 10 *P. tuberosus* Chuin accessions, which are very rare in the yam bean gene pool. These accessions have high dry matter (DM) storage root content (26–33%), whereas all other yam beans have low DM storage root content (less than 24%). Chuin accessions are cooked or processed into flour, whereas other yam beans are consumed raw as a root fruit or in salads. So far, only 4 Chuin accessions were maintained in CIP's genebank. Owing to our collections, 14 Chuin accessions are now available for research in Peru—nowhere else is this Chuin material available. Moreover, CIP obtained dissemination permission for the original 4 Chuin accessions and derivatives (cross populations), which are restricted to research purposes. This allows us to incorporate high DM genes/alleles into the remaining yam bean gene pool and to disseminate *P. erosus* x *P. tuberosus* Chuin and *P. erosus* x *P. tuberosus* Chuin cross populations, which were recently generated as part of this project at CIP.

The annex contains photos documenting several important activities of the project.

1. GENERAL INFORMATION

1.1 PROJECT NAME

"Re-Collection, evaluation, and conservation of genetic resources of *Pachyrhizus spp*. *(P. tuberosus* and *P. ahipa*) in Peru"

1.2 LOCATION

District: San Ramón

Province: Chanchamayo

Department: Junín

1.3 DURATION: 2010–2013

2. PROJECT INFORMATION

2.1 PROJECT DESCRIPTION

Yam bean cultivation is very old in Peru, going back to the Pre-Colombian cultures Nazca and Mochica. There are five species of *Pachyrhizus* (*P. erosus, P. ferrugines, P. panamensis, P. tuberosus,* and *P. ahipa*). Three are grown: *P. tuberosus, P. erosus,* and *P. ahipa* (Sorensen 1996). *Pachyrhizus* spp. are species with high nutritional value, rich in protein (18% dry matter [DM]), and with high micronutrient content (130 ppm of iron). It is a marginal crop sown in association with other crops.

P. ahipa is limited to the highland valleys of Bolivia and probably Peru, where the species is endangered. *P. ahipa* should be in the Andes of Peru between 1,800 and 2,600 masl. According to Brack (2003) *P. ahipa* is native to the Peruvian Andes, where it was domesticated, and has been present in Ayacucho since 8000 B.C. *P. tuberosus* is distributed in tropical regions of Southwestern America. The greatest diversity is located in Peru and Ecuador, where there are 11 farmer varieties classified into four groups: jíquima (Ecuador), ashipa (Amazonia), Chuin (endemic in Peru), and Yushpe (Peru). Chuin and Yushpe are sown along riverbanks and are in danger of extinction. Therefore, it is necessary and urgent to protect the genetic resources of *Pachyrhizus* spp. collecting in Peru.

2.2 PROJECT GOALS

- Collect at least 60 accessions of the species mentioned
- Broaden the gene pool and record passport data in order to contribute to the conservation of genetic resources in danger of extinction
- Make collection trips to different areas of Peru during 2010–2013.

3. PARTICIPATION IN MEETINGS WITH CENTRAL ASKANINKA DEL RIO TAMBO (CART) AND ASOCIAIÓN INTERÉTNICA DE DESARROLLO DE LA SELVA PERUANA (AIDESEP)–UCAYALI (2010)

The technical cooperation agreement between CIP and the Instituto Nacional de Innovación Agraria (INIA) was signed on 19 October 2010. Attached with it was a request for access to yam bean genetic resources, which had been approved by INIA. Therefore CIP took the initiative to establish communication and coordination with the various Federations of AIDESEP and participated at the following meetings:

- XXIV ordinary Congress of CART, held on 18–20 August 2010.
- Coordination meeting with the regional organization AIDESEP–Pucallpa, held on 11 November 2010.
- Presentation of technical cooperation agreement between CIP and INIA to Organización Regional AIDESEP Ucayali (ORAU), held on11 November 2010.

During the meetings with CART, it was suggested that before starting collection activities, an agreement should be signed with the organization leaders. AIDESEP–Ucayali gave its approval to enter into their native communities to make the first collection of ahipa.

4. ACTIVITIES TO GAIN ACCESS TO YAM BEAN GENETIC RESOURCES, TRADITIONAL KNOWLEDGE, AND SIGNATURE OF AGREEMENT FOR A TRAINING POSITION BEFORE THE SECOND COLLECTION TRAVEL

Coordination with the AIDESEP members was continuous, and the following activities took place:

- On 31 January 2011, a trainee related to CART was hired, through the signature of an agreement of training with the Instituto Superior Tecnológico Públic Ashaninka–CC. NN. Puerto Ocopa–Rio Tambo Satipo, the Ministry of Labor, and Mr. Jacob Américo Campos Motiquiri, for three months. The training was to be conducted at the Estación Experimental Agraria La Molina, Lima, in order to instruct on the use and importance of yam bean as part of human diets and because of an ancient tradition of conservation.
- From 27 April 2011 to mid-2012, CIP pursued the signing of the agreement with AIDESEP and INIA to get access to the traditional knowledge about growing yam bean. The agreement was signed between CIP and AIDESEP; we are still waiting for approval and signature by INIA. The aim of this agreement is to document access to traditional or collective knowledge linked to two species of *Pachyrhizus* spp. (*P. tuberosus* and *P. ahipa*).
- During the period 2010–2012, a request for access to genetic resources of cultivars of ahipa was made to INIA. On 7 June 2012, by an official document numbered 0428-2012-INIA-SUDIRGEB-DIA/J and addressed to Dr. Pamela K. Anderson, CIP's director general, the General Directorate of INIA, represented by its director, Eng. Arturo Florez Martinez, authorized the exceptional access permit to genetic resources of ahipa. This document states that in accordance with the law and the procedure specified in the Decision No. 391 of the Andean Community of Nations, which decision establishes the common regime for access to genetic resources, and the regulation enacted by the Supreme Decree No 003-2009-MINAM, "this Directorate authorizes the access to Genetic Resources of *Pachyrhizus spp.* for the purpose of scientific research, within the framework of the project of "Re-collection, evaluation, and conservation of the genetic resources of *Pachyrhizus* spp. (*P. tuberosus* and *P. ahipa*) in Peru."

5. YAM BEAN SEED FAIR

A yam bean seed fair was carried out at CIP-San Ramón facilities on 27 June 2013. It aimed to distribute seed of different yam bean accessions (*Pachyrhizus* spp.) to native communities of the Peruvian Amazon region. It was attended by the following federations:

- Federación de las Comunidades Nacionalidades Yaneshas (FECONAYA)
- Unión de las Nacionalidades Ashaninkas- Yaneshas (UNAY)

- Central Ashaninka del Rio Tambo (CART)
- Federación de Comunidades Nativas de puerto Inca y Afluentes (FECONAPIA).

CIP gave incentives to conservationists and donors of seed and to other participants of the seed fair. It was possible to distribute 22 yam bean accessions (*P. tuberosus* and *P. erosus*) with a total of 9,580 seeds to 19 farmers of native communities of the Peruvian Amazon region.

6. YAM BEAN COLLECTIONS IN THE PERUVIAN AMAZON REGION

6.1 FIRST COLLECTION TRIP

AIDESEP Pucallpa and other institutions that participated in the meetings on 11 November 2010, agreed that the first expedition would be on the Pucallpa–Atalaya route from 19 to 30 November 2010. The members of the expedition were from INIA–Pucallpa staff (Ing. Héctor Campos) and CIP staff (Dr. Bettina Heider and Ing. Elisa Romero), plus an ORAU guide.

The ORAU president (Mr. Joshua Faquin Fernández) was informed of the date of the trip, as was the communication area of ORAU (Mr. Dari Sanchez Macedo) in order to communicate by radio about our presence to the different communities, villages, and other places on the route of Atalaya and Pucallpa. Written communications were dispatched to the commander of the Air Force of the Fourth Naval Zone (Mr. Francisco Calixto Jampetri) and to the governor (Luis Carlos Augusto Buitano del Aguila).

With Mr. Joshua Faquin Fernández's authorization allowing us into ORAU's native communities, we started the journey on the route of the Pachitea River basin, between Pucallpa and Atalaya, in the Department of Ucayali, and visited 15 native communities. Of these, 10 belonged to the ethnic group Shipibo, 4 to the ethnic group Ashaninka, and 1 to the ethnic group Yine (Piro). For each single collection, CIP and INIA received a copy.

As a result of the first collection trip, we obtained until August 2013, 12 accessions (BEH1, BEH2, BEH5A, BEH5B, BEH6, BEH7, BEH8, BEH10A, BEH10B, BEH13A, BEH13B, and BEH14) that survived and were multiplied in two campaigns during 2011–2012 and 2012–2013.

Accessions BEH3, BEH4, and BEH12 died from nematodes, and accessions BEH6 and BEH9 were moth-eaten and the seeds failed to germinate. Furthermore, accession BEH11 did not survive because, when it was received, the seedling was small and weak.

After the first harvest on 15 February 2012, a CIP code was assigned to each of the 12 accessions and were put into the CIP genebank with a total of 9,650 virus-free seeds. A total of 140 seeds of 7 accessions (BEH5B, BEH6, BEH7, BEH8, BEH10A, BEH10B, and BEH13B) were given to INIA-Pucallpa so they could restore its collection of the first collection that was attacked by nematodes.

A second multiplication campaign was harvested on 1 February 2013. A total of 17,218 seeds of 12 accessions were obtained. Some 5,740 seedlings of the 12 accessions were donated to the native communities of the Federations CART, UNAY, and FECONAYA on 27 June 2013.

Data from the first collection trip are shown in Tables 1–4.

Table 1 Accessions collected in expedition 1 on the Pucallpa–Atalaya route and evaluation of the number of survived plants in the facilities of CIP San Ramón and INIA Pucallpa, during 2010–2011

	General Information							CIP San Ramón		INIA -Pucallpa 2010		
Collection code	Location	Species	Common name	Collaborator name	Latitude	Longitude	Altitude	Type of sample	# roots/sowed seed	Collected root	Collected seed	Observations
BEH1	CCNN Nuevo Paraíso	*P. tuberosus*	Chuin	Inés Maynas Inuma	08º 37' 37.1"	74º 24' 23.7"	160	Seed	1		1G 2R	CIP – INIA
BEH2	CCNN Ahuaypa	*P. tuberosus*	Chuin morado	Sonia Soto	09º 04' 28.1	74º 28' 06.6"	163	Root	2	1		CIP – INIA
BEH3	CC NN Ahuaypa	*P. tuberosus*	Chuin morado	Angel Maynas Pezo	09º 04' 28.1	74º 28' 06.6"	163	Root	Died	X		CIP
BEH4	CCNN Puerto Belen	*P. tuberosus*	Chuin morado	Adela Chávez Muñoz	09º 14' 11.6"	74º 20' 27.1"	166	Root	Died	1		CIP – INIA
BEH5	CCNN Puerto Belen	*P. tuberosus*	Chuin morado	Salomena Teco Shuña	09º 14' 11.6"	74º 20' 27.1"	166	Seed	16	1	2Vr	CIP – INIA
BEH5	CCNN Puerto Belen	*P. tuberosus*	Chuin morado		09º 27' 49.6"	74º 23' 37.8"	162	Root	1			CIP
BEH6	CCNN Amaquiria	*P. tuberosus*	Chuin morado	Nilda Bautista Ruiz	09º 27' 49.8"	74º 22' 37.8"	162	Seed		1	1Vr	CIP – INIA
BEH6	CCNN Amaquiria	*P. tuberosus*	Chuin morado		09º 27' 49.6"	74º 23' 37.8"	162	Root	1			CIP
BEH7	CCNN Colonia de Caco	*P. tuberosus*	Chuin morado		09º 21' 18.4"	74º 18' 18.2"	161	Seed	6			CIP
BEH7	CCNN Colonia de Caco	*P. tuberosus*	Chuin morado		09º 21' 18.4"	74º 18' 18.2"	161	Root	1			CIP
BEH8	CCNN Colonia de Caco	*P. tuberosus*	Chuin Blanco	Arcelia Muñoz Rengifo	09º 21' 18.4"	74º 18' 18.2"	161	Root	1	X	3R 1Vm	CIP – INIA (Seed)
BEH8	CCNN Colonia de Caco	*P. tuberosus*			09º 21' 18.4"	74º 18' 18.2"	161	Seed	1			CIP
BEH9	CCNN Colonia de Caco	*P. tuberosus*	Chuin morado	Rosa López Muñoz	09º 21' 18.4"	74º 18' 18.2"	161	Seed			5R 3B	CIP – INIA
BEH10A	CCNN Shahuaya	*P. tuberosus*	Chuin morado	Hugo Franco Vásquez	09º 50' 51.3"	74º 06' 12.9"	159	Root	1	1		CIP – INIA
BEH10B	CCNN Shahuaya	*P. tuberosus*	Chuin morado	Esther Muñoz Tuesta	09º 50' 51.3"	74º 06' 12.9"	159	Seed	1		3G 1B	CIP – INIA
BEH11	CC NN Fernando Sthall	*P. tuberosus*	Yushpe	Erminio Bautista Rojas	09º 53' 20.6"	74º 11' 27.5	185		Died	X		CIP
BEH12	CCNN Chumichinia	*P. tuberosus*	Ashipa	Dimas Gómez Gómez	10º 08' 31.5"	74º 03' 13.6"	184	Raíz	Died	1		CIP – INIA
BEH13	CCNN Toniromashi	*P. tuberosus*	Ashipa amarilla	Lidia Gonzáles Pérez	10º 17' 43.4"	73º 59' 13.1"	180	Seed	9		11G 5B	CIP – INIA
BEH14	CCNN Boca Cocani	*P. tuberosus*	Ashipa	Marcela Orita Avenchari	10º 32' 12.2"	73º 59' 37.1	213	Seed	12		11G 2B	CIP – INIA

G = Good, R = Regular, B = Bad, Vr = Vain regular, Vm = Vain bad, X = Muestra en San Ramón.

* The accessions highlighted with red.

Table 2 The 12 survivor accessions of the first collection on the route Pucallpa–Atalaya, November 2010, Ucayali region, Peru

CIP Number	Common Name	Collection code	Altitude	Locality	District	Province	Latitude	Longitude
209062	Chuin	BEH1	160	Nuevo Paraiso	Masisea	Coronel Portillo	08°37’37.1’’	74°24’23.7’’
209063	Chuin morado	BEH2	163	Ahuaypa	Iparia	Coronel Portillo	09°04’28.1’’	74°28’06.6’’
209064	Chuin morado	BEH5A	166	Puerto Belen	Iparia	Coronel Portillo	09°14’11.6’’	74°20’27.1’’
209065	Chuin morado	BEH5B	162	Puerto Belen	Iparia	Coronel Portillo	09°27’49.6’’	74°23’37.8’’
209066	Chuin morado	BEH6	162	Amaquiria	Iparia	Coronel Portillo	09°27’49.6’’	74°23’37.8’’
209067	Chuin morado	BEH7	161	Colonia de Caco	Iparia	Coronel Portillo	09°21’18.4’’	74°18’18.2’’
209068	Chuin blanco	BEH8	161	Colonia de Caco	Iparia	Coronel Portillo	09°21’18.4’’	74°18’18.2’’
209069	Chuin morado	BEH10A	159	Shahuaya	Tahuania	Atalaya	09°50’51.3’’	74°06’12.9’’
209070	Chuin morado	BEH10B	159	Shahuaya	Tahuania	Atalaya	09°50’51.3’’	74°06’12.9’’
209071	Ashipa amarilla	BEH13A	180	Toniromashi	Tahuania	Atalaya	10°17’43.4’’	73°59’13.1’’
209094	Ashipa amarilla	BEH13B	180	Toniromashi	Tahuania	Atalaya	10°17’43.4’’	73°59’13.1’’
209072	Ashipa	BEH14	213	Boca Cocani	Raymondi	Atalaya	10°32’12.2’’	73°59’37.1’’

Table 3 Seeds stock of the 12 survivor accessions of the first collection on the route Pucallpa–Atalaya and number of seeds delivered to CIP’s genebank in Lima, during the 2011–2012 campaign

CIP Number	Common Name	Collection Code	Altitude	Locality	No. of Harvested Plants	No. of Seeds, Feb. 2012	No. of Seeds Delivered to CIP Genebank	Remained Seed
209062	Chuin	BEH1	160	Nuevo Paraiso	1	464	150	314
209063	Chuin morado	BEH2	163	Ahuaypa	2	109	50	59
209064	Chuin morado	BEH5A	166	Puerto Belen	5	1788	1200	588
209065	Chuin morado	BEH5B	162	Puerto Belen	5	2443	1100	1343
209066	Chuin morado	BEH6	162	Amaquiria	1	280	150	130
209067	Chuin morado	BEH7	161	Colonia de Caco	6	1511	800	711
209068	Chuin blanco	BEH8	161	Colonia de Caco	1	840	500	340
209069	Chuin morado	BEH10A	159	Shahuaya	1	323	100	223
209070	Chuin morado	BEH10B	159	Shahuaya	1	381	150	231
209071	Ashipa amarilla	BEH13A	180	Toniromashi	9	2192	1400	792
209094	Ashipa amarilla	BEH13B	180	Toniromashi	1	250	50	200
209072	Ashipa	BEH14	213	Boca Cocani	13	4899	4000	899
				TOTAL		**15480**	**9650**	**5830**

The genetic material of the two campaigns was installed in the greenhouses of San Ramon experimental station, located 835 masl. During 2011 and 2012, seed was multiplied, the allocation of CIP numbers was requested, and 9,650 seeds were delivered to CIP’s genebank on 20 February 2012, for conservation and further distribution.

Table 4 Seeds stock of the 12 survivor accessions of the first collection on the route Pucallpa–Atalaya and number of seeds donated to the native communities of the federations of CART, UNAY, and FECONAYA, from the 2012–2013 campaign

CIP Number	Common Name	Collection Code	Altitude	Locality	Remained Seed, Jan. 2013 (virus free)	No. of Seeds, Donated to Native Communities	Harvested on Aug. 2013 (virus free)	Remained Seed, Aug. 2013 (virus free)
209062	Chuin	BEH1	160	Nuevo Paraiso	1285	500	1858	2643
209063	Chuin morado	BEH2	163	Ahuaypa	511	200	4609	4920
209064	Chuin morado	BEH5A	166	Puerto Belen	1001	600	1774	2175
209065	Chuin morado	BEH5B	162	Puerto Belen	3169	1000	974	3143
209066	Chuin morado	BEH6	162	Amaquiria	107	40	4293	4360
209067	Chuin morado	BEH7	161	Colonia de Caco	1856	1000	3932	4788
209068	Chuin blanco	BEH8	161	Colonia de Caco	470	200	2097	2367
209069	Chuin morado	BEH10A	159	Shahuaya	600	300	1839	2139
209070	Chuin morado	BEH10B	159	Shahuaya	205	100	3563	3668
209071	Ashipa amarilla	BEH13A	180	Toniromashi	1842	600	1435	2677
209094	Ashipa amarilla	BEH13B	180	Toniromashi	2992	600	1204	3596
209072	Ashipa	BEH14	213	Boca Cocani	3180	600	790	3370
				TOTAL	17218	5740	28368	39846

All the genetic material remained so far are free of the yam bean mosaic virus. The number of seeda obtained with the two multiplication campaigns amounts to 39,846 for the 12 accessions. All this material will be delivered to the CIP genebank for storage and distribution.

6.2 SECOND COLLECTION TRIP

Once access to the yam bean genetic resource was obtained, and the agreement about informed consent and the conditions to access to the collective knowledge of *Pachyrhizus* spp. (*P. tuberosus* and *P. ahipa*) was signed, a second trip was scheduled to collect yam bean.

In coordination and with the approval of UNAY and FECONAYA, located in the Department of Pasco, between the districts of Oxapampa and Ciudad Constitución, represented by its leaders Mr. Arnaldo Cruz Sebastian and Mr. Héctor Colina Soto, the second trip was scheduled from 6 to 8 August 2012. It was led by Ing. Elisa Romero and Vilma Aliaga (CIP), Ing. Wilfredo Guillen (INIA), and Mr. Arnaldo Cruz Sebastian (president of UNAY) as a translator and guide. Seven accessions of yam bean were collected, each with passport data and collective knowledge. Seeds were multiplication at CIP–San Ramon (see Table 5 and Table 6, for seed stock).

Table 5 Passport data for second yam bean collection conducted on 7–11 August 2012, on the Oxapampa–Ciudad Constitución route, Department of Pasco

Conservationist	Collection Code	Common Name	Ethnic Group	Locality	Collection Date (2012)	District	masl	Latitude	Longitude	No. of Samples (seeds/root)
Francisco Espíritu Antazú	BEH15	Ashipa	Yanesha	Tsachopen	08/07	Chontabamba	1,805	10°32'38.5''	75°26'17.2''	2 vines
Luis Ortiz Ballesteros y Eduardo Ortiz Espiritu	BEH16	Ashipa o meché	Yanesha	Tsachopen	07/08	Chontabamba	109	10°32'31.7''	75°26'26.7''	5 vines
Alejandrina Pérez Incarina y Isaías Evel Lázaro	BEH17	Ahipa	Ashaninkas	Yarina	08/08	Puerto Bermúdez	250	09°53'42.7''	75°00'8.4''	16 vines
Alejandrina Pérez Incarina y Isaías Evel Lázaro	BEH18	Ahipa	Ashaninkas	Yarina	08/08	Puerto Bermúdez	250	09°53'42.7''	75°00'28.4''	1 vine
Moisés Blanco Alvarado y Elmira Pérez Camante	BEH19	Ashipa	Ashaninkas	Mosquito Playa	08/09	Constitución	286	09°57'31.0''	74°59'50.2''	5 vines from 1 plant
Augusto Edgardo Valerio Araujo y Lino Salvador Bautista Bautista	BEH20	Ashipa	Yaneshas	Hanswald, sector nuevo progreso	08/11	Palcazú	248	09°52'18.1''	75°04'40.3''	45 vines aprox.
Sorayda Ampichi Lino	BEH21	Ashipa	Yanesha	Nuevo Porvenir	08/11	Constitución	238	09°55'36.0''	75°02'35.5''	7 vines

Table 6 Stock for the first harvest of seed on the second yam bean collection conducted on 7–11 August 2012, on the Oxapampa-Ciudad Constitución route, Department of Pasco, and multiplication carried on at CIP–San Ramón, from the 2012–2013 campaign

Conservationist	Collection Code	Common Name	Ethnic Group	Locality	District	masl	No. of Samples (seeds/root)	No. of Seeds, Aug/ 2012	No. of Seeds, Donated to Native Communities, June 2013	Harvested (virus free)
Francisco Espíritu Antazú	BEH15	Ashipa	Yanesha	Tsachopen	Chontabamba	1,805	2 vines	2,409	400	334
Luis Ortiz Ballesteros y Eduardo Ortiz Espiritu	BEH16	Ashipa o meché	Yanesha	Tsachopen	Chontabamba	109	5 vines			898
Alejandrina Pérez Incarina y Isaías Evel Lázaro	BEH17	Ahipa	Ashaninkas	Yarina	Puerto Bermúdez	250	16 vines	42		3206
Alejandrina Pérez Incarina y Isaías Evel Lázaro	BEH18	Ahipa	Ashaninkas	Yarina	Puerto Bermúdez	250	1 vine			1647
Moisés Blanco Alvarado y Elmira Pérez Camante	BEH19	Ashipa	Ashaninkas	Mosquito Playa	Constitución	286	5 vines from 1 plant			1106
Augusto Edgardo Valerio Araujo y Lino Salvador Bautista Bautista	BEH20	Ashipa	Yaneshas	Hanswald, sector nuevo progreso	Palcazú	248	~45 vines	442		452
Sorayda Ampichi Lino	BEH21	Ashipa	Yanesha	Nuevo Porvenir	Constitución	238	7 vines	16		434

On 6 August, the first harvest of the accession of the second collection has been made, and there are still immature vines that are beginning to mature. With accession BEH15, 400 seeds were distributed to the native communities in the fair seed of 27 June 2013.

6.3 THIRD COLLECTION TRIP

The third collection was coordinated with CART and authorized by its head, Mr. Hector Sebastian Naomi, on 3 August 2012.

Because of a change in leadership of CART, and adverse weather conditions, we (CIP, INIA, and CART) decided to postpone the trip and make it from 9 to 14 June 2013. Members on this trip were Mr. Carlos Flores Marquez (CIP), Mr. Wilfredo Guillen Huachua (INIA-Pucallpa), Ms. Magaly Sebastian Pitsasati (CART), and Mr. Arnaldo Cruz Sebastian (UNAY).

According to plan, on 10 June the members of the third collection trip met at the experimental station of CIP-San Ramon and began the journey to Satipo by land to Puerto Chata, Rio Tambo jurisdiction on the province of Satipo, Department of Junin. The group then traveled by boat to the native communities of Rio Tambo.

We had the support of CART and UNAY for collection in the communities of Rio Tambo. Nine native communities were visited; three of these, Vista Alegre, Mayapu, and Cushireni, no longer grow yam bean, so no plants could be found there.

Yam bean was collected in five native communities: Betania, Cheni, Anapate, Oviri, and Mazaroveni. The samples were mostly vines that were just starting their physiological maturity but had moths.

Of the 10 collected accessions (BEH22, BEH23, BEH24, BEH25, BEH26, BEH27, BEH28, BEH29, BEH30, and BEH31), 9 germinated. Only accession BEH25 died, because the seeds were heavily moth-damaged (data given in Table 7).

Table 7 Accessions collected on the third trip on the CART route, Río Tambo district, Satipo province in Junin Department, and evaluation of the number of survived plants up to June 2013

Conservationist	Collection Code	Ethnic Group	Locality	Collection Date (2013)	masl	Latitude	Longitude	No. of Samples	Collected or Donated Material	No. of Healthy Seeds	No. of Moth-eaten Seeds	No. of Live Seedlings	Grain color	Seed Color (table)
Delina Cárdenas Shirapa	BEH22	Ashaninkas	Betania	11/06	261	11°2’24.7’’	73°45’26.4’’	1	6 vines	24		4	Red wine	Red-purple 59A
María Levi Torres	BEH23	Ashaninkas	Cheni	12/06	295	11°17’59.4’’	73°44’22.6’’	1	10 vines	43		3	Black	Black 203C
Benigno Sebastian Cristo	BEH24	Ashaninkas	Cheni	12/06	305	11°17’24.3’’	73°43’42.2’’	1	7 vines	3	15	4	Red	Red-purple 59A
Benigno Sebastian Cristo	BEH25	Ashaninkas	Cheni	12/06	305	11°17’24.3’’	73°43’42.2’’	1	3 vines		6	0	Dark red	Red-purple 59A
Sarcinto Fernández Vásquez and Emy Vásquez Onija	BEH26	Ashaninkas	Anapate	12/06	289	11°16’25.0’’	73°47’6.6’’	1	8 vines	32		5	Black	Black 203C
Rojelio Matías Quentiovia and Karina Angulo la Torre	BEH27	Ashaninkas	Oviri	13/06	300	11°15’09.0’’	73°49’54.0’’	1	13 vines	48	4	3	Red	Red-purple 57B
Eliseo Torres Shiampa	BEH28	Ashaninkas	Oviri	13/06	372	11°16’37.9’’	73°50’06.5’’	1	10 vines	36	12	5	Red	Red-purple 57B
Alejandro Torres Shiampa	BEH29	Ashaninkas	Oviri	13/06	333	11°15’50.8’’	73°50’43.9’’	1	4 vines	9	13	4	Red	Red-purple 57A
Isac Manuel Roberto	BEH30	Ashaninkas	Mazaroveni	14/06	334	11°11’31.0’’	74°03’02.5’’	1	12 vines	39	27	2	Red	Gleyed-red 181A
China Shipiyo Quishohuancho	BEH31	Ashaninkas	Mazaroveni	14/06/	323	11°09’52.2’’	74°05’45.7’’	1	10 vines	22	7	3	Red	Gleyed-purple N187E

7. RESULTS

- CIP solicited access to the genetic resources of yam bean to INIA from 2010 to 2012, getting the authorization for research purposes on 7 June 2012.
- CIP has given INIA the three agreed payments for a total of 180,100 Nuevos Soles.
- Two reports have been submitted to INIA–Lima, on 6 July 2011 and on 2 June 2012.
- The yam bean manual is being revised.
- During the three collection trips conducted from November 2010 to August 2013, on the routes Pucallpa–Atalaya, Oxapampa–Ciudad Constitution, and Rio Tambo, 31 accessions of *Pachyrhizus* spp. were collected, each with passport data. Twenty-eight of these 31 survived and were multiplied at CIP–San Ramón experimental station.
- During 2011 and 2012, the seeds of the 12 surviving accessions from the first collection were multiplied and entered into CIP's genebank on 20 February 2012, free of viruses, for preservation and distribution. Also, seeds of 7 of these accessions were given to INIA-Pucallpa so they can restore their material for the first collection. This same material had a second multiplication campaign in order to have more seed to return to the native communities.
- During the second collection trip on the route Oxapampa–Ciudad Constitución, between 6 and 11 August 2012, 7 accessions were collected. This genetic material was multiplied from August 2012 to August 2013. Very recently the first crop was harvested, and there are still some immature vines on the greenhouse to harvest later on.
- During the third collection trip (10–15 June 2013), in the communities of Rio Tambo, 10 accessions were collected. To date, 1 accession has died because it was fully moth-eaten; the other 9 have germinated. The harvest of this material is planned for August 2014.
- Finally, on 27 June 2013, the yam bean seed fair was conducted at the CIP–San Ramon experimental station. The CIP yam bean project gave an incentive to conservationists and donors of seed and to other participants and distributed 22 accessions (*P. tuberosus* and *erosus* spp.), with a total of 9,580 seeds to farmers in 19 native communities within the collecting areas. This was done in order to return the donated genetic material to encourage its dispersion, and prevent the loss of this ancient crop of the Peruvian Amazon.

8. CONCLUSIONS

According to the objectives set out in the Technical Cooperation Agreement between INIA and CIP, the collecting goal was achieved. We got 30 accessions on the three collection trips.

CIP and INIA intend to use the yam bean collections of the Peruvian Amazon to increase the genetic pool and avoid their extinction. In addition, we hope to get small farmers involved with this crop so that they can incorporate it into their diets.

9. RECOMMENDATIONS

We recommend that all the information obtained so far be published, and that the seeds continue to be conserved and distributed to farmers and researchers.

10. REFERENCES

Sorensen, M. 1996. Yam vean (*Pachyrhizus DC*). Promoting the conservation and use of underutilized and negletected crops. Institute of Plants Genetics and Crop Plant Research, Gatersleben and Internacional Plant Genetic Resources Institute, Rome.

Documento sobre el convenio de Cooperación Técnica entre el Instituto Nacional de Innovación Agraria y el Centro Internacional de la Papa.

ANNEX

Figure 1. XXIV Ordinary meeting of the Central Ashaninka del Río Tambo (CART), held on 18–20 August 2010.

Figure 2. Multiplication of the 12 yam bean accessions collected during the first trip of collection on the Pucallpa–Atalaya route during the 2011–2012 campaign in San Ramon.

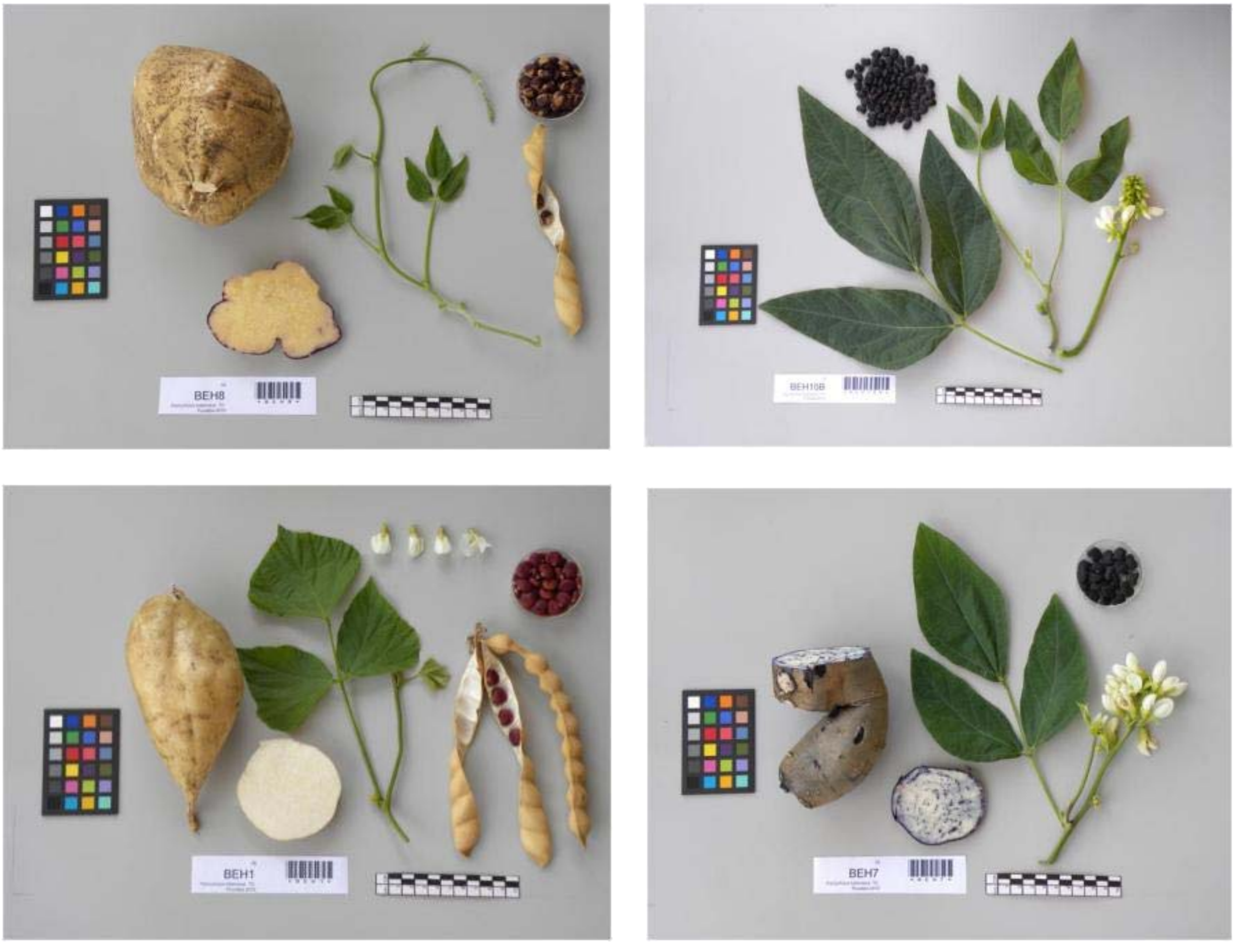

Figure 3. Accessions BEH1, BEH7, BEH8, and BEH10B of the first collection of Ahipa on the Pucallpa–Atalaya route, 2010–2011.

Second collection trip on the native communities of FECONAYA and UNAY (7–11 August 2012)

Figure 4. Eng. Elisa Romero from CIP, people from INIA, and Mr. Francisco Spirit Antazú and wife from UNAY discuss the yam bean project, access to genetic resources, and traditional knowledge about ahipa growing (*left*), and collection of yam bean on the farm of Mr. Luis Ortiz Ballesteros and Eduardo Ortiz Espíritu, members of the native community of Tsachopen-Oxapampa, Pasco, Peru, 2012 (*right*).

Figure 5. Yam bean collection in the native community of Yarina on the farm of Mrs. Alejandrina Pérez Incarina and Isaías Evel Lázaro (*right*) and in the native community of Hanswald on the farm of Mr. Augusto Edgardo Valerio Araujo and Lino Salvador Bautista Bautista (*left*) in August 2012. Both communities are in the Ciudad Constitución district, Oxapampa province.

Figure 6. Plants and vines of the accessions of the second collection of yam bean under conditions of San Ramon, collected on the route Oxapampa–Ciudad Constitución and multiplied during 2013.

Figure 7. Third collection trip in June 2013 in the native community of Cheni, on the plot of Mrs. María Levi Torres.

Figure 8. Presentation of roots, seeds, and products based on yam bean from Dr. Bettina Heider, Eng. Elisa Romero, C. Flores, and L. Ulloa, at the seed fair, 27 June 2013.

Figure 9. Visit to the yam bean greenhouse of Mr. Luis Ortiz Ballesteros and Eduardo Ortiz Espírit in the native community of Tsachopen during the seed fair in San Ramon, June 2013.

Figure 10. Seed packs for yam bean conservationists of the federations of UNAY, FECONAYA, FECONAPIA, and CART, during the seed fair.

Figure 11. Yam bean conservationist diplomas conferred by CIP on the seed fair held at CIP–San Ramon, on 27 June 2013.

Figure 12. Participants at the yam bean seed fair (FECONAYA, UNAY, FECONAPIA, and CART).

APPENDIX 3

FINAL REPORT RAB (RWANDA)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: RAB–Rwanda: Identify adapted high-yielding yam beans for Central Africa and Develop yam bean storage root products for Rwanda/Central Africa

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: RWANDA AGRICULTURE BOARD, RWANDA

M A R C H 2 0 1 5

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: March 28, 2015

On behalf of RAB

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CONTENTS

ABSTRACT

Root and tubers (R&T) have potential to contribute to solve food insecurity in sub-Saharan Africa, especially Rwanda. Consumption rates of R&T are very high in Rwanda: the per capita consumption rate of sweetpotato is estimated to be 300 kg/year. R&T crops are key staples for both rural and urban populations in Rwanda to support almost nine million people living in densely populated areas. A major target of the Rwanda Agriculture Board (RAB) is sustaining agriculture with a diverse range of cultivated species. Therefore, RAB is bringing in new promising crops to evaluate these for adaptability and quality attributes such as yam bean (*Pachyrhizus* spp.). The overall goal is to minimize malnutrition and enhance the health status of people in Rwandan communities. Rwanda farming conditions are characterized by bimodal tropic rainfall and intensively cultivated fields. Three yam bean species (*P. ahipa*, *P. erosus*, and *P. tuberosus*) and their hybrids were introduced into Rwanda.

This final report contains the recap of major activities for the main objectives of the project in Rwanda and Central Africa, respectively, which aimed at objective 2: Identify adapted high yielding yam beans for Central Africa and objective 3: Develop yam bean storage root products for Central Africa (for RAB these objective were merged: evaluating yam bean for improving food quality and availability and sustainability of farming systems in Rwanda). The specific objectives of the project in Rwanda were to: (1) introduce, maintain, and identify adapted, high-yielding yam bean genotypes for Rwanda; (2) test fresh yam bean roots and develop yam bean storage root products for Rwanda; (3) evaluate new segregating populations of yam beans obtained from parents with early maturing but with low dry matter (DM) storage root content and late maturing but with high DM storage root content; (4) provide proof of concept that selected yam bean accessions are adapted to growing conditions and consumer taste preferences in Rwanda, and can be used in local or introduced storage root processing procedures; and (5) determine food quality of F2 segregating population in collaboration with CIP platforms in Uganda or Peru for further food quality determination, under PhD training at Makerere University, Uganda.

Adaptability trials with farmers’ participation showed that Rwanda is suitable for yam bean production. The best performing genotypes which were identified as promising for adoption are accessions 209018, 209032, 209033, and 209035. We demonstrated that local storage root food products were flour, *ugali*, mixed flour for weaning food, and juice. Remarkable is that yam bean juice was obtained in the process of many other food preparations by pressing. This juice should not be wasted, and can even be a major product. In our study with taste panelists, most preferred yam bean juice over pineapple juice. Yam bean needs a much shorter crop duration, less land preparation, and planting efforts than pineapple does. Other attractive products to be prepared from yam bean storage roots are “ready-to-eat breakfast” foods such as porridge.

1. MAINTENANCE OF INTRODUCED ACCESSIONS AND BREEDING LINES

The maintenance of introduced accessions through in-situ and screenhouse multiplication was done both at Rubona (Figs. 1a and 1b) and Karama research stations, to rejuvenate, restore, and maintain all yam bean accessions with interesting characteristics/traits. Rubona is located in Huye, South Province district at 1,650 masl, 29°46’ longitude E; 2°29’ latitude; Karama at 1,457 masl at latitude 02°17.18 S, 030°15.49 E.

Figures 1a and b. Yam bean screenhouse and field multiplication at Rubona station

In total, 37 accessions with interspecific 27 hybrids (from the six parental lines) were maintained: 10 *P. ahipa* accessions, 11 *P. erosus,* and 2 *P. tuberous* accessions. Accessions 209032, 209031, and 209018 multiplied gave the highest seeds weight: 145 g, 750 g, and 600 g, respectively. Through regional collaboration, accession 209013, which has high dry matter (DM) content, was introduced and multiplied through ISABU/Burundi, where this high DM accession performs well.

1.1 ADAPTABILITY EVALUATION OF INTRODUCED YAM BEAN ACCESSIONS

In accordance with objective 2 of the project, high-yielding yam bean accessions were identified across locations. Accessions 209018 and 209019 were identified as high-yielding accessions for both low- and mid-agro-ecological zones of Rwanda (Table 1). Accessions 209029, 209032, 209033, 209034, and 209035 were high yielding and selected for low zones. The bush yam bean type (*P. ahipa*)—namely accessions 209034 and 209035—were selected by most farmers for intercropping due to early maturing characteristic. In term of taste, the *P. ahipa* yam beans (209033, 209034, and 209035) were more preferred than the climbing *P. erosus* yam bean, such as accession 209018.

Table 1 Means of storage root yields, storage root DM, and harvest index for nine yam bean varieties evaluated in Rwanda during two seasons (2011B and 2012A) and two locations (Rubona and Karama) with treatment reproductive pruning to avoid seed production

Accessions	Storage Root Fresh in 2011B (t/ha) Rubona	Storage Root Fresh in 2012A (t/ha) Karama	Storage Root DM (%)	HI (%)
209003	5.41	13.50	20.84	69.72
209006	5.13	34.48	17.49	61.07
209018	73.19	111.33	17.97	53.13
209019	55.96	108.00	19.15	62.80
209032	12.37	27.55	17.55	62.50

209033	9.67	38.28	18.29	65.57
209034	3.74	26.42	16.45	66.52
209035	8.74	26.25	16.55	59.70
209029	9.63	30.25	19.58	57.49
Grand mean	10.43	51.34	16.73	62.05
L.S.D (5%)	12.98	17.25	0.25	3.71

Mean performance of fresh roots yield in t/ha showed that introduced yam bean accessions yielded high at Rubona and Karama – especially root yields of 209018 and 209019 (two *P. erosus* accessions) can be incredible high (Fig. 2). Note that results from the location Musanze (high altitude at the border of Uganda) were not included due to very low performance of the crop at this location. The highest storage roots yields were produced by genotype 209018 (111.3 t/ha) and genotype 209019 (108.0 t/ha); this corresponds to good sugar beet yields in temperate regions of the world. However, *P. ahipa* and *P. ahipa* x *P. tuberosus* hybrids also showed high yields and slightly elevated DM: 209033 and 209029 with 38.28 t/ha and 30.25 t/ha, respectively. Genotype 209003 had the highest DM, with 20.8%. (NB: This evaluation was conducted before high DM yam beans were introduced and evaluated in Rwanda, which required special permission form Peruvian authorities.) Variety 209032 appeared to have large adaptability across locations. Fresh root yield was poor in higher altitudes of Rwanda (>2,000 masl), which indicates that yam bean is not performing well at these altitudes, which are characterized by low temperature and lots of rain and low temperatures. This was confirmed by genotype by environment study in term of mega environments of yam bean adaptability in Rwanda (personal communication, Ndirigwe, 2014).

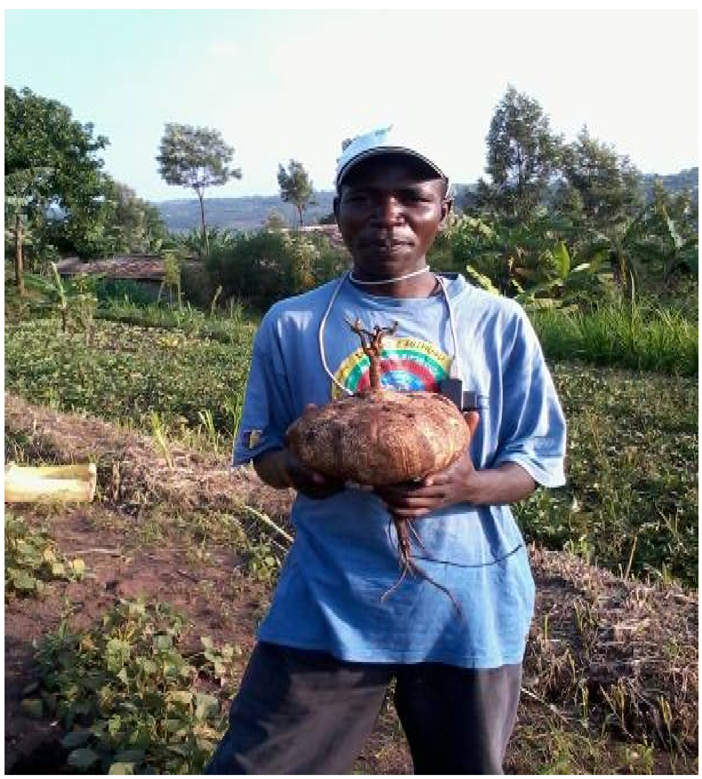

Figure 2. Farmer in Nyanza district (Southern Rwanda) with high yielding accession 209018.

1.2 TEST FRESH YAM BEAN FOR STORAGE ROOT PRODUCTS

Related to objective 3, fresh storage roots for the four high-yielding accessions (209032, 209033, 209035, and 209018) were tested for storage root food products (e.g., flour-making, ugali preparation, mixed flour for weaning food preparation, and juice). Selected famers from on-farm trials participated in taste-testing of each product. Only protein content was determined for the four promising accessions. More focus was put on making juice and weaning food as a way to help promote the adoption of yam bean, as more Rwandese like juice.

A protocol was developed for producing a clear and stable yam bean juice. Chemical analyses of processed juice were done to study its nutritional quality. A consumer preference assessment of juice was conducted by 30 panelists who scored the samples of juice based on sensory attributes (Figs. 3a and 3b). Pineapple juice was used as control. **The results showed that most of the panelists preferred yam bean juice (from low DM yam beans) to pineapple juice.**

Figures 3a and 3b. Panelists tasting yam bean juice at Rubona research station.

Protocols were developed for yam bean porridges, where three formulas were made. A consumer preference assessment of the porridges was done by 30 panelists. A mix of sorghum and maize was used. The results showed that consumers preferred the formula that contained high amounts of yam bean. Selected accessions of yam bean were promoted through various agri-shows and international exhibitions in Kigali and provinces (Figs. 4 and 5).

Figures 4 and 5. Yam bean flour of the two preferred accessions and promotion of yam bean through exhibition in Kigali.

Results for nine accessions in terms of protein content showed that there were no significant differences between locations for protein content in tubers of yam bean accessions. But among yam bean accessions there appears to be wide variation in terms of protein content (Fig. 6). In all locations, accession 209032 had the highest protein content (13.8%), whereas accession 209034 had the lowest protein content (8.1%). Since protein is associated with iron and zinc contents in yam bean (and many other crops), we assume that there is also variation among yam bean accessions for iron and zinc. Note that there were some challenges due to lack of appropriate food processing equipment and adequate skills for analysis of iron and zinc in yam beans.

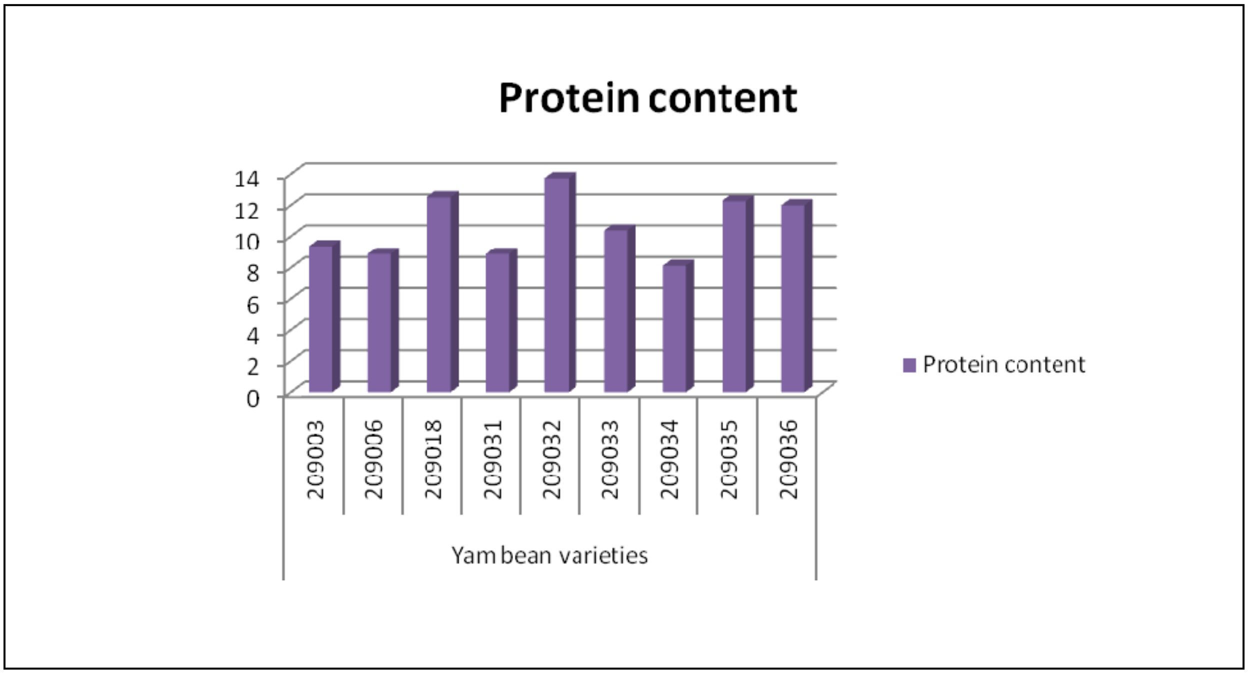

Figure 6. Percentage of protein content in storage roots of yam bean accessions.

1.3 TESTING SEGREGATING GENERATIONS IN F2 AND F3 LINES

Cross populations were obtained from CIP-Lima after Peruvian authorities approved dissemination of the high DM yam beans. (NB: High DM yam beans from Peru are protected by national rights, and so far such yam beans have not been found in other areas of the Amazon.) The PhD training program at Makerere University with these populations is still ongoing. All data trials have been recorded to determine the nature and magnitude of genetic variability in segregating populations—9 populations (9 crosses) and their F2 and F3 lines. Apart from variance component estimations and genetic gain estimations for the PhD study, the target is to select in these populations for genotypes with storage root yield, earliness, and high DM storage root content. F2 progenies and parental lines were raised at Rubona research station for the field for variance component analysis (Figs. 7 and 8). Write-ups of two papers are almost completed.

Figure 7. Determination of inheritance in storage fresh root yield and its components in Rwanda.

Figure 8. Supervisors from College of Agricultural and Environmental Sciences/University of Makerere visit fields in Rwanda.

2. CONCLUSION AND RECOMMENDATIONS

Adaptability trials with farmer's participation showed that Rwanda is suitable for yam bean production. The best performing genotypes that were identified as promising for adoption are accessions 209018, 209032, 209033, and 209035. Parent 209018 was also used as parents in three out of nine interspecific hybrid populations currently under selection. These four accessions may be used either as future parents in breeding programs or as direct cultivars (after variety release) in yam bean production for processing products. Results on hybrid lines (F2 and F3) still have to be analyzed for publication. Another outcome for Rwanda agriculture is the acquisition and conservation of this new crop can enrich Rwanda crop diversity. Further research is needed in term of promoting and diversifying the use of yam bean.

SCIENTIFIC COMMUNICATIONS

Scientific communications about our yam bean work in Rwanda were made as poster and/or oral presentations at the CIALCA International Conference in Kigali–2011/Rwanda (24–27 Oct.); the ISTRC Conference in Abeokuta–2012/Nigeria (24–28 Sept.); the Symposium of ISTRC-Africa in Accra–2013/Ghana (30 Sept.–5 Oct.).

APPENDIX 4

FINAL REPORT INERA (DR CONGO)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: INERA–DR Congo: Identify adapted high-yielding yam beans for Central Africa" and "Develop yam bean storage root products for DR Congo/Central Africa

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: INERA - INSTITUT NATIONAL POUR L'ETUDE ET LA RECHERCHE

AGRONOMOQUES – DR CONGO

M A Y 2 0 1 5

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: May 25, 2015

On behalf of INERA

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CONTENTS

ABSTRACT

Malnutrition and undernourishment are the main scourges that affect developing countries. This can be seen through the poor availability of foods—especially nutrient-dense food. Deficiencies of micronutrients (pro-vitamin A, iron, and zinc) are widespread in Central Africa. The problem increases people's vulnerability to infections and causes numerous deaths. The introduction of new, nutrient-rich crops such as yam bean (*Pachyrhizus* spp.), which have the potential to fit into local farming and food systems, is one way to mitigate this situation. For this reason, the "Enhancing the nutrient-rich Yam Bean (*Pachyrhizus* spp.) to improve food quality and availability and sustainability of farming systems in Central- and West Africa" (Ahipa project) was implemented in Central Africa, including the Democratic Republic of the Congo (DRC).

The overall goal of the project is to improve health, food security, and sustainability of farming systems in Central Africa and in DRC. Together with the International Potato Center (CIP), the Institut National pour l'Etude et la Recherche Agronomoques (INERA) worked specifically on project objective 2: Identify adapted high-yielding yam beans for Central Africa, and objective 3: Develop yam bean storage root products for Central Africa. To achieve objective 2, three cultivated species of Pachyrhizus (*P. ahipa, P. erosus,* and *P. tuberosus*) were introduced in DRC to assess the possibility of growing the crop in Central Africa and to study whether yam beans merit dissemination efforts into the farming systems of this region.

To avoid confusion with the Africa yam bean (*Sphenotylis stenocarpa*)—a completely different species—the yam bean was called generally "ahipa" in DRC, using the name of the Andean highland yam bean *P. ahipa* (the same was done in other African countries). Thirty-nine accessions from all cultivated *Pachyrhizus* species were tested in field trials at different locations across DRC. The results of these evaluations have shown that the new crop is adapted to farming systems in DRC, and many accessions present the potential for dissemination in the country. The six best yielding and quality accessions were *P. ahipa* (209035 and 209036)*; P. erosus* (209017 and 209018); and *P. tuberosus* (209054 and 209055).

To achieve objective 3, product development activities were carried out to investigate whether the storage roots of the American yam bean can be processed into local food products. Storage toots were sun-dried and milled into flour, which was used to make local storage root food products—namely, "fufu," porridge, and fritters; all preparation procedures are given in this report. We intend to publish these as a manual independent of this report.

1. ACTIVITIES TO IDENTIFY ADAPTED HIGH-YIELDING ACCESSIONS FOR DRC

1.1 EQUIPMENT AND INFRASTRUCTURE ACQUISITION

A vehicle (Toyota HiLux, four-wheel drive pickup) and three motorcycles were bought for the project. The vehicle and two motorcycles are based at INERA–Mulungu (Eastern DRC) and one motorcycle at INERA–Mvuazi (western DRC). A greenhouse also was built at INERA–Mulungu.

1.2 GERMPLASM ACQUISITION

In 2009, INERA–Mulungu obtained from CIP-Lima the first yam bean material. It consisted of three *P. ahipa* accessions (209034, 209035, and 209036) and three *P. tuberosus* accessions (209013, 209014, and 209015), each with 20 seeds.

In December 2010, INERA–Mvuazi received from CIP-Lima two *P. erosus* accessions (209018 and 209019), each with 200 seeds for seed multiplication at station.

In January 2011, INERA–Mulungu received 3 accessions (209037, 209039, and 209044) from CIP-Lima. Two sets of accessions have been introduced from CIP-Uganda in February and April 2011, respectively (the material was multiplied in Uganda after introduction from Peru). The first set comprised 20 accessions (209003, 209004, 209006, 209007, 209016, 209022, 209023, 209024, 209025, 209026, 209027, 209028, 209029, 209030, 209031, 209032, 209033, 209034, 209035, and 209036), each with 100 seeds. The second set comprised 11 accessions (209017, 209018, 209046, 209050, 209051, 209052, 209054, 209055, 209058, 209059, 209060), each with 100 seeds.

In February 2011, INERA–Mulungu received from ISAR/Rwanda eight *P. ahipa* accessions (209003, 209006, 209031, 209032, 209033, 209034, 209035, and 209036), each with 60 seeds.

Two accessions (209013 and 209060) have been obtained from Burundi in 2012. Accession 209013 comprised 100 seeds and accession 209060 comprised 500 seeds.

In total, 39 *Pachyrhizus* yam bean accessions comprising 7,690 seeds have been introduced to DRC from Peru, Uganda, Rwanda, and Burundi (Table 1). Overall, the germplasm introduced were 19 accessions of *P. ahipa* (209003, 209004, 209006, 209007, 209022, 209023, 209024, 209025, 209026, 209027, 209028, 209029, 209030, 209031, 209032, 209033, 209034, 209035, and 209036); 8 accessions of *P. erosus* (209016, 209017, 209018, 209019, 209046, 209050, 209051, and 209052); 9 accessions of *P. tuberosus* (209013, 209014, 209015, 209054, 209055, 209058, 209060, and 209061); and 3 accessions of interspecific hybrids of the type *P. tuberosus x P. ahipa* (209037, 209039, and 209044) as advanced breeding lines, with no or very small segregation potential. (NB: *Pachyrhizus* is mainly self-pollinating).

Table 1 Number of accessions and quantity of seeds introduced to DRC

Species	No. of Accessions	No. of Seeds Introduced from				
		Peru	Uganda	Burundi	Rwanda	TOTAL
P. ahipa	19	160	2,000	100	480	**2,740**
P. erosus	8	1,200	1,500	-	-	**2,700**
P. tuberosus	9	660	1,000	500	-	**2,160**
Hybrids *(P.t. x P.a.)*	3	90	-	-	-	**90**
TOTAL	**39**			**600**		**7,690**

1.3 SEED MULTIPLICATION

The first seed multiplication activity started with six yam bean accessions sent by CIP-Lima to INERA. These accessions have been sown in pots in greenhouses during June 2010 at INERA–Mulungu, altitude 1,700 masl (Table 2 and Figs. 1a–c). The objective was to produce seeds for further evaluation trials. The results of this first multiplication in greenhouses have shown that *P. ahipa* produced many seeds, whereas *P. tuberosus* only produced two seeds (Table 2). These first results indicate that the South-Kivu province is obviously too high in altitude for *P. tuberosus* to produce seeds. (NB: *P. tuberosus* is from the Amazonian lowlands—the zone where the Andes meet the Amazon—and is found up to about 800 masl).

Table 2 Preliminary results of yam bean multiplication at INERA–Mulungu, South-Kivu/DRC in 2010

CIP Number	Accessions	Species	No. of Seeds Sown	No. of Seeds Germinated	No. of Pods	No. of Seeds Harvested
209013	TC354	P. *tuberosus* (Chuin)*	10	9	0	0
209014	TC355	P. *tuberosus* (Chuin)*	10	1	0	0
209015	TC361	P. *tuberosus* (Chuin)*	8	4	1	2
209034		P. *ahipa*	20	20	146	847
209035		P. *ahipa*	20	18	167	825
209036		P. *ahipa*	20	20	225	1491

* Chuin accessions export permits (national rights from Peru) were unclear and interpreted in 2009 as available for distribution. Later in 2012, Peruvian authorities formalized and gave clear permits to disseminate these three high dry matter *Pachyrhizus* accessions.

Figures 1a–c. Seed multiplication in greenhouse in Mulungu.

In 2012/2013 emphasis was given on seed multiplication activities in fields at Mulungu and Mvuazi, after plants passed all quarantine inspections in the greenhouses (Figs. 2a and b, 3a and 3b). In total 44,795 seeds were produced in the field (Table 3).

Figures 2a and b. Seed multiplication in field in Mvuazi and in Mulungu.

Table 3 Seeds produced at Mulungu and Mvuazi in 2012/2013

	No. of Seeds Produced in Fields	
Accessions	**Mulungu**	**Mvuazi**
209016	2,990	
209017	1,820	
209018	2,120	8,900
209019	1,900	7,600
209026	1,067	
209027	450	
209028	1,560	
209029	1,850	
209030	2,200	
209031	2,460	
209032	2,400	
209034	2,373	
209035	3,047	
209036	2,058	
Total	**28,295**	**16,500**

Figures 3a and b. Seeds of two *P. ahipa* accessions produced in Mulungu, Eastern DRC.

1.4 FIELD EVALUATIONS

Five **on-station trials** and six on-farm trials were carried out at different locations in DRC. In total, 39 accessions of *Pachyrhizus* yam bean were evaluated for adaptation and yield performance. Experiments were conducted in different environments, especially in Mulungu (1,700 masl) and in Ruzizi Valley (900 masl)—two sites in the eastern part of DRC (Figs. 4a and b). Further trials were carried out at Mvuazi and Kipopo (Southeastern DRC). After harvest, samples of each accession storage roots were sent to CIP–Uganda to determine storage root quality. Table 4 provides an overview of these experiments; Table 5 summarizes accession performance.

The results of field evaluations have shown:

- *P. ahipa* values of storage root yields ranged from 6.4 t/ha to 18.5t/ha in Mulungu and from 5 t/ha to 15 t/ha in Ruzizi valley, showing a higher average yield in Mulungu (13.3 t/ha) than in the Ruzizi valley (10.0 t/ha). The same trends were observed for the storage root size average, which was larger in Mulungu (325.3 g per storage root) than in the Ruzizi valley (187.1 g per storage root). Five *P. ahipa* accessions were selected: 209022, 209031, 209032, 209035, and 209036. The species *P. ahipa* grows well in highlands agro-ecological conditions of Eastern DRC.
- *P. erosus* values of storage root yields ranged from 7.3 t/ha to 31.1 t/ha at Mulungu and from 6.5 t/ha to 24.5t/ha in the Ruzizi valley. The average yields were almost the same as for *P. ahipa* at Mulungu (13.3 t/ha) and in the Ruzizi valley (9.6 t/ha). Four accessions (209017, 209018, 209051, and 209052) were selected. The species *P. erosus* appears to be more widely adapted compared with *P. ahipa*, and can be grown either in lowlands or in highlands agro-ecological conditions of DRC.
- *P. tuberosus* values of storage root yields ranged from 2.2 t/ha to 10.6 t/ha in Mulungu and from 5.3 t/ha to 15.5 t/ha in the Ruzizi valley. The averages of storage root size were 411.6 g and 492.6 g in Mulungu and Ruzizi valley, respectively. For *P. tuberosus* species, two accessions (209054 and 209055) were selected on storage root yield performance. But the Chuin accessions of *P. tuberosus* 209013, 209014, and 209015 clearly were found to have the highest storage root dry matter among *Pachyrhizus* accessions, ranging 27–33% storage root dry matter. The *P. tuberosus* species performs well in lowlands areas of DRC.

Figures 4a and b. Evaluation plots at Mulungu (1,700 masl) and in the Ruzizi valley (900 masl).

On-farm trials in agronomy experiments are relevant to MSc thesis of Kilongo Bulambo through the Makerere University in Uganda.

Table 4. Overview of on-station and on-farm trials conducted in DRC during 2012 and 2013

Type of Trials	Experiment	Locations	No. of Accessions
On-station	Evaluation of accessions in frame of multi-environment trials across countries in Central Africa	Mulungu	11
		Mulungu	34
		Ruzizi Valley	34
	Local trials	Mvuazi	13
		Kipopo	9
		Tshirumbi	9
On-farm	Evaluation of selected yam bean accessions	Runingu	4
		Kakondo	4
		Cibinda	4
	Agronomy trials	Bushuma	2
		Runingu	2

Table 5. Evaluation of yam bean accessions for yield in East DRC across seasons (2012–2013)

	Mulungu (1,700 masl)			Ruzizi (900 masl)		
Trait	Mean	Worst Genotype	Best Genotype	Mean	Worst Genotype	Best Genotype
Pachyrhizus ahipa (n = 19 accessions)						
Storage root yield (t/ha)	13.3	6.4	18.5	10.0	5.0	15.0
Average weight of storage root (g/tuber)	325	200	421	187	108	302
Pachyrhizus erosus (n = 10 accessions)						
Storage root yield (t/ha)	13.3	7.3	31.1	9.6	6.5	24.5
Average weight of storage root (g/tuber)	604	565	1051	416	210	941
Pachyrhizus tuberosus (n = 5 accessions)						
Storage root yield (t/ha)	8.1	10.6	22.0	10.4	5.3	15.5
Average weight of storage root (g/tuber)	412	514	412	493	339	625

2. ACTIVITIES TO DEVELOP YAM BEAN STORAGE ROOT PRODUCTS FOR CENTRAL AFRICA

The study was carried out at INERA–Mulungu, South-Kivu, to assess the consumer acceptance of products processed from yam bean (Figs. 5a–c). Accession 209035 was used in the study. Different products were made using yam bean flour as a basic ingredient, either alone or mixed with wheat flour, cassava flour, and/or with orange-fleshed sweetpotato flour.

2.1 FOOD PRODUCTS TESTED AND ACCEPTED BY CONSUMERS

The food products tested were:

- Fufu developed with 100% yam bean flour (Product A)
- Fritter developed with 50% yam bean flour and 50% wheat flour (Product B)
- Fufu developed with 50% yam bean flour and 50% cassava flour (Product C)
- Fufu developed with 50% yam bean flour and 50% sweetpotato flour (Product D)
- Porridge developed with 100% yam bean flour.

The taste panel evaluated the products by scoring them 1–5: 1, bad; 2, fairly good; 3, good; 4, very good; 5, excellent.

Fritters (Product B), made by mixing yam bean and wheat flour, and porridge were products most appreciated by the taste panel (Fig. 6).

Figures 5a–c. The three food products (clockwise): fufu, porridge, and fritters.

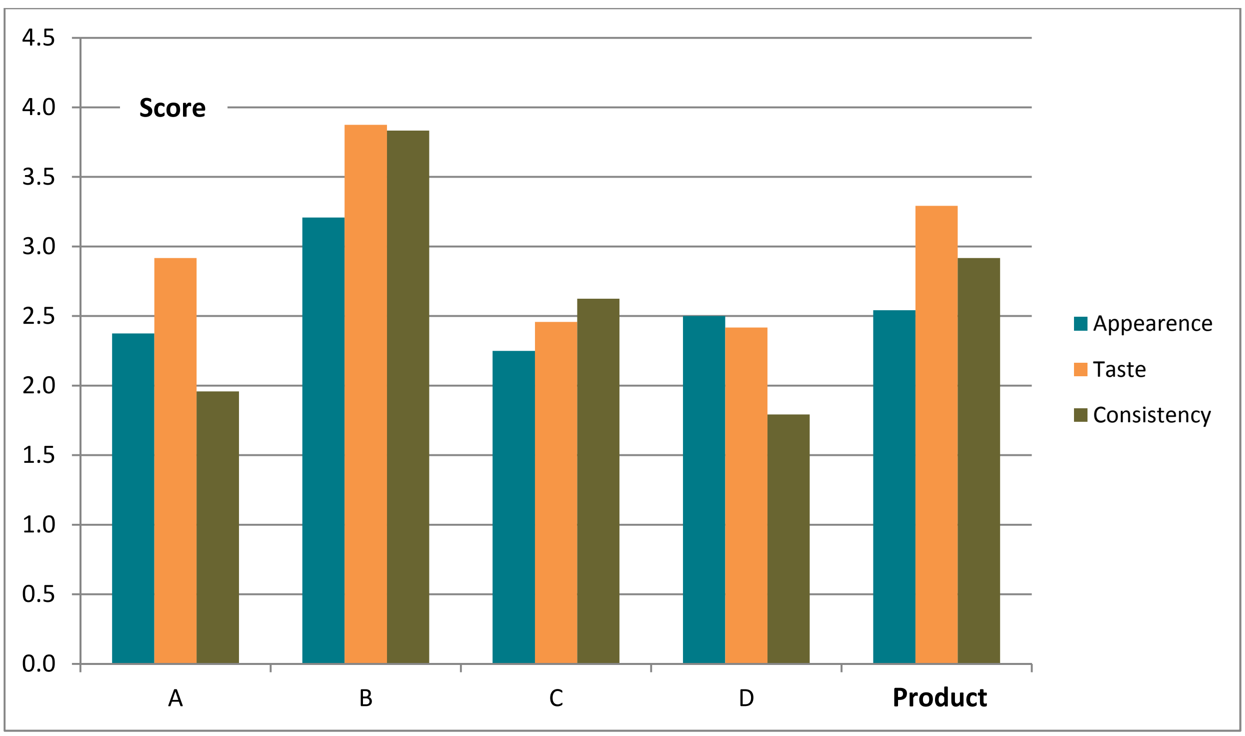
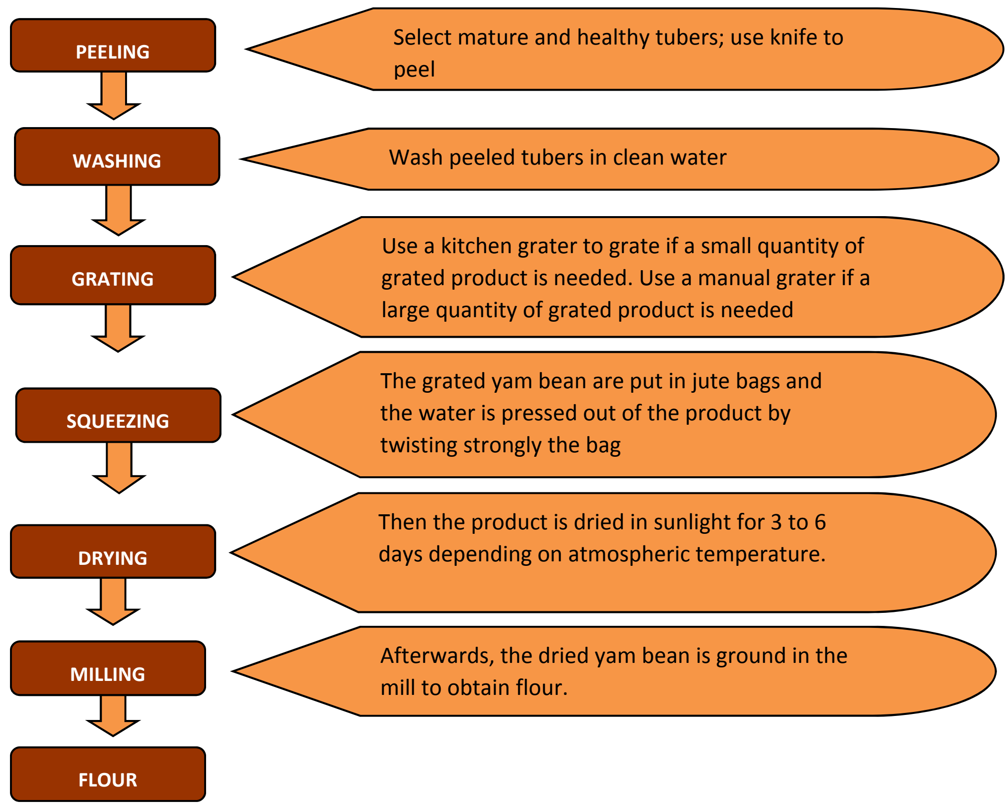


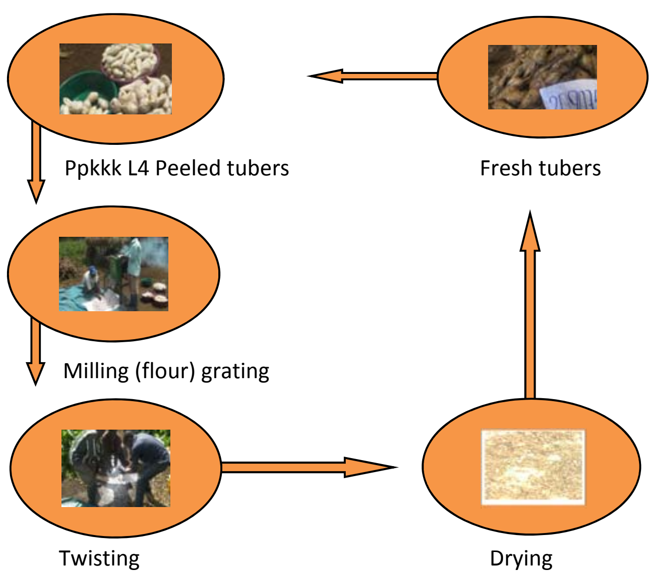
Figure 6. Consumer acceptance of yam bean products (A) fufu developed with 100% yam bean flour, (B) fritter developed with 50% yam bean flour and 50% wheat flour, (C) fufu developed with 50% yam bean flour and 50% cassava flour, (D) fufu developed with 50% yam bean flour and 50% sweetpotato flour, and (E) porridge developed with 100% yam bean flour.

2.2 RECIPES FOR YAM BEAN STORAGE ROOT FOOD PRODUCTS

2.2.1 FLOUR: YAM BEAN PRIMARY PRODUCT USED AS INGREDIENT

Yam bean flour is one of the primary products used as an ingredient for processing of value-added yam bean processed products. The flour is made from yam bean storage root, as illustrated below.





2.2.2 YAM BEAN FUFU (UGALI)

Fufu is a cooked dough often made with flour from the cassava plant (or alternatively another flour, such as that made from maize). Fufu can also be made from yam bean flour alone or a mixture of yam bean and maize flours. The color can vary from yellowish to brownish, depending on the ratio of product constituents. Fufu is a dish that is very important in DRC, because it is the staple food for the majority of Congolese. On basis of results for yam bean flour and yam bean *gari*, it is concluded that yam bean-based fufu can contribute to nutritional health because it has considerable more protein and iron than traditional cassava porridge.

Fufu Formulation 1: Yam bean flour (100%)

Ingredients:	**Amount**
Yam bean flour	600 g (4 standard cups)
Water	1.5 l (6 standard cups)

Procedure:

- Pour the water into the pan and boil it.
- When it is boiled, add yam bean flour.
- Simmer for a few second and then stir using wooden mixer.
- Remove from heat and knead until to get a thick dough.

Now the fufu is ready to be served (Fig. 7).

Figure 7. Fufu made to 100% from yam bean flour.

Fufu Formulation 2: Yam bean x maize flour mixture (50 : 50)

Ingredients	**Amount**
Yam bean flour	300 g (2 standard cups)
Maize flour	300 g (2 standard cups)
Water	1 .5 l (6 standard cups)

Procedure:

- Put the water into the cooking pan and heat till it boils.

- Add maize flour slowly while stirring with a wooden cooking utensil.
- Leave it cooking for about 5 min, but keep stirring it so that it does not burn.
- While the dough is simmering, slowly add yam bean flour while mixing.
- Knead until the dough is thick. You can control the hardness of the fufu by the amount of flour you add.

The whole cooking process takes 10–15 min (Fig. 8).

Figure 8. Fufu made from a yam bean flour x maize flour mixture.

2.3 YAM BEAN PORRIDGE

Porridge is considered in temperate regions of the world as a dish made by boiling ground, crushed, or chopped cereal. But in Africa, it is often made from root crops alone or in mixture with sorghum, maize, and even beans (e.g., *gari* is usually made from 100% cassava, so can be considered as a special type of porridge). In DRC, yam bean porridge can be made from yam bean flour alone or from yam bean x maize flours cooked with water to form a thick liquid. Independent processing and taste panel studies in DRC, Uganda, and Burundi have shown that an excellent tasting porridge can be made from yam beans and that there significant taste differences among varieties. The color is yellowish to brownish depending on the ratio of product ingredients. Owing to the results for yam bean flour and yam bean *gari*, yam bean porridge is thought to have considerable amounts of protein and iron. The yam bean porridge is rich in carbohydrates, proteins, and iron. It can be easily given to children as breastmilk supplements and/or weaning food; however, it can also be used as ready-to-eat breakfast for the entire family.

Porridge Formulation 1: Yam bean flour (100%)

Ingredients	**Amount**
Yam bean flour	1 cupful
Water	4 cupful
Sugar	As you like

Procedure:

- 1 cup of yam bean flour is mixed with 1 cup of cold water in a saucepan to make a thick paste.
- Boil 3 cups of water in a separate saucepan.
- Pour the thick paste into the boiling water and keep stirring for about 10–15 min until the porridge is ready.
- Add sugar as you like.
- Remove from fire and serve warm.

Porridge Formulation 2: Yam bean x maize flour mixture

Ingredients	**Amount**
Yam bean flour	50 g (5 tablespoons)
Maize flour	50 g (5 tablespoons)
Water	1.5 l (6 standard cups)
Sugar	As you like

Procedure:

- Mix yam bean flour with maize flour in a saucepan.
- Add 2 cups of water to the composite flour and mix to make a thick paste.
- Boil (the remaining) 4 cups of water in a separate saucepan.
- Pour the thick paste into boiling water and stir continuously to prevent lumps from forming.
- The product will thicken when ready; this can take about 15–20 min.
- Remove from heat and add sugar as you like.
- Serve when warm (Fig. 9).

Figure 9. Porridge made from a yam bean flour x maize flour mixture.

2.4 FRITTERS

Yam bean-based fritter is a small fried bread made out of yam bean and wheat flours (Fig. 10). Wheat fritters are widely eaten in DRC; children are especially fond of them for breakfast and at school. Fritters contribute to nutritional health as a good source of protein and carbohydrate. The color is usually golden brown.

Ingredients	Amount
Yam bean flour	250g
Wheat flour	250g
Sugar	100g
Baking powder	8g
Water	Adequate
Cooking oil	Adequate for deep frying

Procedure:

- Mix the yam bean flour with wheat flour in a bowl along with yeast and sugar.
- Add water and knead till to get a firm smooth paste.
- Leave the dough to rise (at least 1 hr).
- Make small equal pieces of the dough with spoon; plunge them into preheated oil and keep turning until it is golden brown (Fig. 11).

Figure 10. Preparation of fritters made from a yam bean flour x wheat flour mixture.

Figure 11. Fritters made from a yam bean flour x wheat flour mixture.

3. CONCLUSIONS AND RECOMMENDATIONS

The project was fairly successful in terms of the two specific objectives in DRC. The project proved that yam beans are adapted for cultivation to DRC and can be processed into local storage root food products in the country.

The best accessions that were identified to be good for dissemination are 209017, 209018, 209035, 209036, 209054, and 209055. The crop can fit well into the DRC food system by the development of local food products such as fufu and porridge—porridge from yam bean has an especially good taste.

We think it merits the harnessing of the crop in Central Africa so that it can greatly help to reduce malnutrition and undernourishment in DRC. This would require work on promoting the use of yam beans and processed products; the knowledge and materials are available to make this possible. A good strategy could be to involve all stakeholders of this project in Central Africa to start broader dissemination of this new crop in DRC. However, we observed around field trials informal dissemination of the new crop with respect to the high-yielding, low dry matter yam beans.

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APPENDIX 5

FINAL REPORT ISABU (BURUNDI)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

"Identify adapted high-yielding yam beans for Central Africa" and "Develop yam bean storage root products for Burundi/Central Africa"

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: ISABU–Institut des Sciences Agronomiques du Burundi

M A Y 2 0 1 5

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: May 2015

On behalf of ISABU

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CONTENTS

ABSTRACT

There were three objectives of this project by the Institut des Sciences Agronomiques du Burundi (ISABU) in Burundi:

- To prove the production potential of the yam bean as a storage root crop for a wide range of Burundi farming systems.
- To demonstrate the development of traditional storage root food products from yam bean storage roots—for example, *fufu* (also called *ugali*) and *chigwanga*—with farmer groups and to confirm that these food products have a higher nutritional value (protein, iron, and zinc) than those processed from commonly grown tropical root and tuber crops (cassava, sweetpotato, and yam).
- To establish yam bean storage root production and food products in farming systems.

The first objective was fully achieved. It is possible to establish a seed production system for yam bean in Burundi with most accessions (30 accessions introduced). It is also relatively easy to supply farmer with seeds because this root crop is propagated by true seed. For 18 accessions, a multi-environmental trial (MET) was conducted. Storage root yields across accessions and environments were 22 t/ha under pruning (no seed production allowed) and 10.3 t/ha without pruning. We conclude that most yam bean genotypes are well adapted to Burundi.

The highest yielding accession was 209019, with a storage root yield across environments of 57.9 t/ha. Accessions 209013, 209017, 209031, 209054, and 209060 were moved into on-farm trials and processing studies (NB: 209013 was moved into our study very late due to national rights of Peru, which were unclear at the beginning of the project). Accession 209013 appears to taste similar to cassava. Consumption studies show that accessions 209013, 209060, 209054, and 209031 can be eaten raw and are accepted by farmers, whereas others were good for salads.

For further processing options, see the reports from INRAB/Benin and INEA/DRC in which *fufu* and *chigwanga* were prepared from yam beans. A yam bean demonstration processing unit was constructed in Burundi. ISABU would have moved into more wide dissemination on-farm, but due to limited funds in the phasing-out component of the project (covering only one year for phasing out), this was not possible.

1. BACKGROUND AND JUSTIFICATION

The root and tuber crops produced by legumes have long been recognized as important crops, and the Food and Agriculture Organization has recommended them as a source of human nutrition to improve protein supply. In contrast with other legume root crops, the yam bean shows by far the widest adaptation and the highest yield potential. A legume closely related to soybean, yam bean was placed to the sub-tribe *Diocleinae,* tribe *Phaseoleae,* with the legume family (*Fabaceae*) (Lackey 1977), and was recently replaced into the sub-tribe subtribe Glycininae (Doyle and Doyle 1993; Lee and Hymowitz 2001; Espert et al. 2008).

The yam bean complex comprises three cultivated species:

- *Pachyrhizus tuberosus* (Amazonian yam bean)
- *Pachyrhizus erosus* (Mexican yam bean)
- *Pachyrhizus ahipa* (Andean yam bean).

However, there are no crossing barriers among cultivated yam bean species and the complex could be reclassified into one species in the near future. *P. erosus* is most widely cultivated, more because of its higher yield than lack of agriculturally attractive features in *P. ahipa* and *P. tuberous* (Grum 1990).

There are also two wild species, *P. ferrugineus* and *P. panamensis* (Lackey 1977). Most likely *P. panamensis* is the common ancestor of *P. ahipa* and *P. tuberosus*, while *P. ferrugineus* is the ancestor of *P. erosus* (Sørensen 1996).

Yam beans are cultivated in the Andean highlands, the Amazonian rainforests, across nearly all countries of South and South-east Asia, as well as locally in West Africa, mainly due to the activities of this project. The wide adaptation of the yam bean is illustrated by a target set of yam bean production areas, which correspond to the environmental data of the experimental environments used by Zanklan et al. 2007. However, there is the need to prove yam bean adaptation and yield potential in Burundi, Eastern Democratic Republic of the Congo (DRC), and Rwanda in the environments, which appear to be more suitable for the Andean yam bean and Amazonian x Andean yam bean interspecific hybrids.

New discoveries have made the yam bean a potential source to develop a new nutrient-rich staple. These include adaptation to environmental stress conditions (drought stress periods as well as heavy rainfall), no need for nitrogen fertilizer (plants have an efficient symbiotic relationship with rhizobia that results in N fixation of up to 200 kg/ha), high storage root starch yields linked with high protein contents (up to 18% on storage root dry matter basis), micronutrient concentrations (up to 70 ppm iron[1] on storage root dry matter [DM] basis), and the possible human consumption of seeds (provided that toxic compound in seed can be eliminated technically or by screening breeding material). There are clear indications that the yam bean can lead to greater food availability, improved food quality, more sustainability of farming systems, and new options for income generation for the rural and urban poor in sub-Sahara-Africa. It has been proved that (1) the yam bean is well adapted to the root-crop and millet-sorghum farming system in West Africa; (2) the crop fits into the West African food system by the development of yam bean *gari*, similar in texture and taste to cassava *gari*, which is eaten by millions in West Africa on a daily basis; and (3) the yam bean *gari* has five to seven times more protein content than its cassava form.

[1] Concentrations of 150-ppm iron have been reported from plant quality laboratories, but we think these values were obtained without controlling for non-plant iron contamination in the sample preparation chain.

2. OBJECTIVES

The objectives of this project by ISABU in Burundi have been to (1) prove the high production potential of the yam bean as a storage root crop for a wide range of Burundi farming systems; (2) demonstrate the development of traditional storage root food products from yam bean storage roots—for example, fufu (also called *ugali*) and *chigwanga*—with farmer groups (mainly girls and women) and to confirm that these food products have a higher nutritional value (protein, iron, and zinc) than those processed from commonly grown tropical root and tuber crops (cassava, sweetpotato, and yam); and (3) establish yam bean storage root production and food products in farming systems.

2.1 GERMPLASM ACQUISITION AND SEED MULTIPLICATION

The objective was to introduce and multiply the yam bean germplasm for the project studies in Burundi. During the reporting period, ISABU acquired additional seeds of yam bean germplasm from CIP-Uganda as well as INERA-Mulungu in DRC (Table 1). This was in addition to the batch of germplasm (28 accessions) received in 2010 from CIP-Peru, which unfortunately was partially affected in seed multiplication by high altitude conditions (cold temperatures) at Gisozi/Burundi (especially *P. tuberosus* from the Amazonas region). Thirty yam bean accessions are currently present and maintained in Burundi.

Table 1 Seeds produced under screenhouse and field conditions in Burundi during the first project year

		Field		
Genotype	Screenhouse	Imbo Centre	Station Moso	Total
209003	767	22	198	987
209004	0	0	235	235
209006	280	458	635	1,373
209007	650	928	300	1,878
209013	0	0	5,600	5,600
209016	1,340	6,000	19,412	26,752
209017	2,318	9,000	8,286	19,604
209018	900	6,380	416	7,696
209019	4,133	12,120	22,046	38,299
209022	208	113	103	424
209023	1,426	72	0	1,498
209024	0	0	28	28
209025	0	0	236	236
209026	0	0	275	275
209027	0	0	185	185
209028	0	0	40	40
209029	0	0	42	42
209030	35	1,142	1,352	2,529
209031	4,700	1,475	680	6,855
209032	1,453	275	600	2,328
209033	2,418	1,380	686	4,484
209034	0	0	145	145
209035	487	514	766	1,767
209036	1,779	120	130	2,029
209046	138	188	611	937
209050	600	0	1,135	1,735
209051	787	200	415	1,402
209052	846	2,479	1,450	4,775
209054	131	400	415	946

209058	270	0	0	270
209059	110	1,150	6,000	7,260
209060	0	3,600	2,500	6,100

The maintenance of introduced accessions through in-situ and screenhouse multiplication was done at Bujumbura, Gisozi, and Moso research stations (Fig. 1). Gisozi is located in Mwaro Province at 2,200 masl and Bujumbura is located in lower land at 800 masl.

Figure 1. Yam bean field multiplication at Bujumbura (*left*) and Moso (*right*).

Seed multiplication activities were conducted in the screenhouses (using potted plants) and in the field. In the field, spacing was at 60 cm between rows and 30 cm between plants; stakes were used for climbing accessions. Seed-maturing period was long, varying 4–8 months with some accessions exhibiting continuous flowering and seed production. *P. erosus* accessions 209016, 209017, and 209019 produced more seed than the rest of the accessions. Accession 209013, which has high DM content, was multiplied at Moso Research Station where this high DM accession performs well and was distributed in the neighboring countries.

2.2 ON-STATION MULTI-ENVIRONMENT EVALUATION AND ADAPTABILITY TRIALS

Owing to seed multiplication, ISABU decided to use 22 accessions out of the 30 accessions for multi-site adaptability and 5 accessions for demonstration trials. The trials were established at three sites: Imbo Centre (800 masl), Mparambo (900 masl), and Murongwe (mid-altitude 1,800 masl). The planting dates were April 20th for Imbo Centre and Mparambo and May 12th for Murongwe. The experimental design used is described by Zanklan et al. (2007). Spacing was 30 cm in row and 80 cm between rows; stakes were used for climbing accessions. No fertilization or insecticides were applied in the trials. Irrigation was done dry in the tree sites. Weeding was made with hand tools. Pruning was done in all treatment to increase root yield (Zanklan 2003). The germination rates were good in Mparambo, with an average of 60%, but a little bit low in Murongwe (59%) and Imbo Centre (50%) (Table 2). The poor germination at Imbo Centre was due to a lot of irrigation water. In some areas like Mparambo and Murongwe, we were able to harvest 4 yam bean tubers per plant (Fig. 2).

Figure 2. Farmer in Mparambo with yam bean storage roots (accession 209022).

Table 2 Germination rates for yam bean accessions in Burundi at three locations

Genotype	Repli-cation	No. of Seeds	Germination					
			Mparambo	(%)	Imbo Centre	(%)	Murongwe	(%)
209003	1	20	9	45	7	35	11	55
	2	20	14	70	8	40	13	65
209006	1	20	11	55	4	20	13	65
	2	20	11	55	5	25	13	65
209007	1	20	10	50	7	35	9	45
	2	20	11	55	10	50	13	65
209016	1	20	13	65	8	40	18	90
	2	20	10	50	19	95	18	90
209017	1	20	12	60	10	50	17	85
	2	20	14	70	14	70	16	80
209018	1	20	11	55	14	70	18	90
	2	20	15	75	14	70	18	90
209019	1	20	8	40	10	50	14	70
	2	20	14	70	15	75	15	75
209022	1	20	13	65	10	50	8	40
	2	20	16	80	11	55	8	40
209023	1	20	7	35	16	80	9	45
	2	20	17	85	16	80	11	55
209030	1	20	11	55	10	50	13	65
	2	20	6	30	4	20	9	45
209031	1	20	11	55	10	50	9	45
	2	20	16	80	14	70	15	75
209032	1	20	8	40	8	40	12	60

Genotype	Repli-cation	No. of Seeds	Germination					
			Mparambo	(%)	Imbo Centre	(%)	Murongwe	(%)
	2	20	17	85	11	55	13	65
209033	1	20	5	25	17	85	14	70
	2	20	11	55	8	40	13	65
209035	1	20	8	40	6	30	10	50
	2	20	12	60	8	40	7	35
209036	1	20	15	75	9	45	10	50
	2	20	9	45	9	45	7	35
209046	1	20	14	70	13	65	18	90
	2	20	10	50	14	70	17	85
209051	1	20	11	55	18	90	12	60
	2	20	11	55	11	55	15	75
209052	1	20	15	75	15	75	16	80
	2	20	16	80	17	85	18	90
209054	1	20	16	80	2	10	3	15
	2	20	5	25	3	15	7	35
209059	1	20	18	90	4	20	2	10
	2	20	14	70	2	10	3	15
209060	1	20	9	45	7	35	4	20
	2	20	16	80	5	25	3	15

Table 3 show some results obtained under pruned and unpruned treatments at across locations.

Table 3 Storage root yield and leave yield evaluated across two seasons

Accession	Storage Root Yield (t/ha)		Leaves Yield (t/ha)	
	pruned	unpruned	pruned	unpruned
209003	15	1.25	0.3	0.7
209006	8.75	0.83	0.7	1.3
209007	15.42	0.69	3.8	2.6
209016	14.86	0.42	19.7	21.9
209017	36.94	5.69	11.7	21.5
209018	46.53	6.11	21.7	16
209019	57.92	3.33	35.8	36.3
209023	26.81	0.42	1.7	0.7
209031	19.31	1.67	6.9	3.3
209032	19.72	0.83	3.5	2.4
209033	14.86	0.97	2.5	0.8
209035	13.19	0.69	1.5	1.7
209036	23.19	0.97	4	1.1
209046	12.78	2.08	22.5	21.8
209051	32.08	0.42	11.8	13.9
209052	22.22	1.11	14.6	18.2
209054	4.44	1.11	17.1	8.7
209060	12.78	2.36	6.1	4.4
Means	**22.04**	**1.72**	**10.3**	**9.9**

LSD	3.09		2.58	
CV	54.3		53.5	
FP	<.001	<.001	<.001	<.001

The best accessions were selected and evaluated on farm (i.e., 209013, 209017, 209031, 209054, and 209060) at two sites of Ngozi Province (Kiremba and Tangara Commune; Fig. 3).

Figure 3. A farmer of Tangara community monitoring his yam bean field 3 weeks after planting.

2.3 DEVELOP YAM BEAN STORAGE ROOT PRODUCTS FOR BURUNDI

Regarding objective 3, fresh storage roots for 7 accessions—namely, 209013, 209017, 209018, 209031, 209032, 209054, and 209060—were tested for storage root food products such as chips, salad, and *katogo* preparation (Figs. 4a and b, Figs. 5a and b). Selected famers from on-farm trials participated in taste testing each product (Fig. 6a–g). More focus was put on *katogo* and salad in order to contribute to food security of the farmers. Yam bean salad and *katogo* protocols were developed. Twenty consumers assessed the two products based on sensory attributes given. **The results showed that accessions 20901, 209060, 209054, and 209031 can be eaten raw and accepted by farmers, whereas others were good for salad**.

Figures 4a and b. Yam bean salad of high DM yam bean accessions at CEPLODRIC hotel in Bujumbura.

Figures 5a and 5b. Yam bean chips of high DM accession 209013 (which tastes comparable to cassava).

Figures 6a–f. Panelists tasting yam bean products at Bujumbura Research Centre.

A processing unit has been established in Gisozi Research Station in June 2014 in order to initiate yam bean processing (Figs. 7a–c). This processing unit will also be used for sweetpotato and cassava processing. Planned activities on development of yam bean products were changed due to this processing facility.

Figures 7a–c. Processing unit constructed at Gisozi Research Station.

2.4 AWARENESS, COMMUNICATION, TRAINING, AND CAPACITY BUILDING

One ISABU staff (Ernest Vyzigiro) was admitted and registered for MSc training in agronomy at Makerere University in September 2011**.**

The topic of his project research was "Effect of plant density populations and manure application on growth and yield of Yam Bean in Burundi."

Objectives

The overall objective of the study was to promote the adoption of yam bean varieties within Burundi's major farming systems for crop diversification, food and nutritional diversity, and environmental stewardship. The specific objectives were to determine:

- An optimum yam bean plant population for high and stable yields in Burundi.
- The effect of organic manure soil amendment on growth and yield of yam bean in Burundi.

3. MATERIALS AND METHODS

3.1 STUDY 1: DETERMINATION OF THE OPTIMUM PLANT DENSITY

3.1.1 MATERIALS

Two introduced yam bean accessions were selected for the study (209031 and 209058) and are introduced from CIP-Uganda (Namulonge screenhouse). The choice of these accessions was imposed by seed availability. These accessions are being multiplied at Moso Research Station to generate more seeds for next trials (Table 4).

Table 4 Sites (ISABU 1993)

Site	Location	Altitude (masl)	Annual Rainfall (mm)	Annual Temperature Minimum	Maximum	Soil Type
Moso	-	1,200	1,197.3	18.1	30.	-
Imbo-Centre	3°11'S-29°21'E	900	789.1	18.1	30.1	clay

In this study, three plant density populations were used at planting: 40,000 (P1); 60,000 (P2), and 80,000 (P3) plants/ha. The planting dates were April 13th in Imbo-Centre and April 11th in Moso. Treatments were arranged in a split plot experimental design, in a randomized complete block with three replications. In each strip and replication, subplots were established randomly, and consist of nine treatments resulting from the factorial arrangement and growing population. In each experiment, spacing differed between rows: 0.75, 0.80, and 1.00 m.

Each experimental unit consisted of two rows of 10 plants each and one seed per hole. Each accession had 9 treatments. No fertilization or insecticides were applied in the trials. Irrigation was provided because of dry season. Weeding was done with hand tools. Pruning was done in all treatment to increase root yield (Leidi, et al. 2004; Zanklan 2003). Data on emergence rate, growth parameters, and yield component were taken. Yield component was essentially root weight (g/plant), which was determined using a balance, number of tuber/plant, and tuber size.

3.1.2 RESULTS

Significant differences were observed among locations, accessions, and season for most of the characteristics. The highest mean storage root fresh yield was obtained under 80,000 plants/ha, with an overall mean for storage root fresh yield of 13.43 t/ha; followed by 60,000 plants/ha (10.29 t/ha), and the lowest yield was identified in 40,000 plants/ha (7.58 t/ha).

The storage root fresh yields were significantly different across the different seasons (p<0.001). Season 2013A had the highest mean yield (14.17 t/ha) and 2012B (6.71 t/ha, $LSD_{0.05}$= 2.496). Most of the traits presented their higher value at Moso than at Imbo-Centre. The ideal season for yam bean production was 2013A with mean storage root fresh yield (14.17 t/ha) and 2012B (6.71 t/ha). Weight of big roots, total numbers of big roots, and fresh tuber size are important yield components in yam bean improvement (Figs. 8a and b).

No significant effect of plant population was observed on yam bean accessions for the most of the traits, except for plant height, fresh storage root yield, and biomass in one location. This is probably due to the range of plant population used, which was not so wide for us to conclude the right plant population recommended for yam bean production in Burundi. Another reason could be the number of rows per plot. In our experiment, two rows per plot were planted. Probably there was not enough competition for light and nutrients.

Figures 8a and b. Yam bean field trail and an overweight yam bean storage root at Moso site.

3.2 STUDY 2: DETERMINATION OF THE EFFECT OF ORGANIC MANURE

3.2.1 MATERIAL

The same material as in study 1 was used. The two accessions selected were 209031 and 209058, introduced from CIP-Uganda (Namulonge screenhouse). The study was conducted in the same location as study 1 at research stations of ISABU—namely, Moso Research Station and Imbo-Centre station.

Treatments were arranged in a split plot experimental design, in a randomized complete block design with three replications at the two locations. There were four treatments or level of organic manure: 0 t (0), 5 t (125), 10 t (250), and 20 t (500) per hectare (g/plant).

Each plot consisted of two rows of 10 plants each and one seed per hole. In the experimental plots, planting distances were 0.80 m between rows and 0.30 m within a row.

No fertilization or insecticides were applied; irrigation was provided. Weeding was done with hand tools. Pruning was done in all treatment to increase root yield (Leidi, et al. 2004; Zanklan 2003).

3.2.2 RESULTS

Significant effect was observed among organic manure levels for storage fresh root yield, biomass, and harvest index across different locations. Most of the values were higher under 500 g/plant. Accession 209054 was the highest yielding in terms of storage root yield and biomass, followed by accession 209031.

High values of most of the traits were observed in Moso; therefore, the ideal site for yam bean production in Burundi would be Moso (Figs. 9a and b).

No significant difference in terms of effect of organic manure on the yam bean accession was noticed in this study, except storage root yield, the total biomass, the vines and leaves weight, and the percentage of damage to storage root by nematodes.

Figure 9. Measuring yam bean storage root weights (a) and observing a plant with four storage roots with 11 kg (b).

4. CONCLUSION AND RECOMMENDATIONS

Participatory trials showed that Burundi is suitable for yam bean production, especially at Moso, where we observed a 11-kg yam bean tuber. The best performing genotypes that were identified as promising for adoption are accessions 209013, 209017, 209018, 209031, 209054, and 209060. Accessions 209013 and 209060 may be used either as future parents in breeding programs or directly as cultivars (after variety release) in yam bean production for processing products. Another outcome for Burundi is the acquisition of a processing unit that can be used for yam bean, sweetpotato, and cassava products. Accession 209013 was able to produce seeds only in Burundi and has high DM content. Further research is needed in term of promoting and diversifying the use of yam bean.

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APPENDIX 6

FINAL REPORT INRAB (BENIN)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: Develop marketing strategies for yam bean products and promote their use in West Africa—Analysis of the dissemination and adoption of yam bean (*Pachyrhizus spp.*) in Benin

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: INRAB, NATIONAL AGRICULTURAL RESEARCH INSTITUTE OF BENIN, AGONKANMEY AGRICULTURAL RESEARCH CENTER, & AGRICULTURAL POLICY ANALYSIS PROGRAM

J U N E 2 0 1 4

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: June 6, 2014

Revision: September 15, 2014
Develop marketing strategies for yam bean products and promote their use in West Africa - Analysis of the dissemination and adoption of yam bean (*Pachyrhizus spp.*) in Benin

On behalf of INRAB

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ABSTRACT

Yam bean (*Pachyrhizus* spp.), promoted since 2009 in Benin, can become an integral part of farming systems in Benin. Owing to its potential to improve quantitatively and qualitatively nutritious staple food for the population, we found that the crop contributes to sustainability of rural farming systems and can generate new sources of revenues for resource-poor farmers. This study documents yam bean dissemination in Benin. It analyses the status of adoption and factors that influence the continuation of yam bean cultivation in the communities where it has been introduced.

A total of 101 producers were surveyed in 75 villages across 19 communes of 12 departments in Benin, covering six of the country's total of eight agro-ecological zones (AEZs). Across AEZs we estimate currently an adoption rate of 47% for the yam bean compared with that of 31% for orange-fleshed sweetpotato (OFSP). The baseline of OFSP production in Benin is close to zero and was therefore used as a reference with respect to adoption rates. The West-Atacora AEZ presents the best yield average for yam bean grain production (true yam bean seed), with 301 kg/1,000m^2. The best average storage root yields of the yam bean were recorded in the Cotton Zone of Center-Benin, with 3,566 kg/1,000m^2. In contrast, the best average storage root yield for OFSP was recorded in the zone of *terres de barre*, with 1,050 kg/1,000m^2. The average selling price of raw yam bean storage roots is relatively low—20 Fcfa/kg (conversion rate of 2.7.2015: Fcfa/USD = 591.93). However, the processed storage root to flour and/or *gari* has an average selling price of 1,630 Fcfa/kg. In contrast, the average selling price of raw OFSP storage roots is 105 Fcfa/kg (processed OFSP has an average selling price of 160 Fcfa/kg).

The main advantages of cultivating the new crop are high storage root yields in combination with high grain yields, which facilitates rapid propagation and dissemination (this root crop is propagated by true seed) and various options for small-scale storage root processing, including *gari*, juice, yogurt, alcohol, snacks, and flour. The main constraints related to the cultivation of yam bean are laborious cropping operations, tedious tilling, and limited knowledge of planting techniques.

Key words: gro-ecological zone, dissemination, yam bean, constraints

1. INTRODUCTION

The production and consumption of yam bean (*Pachyrhizus* spp.), as well as derivative products, have been promoted in Benin since 2009. This promotion is part of the project known in Benin as **CIP Project No. 03-13**: "**Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa."** The project investigates the assumption that yam bean adoption can lead to (1) qualitative and quantitative improvements in food supply, especially for children and women of child-bearing age; (2) more sustainable farming systems through improving soil fertility (more organic matter and soil nitrogen); and (3) new sources of revenues. The project is funded by the Belgian Cooperation through the International Potato Center (CIP). It is implemented in Benin by the *National Agricultural Research Institute of Benin* (INRAB) and the nongovernmental organization (NGO) BØRNEfonden-Bénin.

The project falls well within the scope of Benin's agricultural policy, which aims through the 2011 Strategic Plan to boost the Agricultural Sector and improve agricultural performances to sustainably ensure food self-sufficiency and alleviate poverty in Benin. It is estimated that 12% of Benin households are food insecure and that about 13% of food-secure households are likely to become food insecure (WFP 2009). Food insecurity is linked to nutritional insecurity. More than one-third of Benin children (aged 6–59 months) suffer from chronic malnutrition, and 9% of Benin women have chronic energy deficiency (ibid.). About 37% of Benin's population lives below the poverty line, with an incidence of 39% in rural area against 35% in urban area (EMICoV 2009).

Maintaining the self-sufficiency ratio in staple foods under the current population growth rate in Benin compels farming households to intensify land use with low fertilizer application and reduced fallow periods. This leads to rapid soil depletion and results in poor fertility of soils and poor sustainability of farming systems. Land depletion is a major constraint to farm production in Benin (DSCPR 2007). It is necessary to move toward diversifying production by introducing new crops or technologies that can help alleviate poverty, food insecurity, children and women's malnutrition, and soil depletion. Yam bean has a high potential to improve staple food supply, to contribute to more sustainable cropping systems, and to generate new sources of revenues in Benin.

Promotion of yam bean in the framework of this project comprised four components: (1) producing seeds and establishing seed supply; (2) conducting research to develop adapted technical itineraries; (3) developing yam bean-based food products; and (4) evaluating the profitability of the crop by processing it into *gari* and to conduct research activities on the market. In addition to the research work, there has been a component of large-scale dissemination of the yam bean and of its derivative products obtained by processing, which started in 2011. This study documents yam bean dissemination in Benin. It analyses the status of adoption and factors that influence the continuance of yam bean cultivation in the communities where it has been introduced. The report is structured as follows: Section 2 presents the study objectives. Section 3 describes the strategy to promote yam bean in Benin. Section 4 presents the material and methods used to conduct this study. It is subdivided into three subsections that describe, respectively, the agro-ecological zones (AEZs) where the study has been conducted, data collection methods, and analysis methods. Section 5 presents and discusses the results. The last section gives perspectives and implications.

2. OBJECTIVES OF THE STUDY

The overall objective of this study is to analyze the dissemination and adoption of yam bean cultivation in Benin. Specifically, this is to:

- Describe cropping systems in those zones where yam bean is disseminated in Benin.
- Estimate yam bean adoption and rejection rates in Benin since 2011 (the year when the dissemination operation started).
- Analyze yam bean dissemination in Benin since 2011.
- Analyze favorable and unfavorable factors to large-scale dissemination and adoption of yam bean in Benin.

3. STRATEGY TO PROMOTE YAM BEAN IN BENIN

The first step to disseminate yam bean was to have accessions adapted to agro-ecological conditions in Benin and to have quality seeds in sufficient quantities.

Tables 1 and 2 present, respectively, the accessions of *Pachyrhisus* spp. with low and high dry matter (DM) content, introduced in Benin.

Table 1 *Pachyrhizus* spp. accessions (low DM type) introduced in Benin 2009/10

Available *Pachyrhizus* spp. Accessions in Benin	*Pachyrhizus* spp. Accessions Available and Disseminated in Farming Areas of Benin
CIP-209004; CIP-209007; CIP-209016; CIP-209017; CIP-209018; CIP-209019; TC-355; TC-361; AC-280; AC-279; 901438872376	EC 533; EC KEW

Table 2 *Pachyrhizus* spp. accessions (high DM type) received/introduced in Benin 2012

Accession	Species	Progenitor Hembra	Progenitor Macho
CIP-209013	*P. tuberosus*	-	-
CIP-209014	*P. tuberosus*	-	-
CIP-209015	*P. tuberosus*	-	-
CIP-209037	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209038	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209039	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209040	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209041	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209042	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209044	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)
CIP-209045	Hybrid	*P. ahipa*	*P. tuberosus* (Chuin)

The two accessions with low DM content, EC-533 and EC-KEW, gave satisfactory results during scientist-led experimentations in station and in farmers' fields. So far only these two accessions have been used in the dissemination of yam bean in Benin. They were distributed to individuals or groups of producers in 2011 and 2012 in collaboration with lead producers, the municipality, the NGO CARE International, and BØRNEfonden-Benin (depending on the areas). This operation was accompanied by a technical sheet on crop production. In 2012, each producer who had experimented with yam bean in 2011 helped in selecting at least five new producers who wished to establish the crop. The surface area of *Pachyrhisus* spp. plots were 1,000 m^2 or 1,500 m^2 for the groups of producers and 200 m^2 for individual producers. Those of OFSP were 100 m^2. The costs of labor to clear and plow land were paid to producers at a lump sum of 5,000 Fcfa.

To ensure that producers and members of their households or animals did not eat the grains, in addition to sensitization of experimenters about the potential toxicity of the grains during seed distribution, sessions on practical demonstration of flower removal of yam bean were organized in 2011 with experimenters. A pair of scissors was offered to producers to remove flowers. Producers were trained in how to prune flowers to avoid pod formation. The advantages related to ahipa storage root production (about 50% storage root yield increases), when flowers are removed were also explained. This operation does not allow farmers to produce seeds themselves. It is therefore planned to produce seeds from INRAB trials with the collaboration of NGOs. Multiplication trials of EC-533 and EC-KEW accessions were conducted in N'Dali in North Benin and in Missérété in South Benin.

4. MATERIALS AND METHODS

4.1 STUDY AREA

The study was carried out in the 12 departments of Benin (except Alibori, which was not included in the dissemination phase). The study zone covers six of the eight AEZs of Benin except for the extreme North zones (Zone 1) and cotton North (Zone 2) of Benin (see map of Benin AEZs in Annex 1).

Four of the AEZs covered in this study are characterized by Sudan-Guinean climate type with two rainy seasons with important intra- and inter-AEZ rain variations (Zone 5: 1,100–1,400 mm/year; Zones 6 and 8: 800–1,400 mm/year; Zone 7: 900–1,300 mm/year) (MEPN 2008). In these zones the rainy seasons cover the period March–November, with a brief interruption in August before resuming in September (Fig. 1). The climate is a Sudanese type with only one rainy season of 900–1,300 mm/year in Zone 3, whereas it varies from Sudan-Sahelian to Guinea-Sudanese with a yearly rainfall of 800–1,300 mm/year in Zone 4. The rainy season is generally from May to October

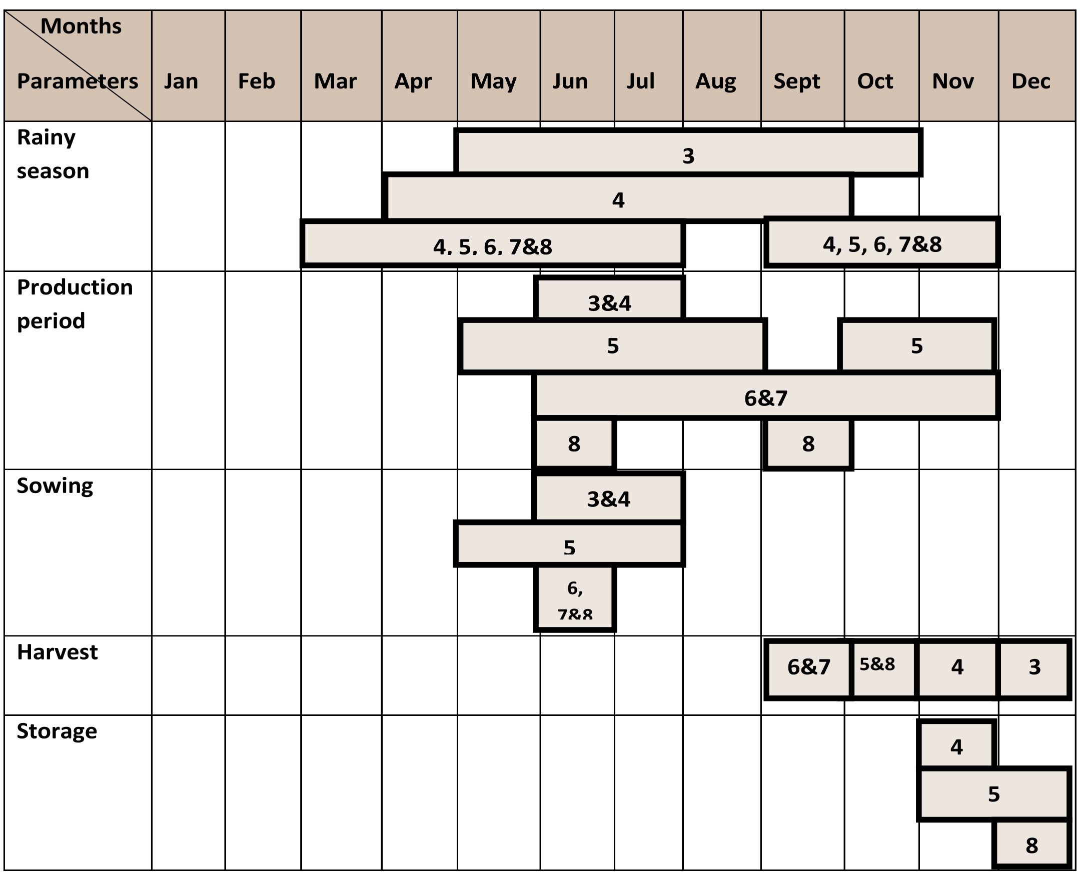


Figure 1. Rainy seasons and cropping calendar per AEZ.

In Zone 5, the soils are tropical ferruginous types on crystalline basement with varied characteristics. In addition to these soils, there are vertisols and hydromorphic soils in the depressions and/or river valleys that cross the zone. These vertisols are deep, melanized, fertile soils but difficult to cultivate (characterized as Zone 7, they have a very high production potential) (INSAE 2005). In Zone 6, the soils of *terres de barre* are mostly degraded but deep and easy to cultivate. In Zone 8 the soils are very fertile alluvial and less fertile sandy types on the littoral. Zone 3 soils are tropical ferruginous with very varied characteristics, average fertility, and very sensitive to leaching. Zone 4 soils are ferruginous soils on basement that are often deep, with low water reserve and fertile except in the lowlands.

Infrastructure like roads, warehouses, markets, and schools exist in almost all the AEZs covered by this study. The Cotton zone has the shortest distance (4.73 km) from the village to the most popular market and the Fisheries zone has the shortest distance to school (0.42 km) (Table 3).

Table 3 Average distances (km) to the most popular market and to school

	Agro-ecological zones						
Distance To	**Food Crop Zone South-Borgou**	**West Atacora**	**Cotton Zone Center-Benin**	***Terres de barre***	**Depression**	**Fisheries**	**Benin**
The most popular market	5.50	9.27	4.73	5.65	11	11	6.41
School	11.10	0.63	1.09	0.83	1.06	0.42	0.87

Source: Results, survey May 2014.

4.2 SAMPLING AND COLLECTION METHOD

Survey activities were carried out in 75 villages scattered in 19 communes in 12 departments in Benin. These villages are those in which seeds of *Pachyrizus* spp. and OFSP were distributed to voluntary producers in 2011–2013. To these were added the villages of producers who have grown *Pachyrisus* spp. at their own initiative.

The surveyed producers were those who have grown *Pachyrisus* spp. from seeds received from the project in 2011 and 2012 and who were present during the surveys. Surveys were also conducted with producers who have seen *Pachyrisus* spp. with the first producers and who have grown it. A total of 101 producers were surveyed in all visited villages. Table 4 presents the number of producers who participated in the first phase of dissemination in 2011–2013 and the number of surveyed producers per commune and AEZ.

Table 4 Distribution of participants to the dissemination and surveys

Agro-ecological Zone	Commune	Village	Participating in the Dissemination Phase 2011–2013	Surveyed in 2014
Terres de barre (Zone 6)	5	17	55*	24
Depression (Zone 7)	1	3	3	2
Cotton zone Center Benin (Zone 5)	10	18	108	44
West-Atacora (Zone 4)	4	8	28	18
Fisheries zone (Zone 8)	4	23	55	10
Food crop zone of South Borgou (Zone 3)	3	6	15*	3
Total	**27**	**75**	**264**	**101**

* Includes participants of the trials conducted by the NGO BØRNEfonden in 2012 and 2013.

Quantitative and qualitative data were collected in May 2014. Interviewers received training on the content of the questionnaire and the interview guide. A focus group discussion was organized in each village using an interview guide in order to have the producers' perceptions on the constraints and the opportunities of *Pachyrhizus* spp. cultivation. Then individual surveys were conducted with a sample of 101 producers using a structured questionnaire developed by CIP. It should be specified that in the case of groups of producers, only one questionnaire was administered. In the case where each member of the group had a plot of *Pachyrhizus* spp., the questionnaire was administered by each of them. At the end of the surveys, the geographic coordinates and the measures of the plots sown in 2013 and 2014 were taken using Global Position System. In each village, resource persons identified during the dissemination phase gathered producers in a public place or the team of interviewers went to each *Pachyrhizus* spp. producer. Thus all *Pachyrhizus* spp. and OFSP producers were met, except those who had traveled, those who were sick, those who have moved out or died, or finally those who refused to be interviewed.

4.3 METHOD OF ANALYSIS

Content analysis is the main method used to explore qualitative data collected. It was completed using score computation to prioritize the advantages and constraints of *Pachyrhizus* spp. cultivation*.* For example, the score of the constraint or the advantage *i* is calculated as follows:

$$score_i = \sum_j \frac{a_j p_i}{p_{ij}}$$ with

$score_i$: score of constraint *i*

p_{ij} percentage of producers who have attributed rank *j* to the constraint *i*;

a_j is that $a_1 = 6,\ a_2 = 5,\ a_3 = 4,\ a_4 = 3,\ a_5 = 2,\ a_6 = 1$

j rank (varies from 1 to 6).

5. RESULTS AND DISCUSSION

5.1 CROPPING SYSTEM IN THE DISSEMINATION ZONES

Major crops vary from one AEZ to another. Thus the cropping system in Zone 3 is based on yam. Sorghum is often added to yam and there is a strong expansion of cotton and maize. In Zone 4 producers grow cowpea, fonio, yam, sorghum, groundnut, cassava, bambara groundnut, and rice. Major crops grown in Zone 6 are maize, groundnut, and cassava, and there is an abundance of palm oil tree and wine raffia palm. In Zone 7, cropping systems are based on palm oil tree in association with maize as dominant crop accompanied, depending on the case, by cassava or pure stand of cowpea or sometimes market gardening. The cropping system in Zone 8 is essentially based on maize, cowpea, and market gardening. Maize and cassava dominate in non-sandy areas and out of the mangrove zones.

Crop rotation is practiced in the majority of the AEZs covered by the study. All surveyed producers (100%) in the Depression zone and in the Fisheries zone practice crop rotation (Table 5). Only 33% of the surveyed producers in the Food Crop zone South-Borgou practice this. The same is true for crop association, which is practiced by none (0%) of the producers in the Fisheries zone. Land preparation (plowing) is practiced by all surveyed producers. Ridging and tilling are almost generalized and practiced by, respectively, 86% and 84% of the surveyed producers. Of all these cropping systems, crop rotation has a particular interest in most of the zones.

Table 5 Distribution of producers in (%) depending on the cropping practices by AEZ

Parameter	Agro-ecological zones						Benin
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terres de barre*	Depression	Fisheries	
Crop rotation	33(1)	94 (17)	95 (42)	96 (23)	100 (2)	100 (10)	94 (95)
Crop association	33 (1)	33 (6)	75 (33)	81 (19)	100 (2)	0 (0)	60 (61)
Ridging	33 (1)	67 (12)	91 (40)	100 (24)	100 (2)	80 (8)	86 (87)
Tilling	33 (1)	100 (0)	95 (42)	100 (24)	100 (2)	100 (0)	84 (85)

Source: Results, survey May 2014.
(): Number of producers who have used the cropping practice.

To compare *Pachyrhizus* spp. and OFSP with major crops grown by producers in the dissemination AEZs, maize, bean, and cowpea were retained as three reference crops. Yields estimated by the surveyed producers of these three crops are presented in Table 6.

Table 6 Distribution of producers depending on the cropping practices by AEZ

Crop	Agro-ecological zones						Benin
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terres de barre*	Depression	Fisheries	
Maize	102	121	797	2,826	1,825	93	1,111.9
Common Bean	48	47	313	390	535	54	250.9
Cassava	2,233	2,323	7,019	9,008	8,500	4,300	6,690.0

Source: Results, survey May 2014.

5.2 CULTIVATION OF YAM BEAN AND OFSP

Table 7 provides information about the available and cropped areas and the areas cropped with yam bean. It can be seen that the area cropped with yam bean does not depend on the available area. In fact, the West-Atacora zone, which does not have the largest available area, is the zone with the largest cropped area for yam bean (0.14 ha).

Table 7 Average available and cropped area (ha) per AEZ

Area	Agro-ecological zones						Benin
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terres de barre*	Depression	Fisheries	
Average available	18.50	9.47	7.29	3.21	9.5	5.65	6.76
Cropped on average	0.15	0.18	1.75	1.72	1.12	0.48	1.30
Yam bean on average	0	0.14	0.07	0.04	0.04	0.04	0.05

Source: Results, survey May 2014.

Table 8 provides information on the average production and average yield of yam bean and OFSP. With respect to the cultivation of yam bean, the zones of *terres de barre* and Depression have the highest average production (11 storage roots/m^2), followed by the Cotton zone Center-Benin with 10 storage roots/m^2. For OFSP, the Food Crop zone South-Borgou yields on average 15 storage roots/m^2, followed by the zone of *terres de barre* and the zone of depression with on average 12 storage roots tubers per m^2. In terms of yam bean grain yield, the West-Atacora zone presents the highest yield average (3,010.56 kg/ha). For yam bean storage root the highest average yield was is recorded in the cotton zone of Center-Benin (35,665.85 kg/ha) The best average yield for the storage root of OFSP was recorded in the *terres de barre* zone, with 10,500 kg/ha.

Table 8 **Average available and cropped area (ha) per agro-ecological zone**

Parameters	Agro-ecological zones						Benin
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terres de barre*	Depression	Fisheries	
Production (N of storage roots/m²)							
Yam bean	9	8	10	11	11	7	9
OFSP yield (kg/ha)	15	11	11	12	12	10	11
Yam bean grain	543.3	3,010.6	2,426.5	797.83	1,300	967	1,894.8
Yam bean storage roots	7,000	11,541.7	35,665.9	23,166.7	4,850	9,950	24,043.4
OFSP storage roots			9,416.7	10,500	10,000		9,863.6

Source: Results, survey May 2014.

Storage estimates were not carried out for yam bean in the Food Crop zone of South-Benin, in the zones of *terres de barre* and Depression. For OFSP, storage was estimated in the Cotton zone Center-Benin (Table 9). About 16.7% on average of yam bean production was stored in the Fisheries zone, 68.8% was stored in the Cotton zone Center-Benin, and 70.7% of the yam bean production was stored in the West-Atacora zone. For OFSP, 30% was stored in the Cotton zone North-Benin. The analysis of these results shows that yam bean was stored more than OFSP.

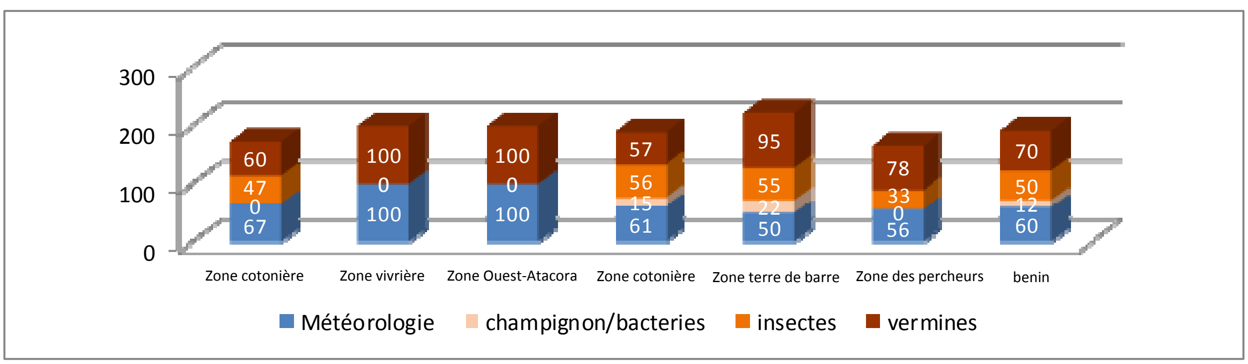
Table 9 Quantity stored (in %) of yam bean and OFSP production

Quantity Stored	Agro-ecological zones						
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terres de barre*	Depression	Fisheries	Benin
Yam bean	0	70.7	68.8	0	0	16.7	56.5
OFSP	0	0	30.0	0	0	0	23.8

Source: Results, survey May 2014.

5.3 AGRICULTURAL PRODUCTION CONSTRAINTS

There are four categories of constraints related to production for the entire study zone. These are weather problems, fungal/bacterial attacks, insect damage, and vermin problems. In the Food Crop zone of South-Borgou and West-Atacora zone, producers are faced with weather problems and attacks by termites and worms (Fig. 2). The observations reveals that all the producers (100%) in these two zones (3 and 4) are faced with weather and vermin problems. To these two categories of constraints is added insect attacks in the Cotton zone North-Benin and in the Fisheries zone. In the Cotton zone Center-Benin and the *terres de barre* zone, producers are faced with all categories of constraints.



Source: Results, survey May 2014.

Figure 2. Distribution of producers reporting agricultural production constraints in AEZs.

These different categories of constraints have adverse effects on the yield, the tubers, the pods, and even on the growth of plants. Table 10 presents damages caused depending on the categories of constraints per AEZ.

Table 10 Quantity stored (in %) of yam bean and OFSP production

AEZ	Weather Damage	Fungal or Bacterial Damage	Insect Damage	Termite and Worm Damage
West-Atacora zone	Ahipa and sweetpotato leaves drying out reduces yields of both crops Cracks of tubers Yellowing of leaves		Infested tubers Tubers with holes Spotted tubers Leaves slightly destructed Plant stunted growth Soft tubers	Rotten tubers
Food crop zone South-Borgou	Seedling blight Stunted growth Reduction of tubers Dried seedlings Seedlings blight Leaves yellowing			Rotten tubers
Cotton zone Center-Benin	Seedling blight Stunted growth Reduction of tubers Dried seedlings Burnt seedlings Leaves yellowing Change in leaves color Loss of leaves	Change in leaves color Black spots on the leaves Shrinking of leaves Destruction of leaves and stalks Plant stunted growth	Perforated leaves Perforated tubers Loss of leaves Destruction of tubers Perforated tubers Change in the color of the leaves Plant stunted growth	Tubers perforated by termites Low yield Attack of tubers by worms
Zone of the *terres de barre*	Leave loss Seedling dried up Burnt seedlings seedling blight Reduction of the weight of tubers Low water content Difficult or slow germination	Stunted growth of the root Yellowing of leaves Rotten tuber Stalk whitening	Perforated leaves Destruction of leaves Pod perforated by caterpillars Perforated tubers Leaves stunting Plant stunted growth	Worm shelters on some tubers Spotted tubers Rotten tubers Attack of tubers by termites
Depression zone	Rotten tubers			
Fisheries zone	Flowers drying out Stunted growth		Perforated leaves Perforated tubers	Rotten tubers Destruction of tubers by rodents

Source: Results, survey May 2014.

5.4 STORAGE PROBLEMS

Producers in the Food Crop zone of South-Borgou and in the zones of the *terres de barre* and Fisheries did not observe storage problems with yam bean and OFSP products. However, producers in the Food Crop zone of South-Borgou and in the zone of the *terres de barre* do not store any of these two products, and those in the Fisheries zone stock only yam bean. In field-storing yam bean and OFSP, the producers reported more problems with fungi/bacteria than with insects and vermin (Table 11).

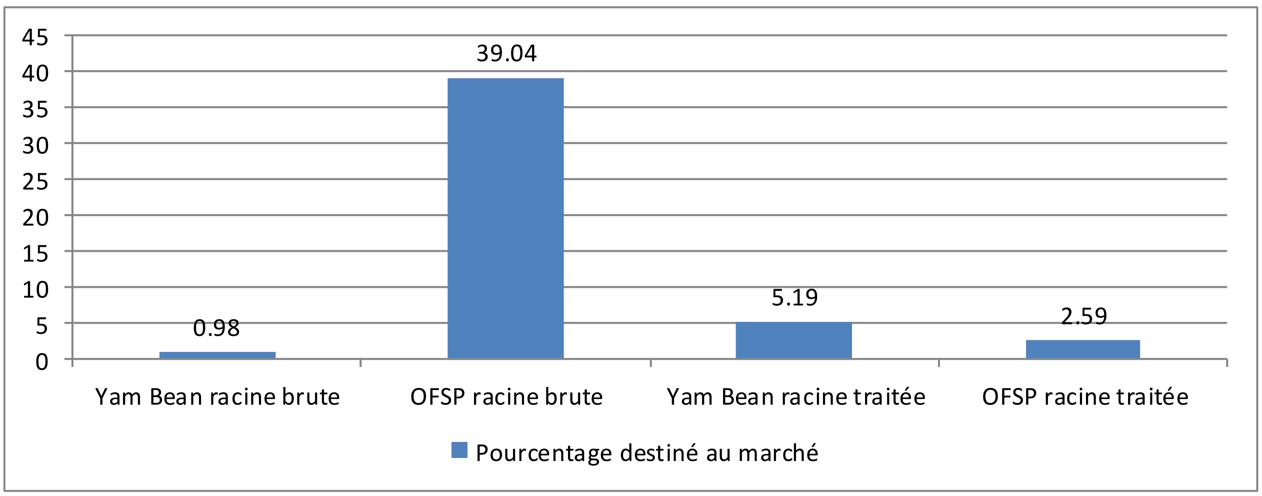
Table 11 Number of producers who have experienced storage problems depending on the types of storage problems per AEZ

Parameter	Agro-ecological Zones						Benin
	Food Crop Zone South-Borgou	West Atacora	Cotton Zone Center-Benin	*Terre de barre*	Depression	Fisheries	
Fungi/bacteria	0	2	5	0	0	0	7
Insects	0	1	3	0	0	0	4
Vermin	0	1	2	0	0	0	3

Source: Results, survey May 2014.

Economics of *Pachyrhizus* spp. and of OFSP

Figure 3 shows the market share of yam bean and OFSP at the raw step and the processed step. The production of OFSP at the raw step has an important market share, about 39%. The estimate of the market share of processed yam bean is 5.2%. Raw root of yam bean has had in our study the smallest market share (1.0%). We conclude that currently producing yam bean in Benin will only be profitable for the producer when yam bean is processed. This is in contrast to the relatively large raw yam bean market in Central and North America and Asia. With OFSP it is not necessary to process the crop to bring it to the market.



Source: Results, survey May 2014.

Figure 3. Market share in (%) of yam bean and OFSP crops at the raw and processed steps.

Information in Table 12 confirms the previous hypothesis according to which the cultivation of yam bean will currently only be profitable when it is processed. In fact, the average selling price of raw root of yam bean is at present only 20 Fcfa/kg compared with 1,630 Fcfa/kg for the processed yam bean storage roots. The selling price of the raw root of OFSP is 105 Fcfa/kg compared with 160 Fcfa/kg for processed storage roots.

Table 12 Number of producers who have experienced storage problems depending on the types of storage problems per AEZ

Crops	Market Share (%)	Average Sales Price (Fcfa/kg)
Raw tubers of yam bean	0.98	20
Raw OFSP	39.04	105
Processed tubers of yam bean	5.19	1,630
Processed OFSP	2.50	160

Source: Results, survey May 2014.

The average sales price of raw root of yam bean (20 Fcfa/kg) is relatively low compared with that of the reference crops (raw maize, raw bean, and raw cassava): 150 Fcfa/kg, 290 Fcfa/kg, and 94 Fcfa/kg, respectively (Tables 12 and 13). This might be because the yam bean is still an unknown crop in Benin—and processed, it comes more closely to known food products. For raw OFSP (105 fcfa/kg), the sales price was very close to cassava (94 fcfa/kg). The situation changes when yam bean is converted from raw to a processed product. Then the price is relatively high (1,630 fcf/kg) compared with the sales price of reference crops of processed maize, processed bean, and processed cassava—that is, 187 fcfa/kg, 372 fcfa/kg, and 84 fcfa/kg, respectively (Tables 12 and 13).

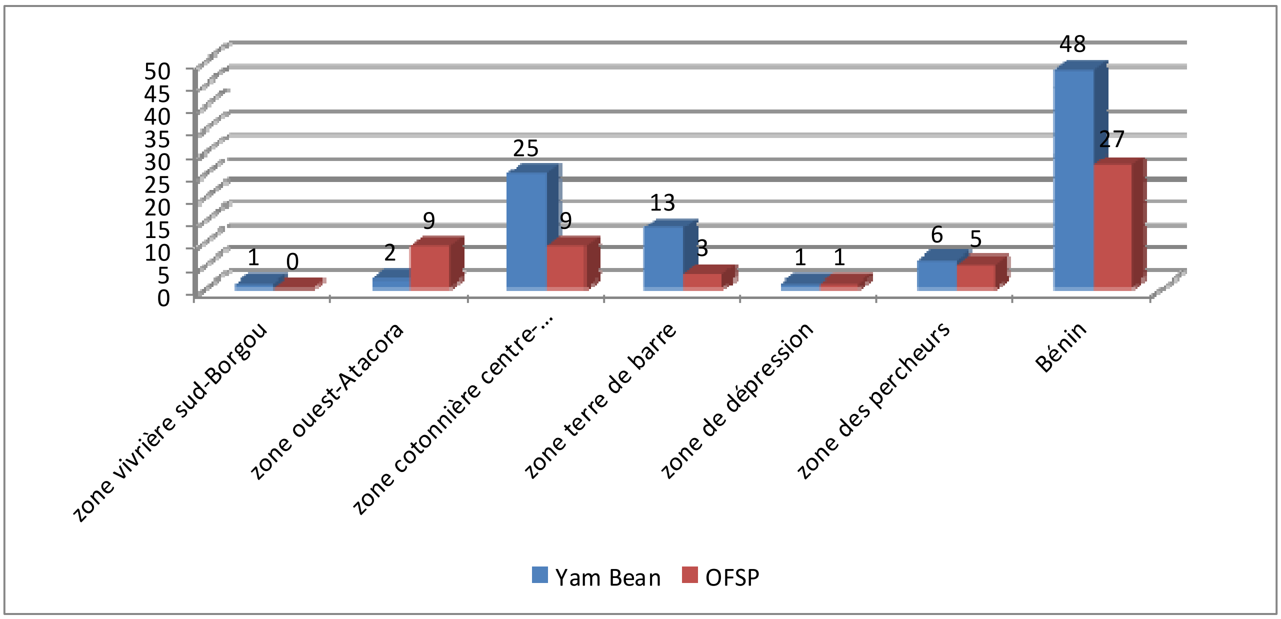
Table 13 Sales price (in fcfa per kg) of raw and processed reference crops (maize, bean, and cassava)

Average Sales Price (in fcfa/kg)	Reference Crops		
	Maize	Bean	Cassava
Raw product	150	290	94
Processed product	187	372	84

Source: Results, survey May 2014.

5.5 ANALYSIS OF THE ADOPTION STATUS OF *PACHYHRIZUS* SPP. AND OFSP IN BENIN

The Cotton zone in Center-Benin has the greatest number of adopters of yam bean (25) and OFSP (9) in our study on 101 farms across the country. We observed that the yam bean adoption rate is higher for yam bean than for OFSP (Fig. 4).



Source: Results, survey May 2014.

Figure 4. Distribution of producers who have adopted yam bean and OFSP among the study group of 101 producers surveyed by per AEZ.

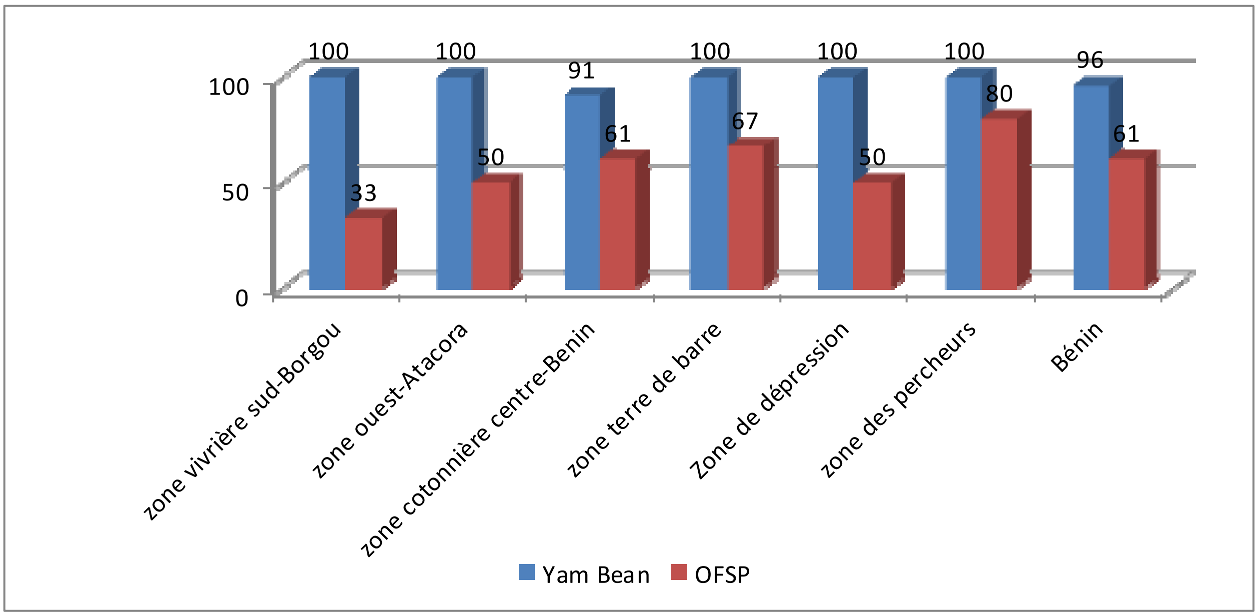
Table 14 shows that in our study group, the yam bean is more known among farmers than is OFSP (100% of farmers know yam bean v. 84% for OFSP). Among those who know the crops, the percentages of those who have used them at least once are 97% for yam bean and 42% for OFSP. The highest adoption rates were observed with 47% for yam bean and 31% for OFSP (Table 14).

Table 14 Adoption status of yam bean and OFSP

Crop (a)	No. of farmers informed about the existence of the crop (b)	No. of farmers who have tried the crop(s) at least once (c)	Implementation rate of the crop (c/b)	No. of farmers who have adopted after the trial (d)	Current adoption rate of the crop (d/b)	No. of farmers who have abandoned after the trial (e)
Yam bean	101 (100)	98 (97)	97,03	48	48 (47)	57
OFSP	85 (84)	36 (42)	42,35	27	27 (31)	18

() = in brackets numbers are given in percentage. Source: Results, survey May 2014.

Figure 5 shows that in the Food Crop zone in South-Borgou, the percentage of producers who intend to continue growing OFSP is less than half of the study group (33%). In general, the percentage of producers who intend to continue growing yam bean is higher than that of those who intend to continue growing OFSP.



Source: Results, survey May 2014.

Figure 5. Percentage of producers who intend to continue growing yam bean and OFSP per AEZ.

5.6 DISSEMINATION OF *PACHYRHIZUS* SPP. AND OFSP

Distribution of *Pachyrhizus* spp. and OFSP producers

Section 3 described the strategy put in place in Benin to promote yam bean and OFSP. At least 264 producers have received the seeds of yam bean and have tried the crop (Table 4, see also subsection 4.2). Figure 6 shows the dissemination of yam bean and OFSP in Benin. Moreover, a self-dissemination of yam bean has been observed. Thus 15 producers have cultivated yam bean on their own initiative after having seen it with their neighbors and/or relatives. According to the surveyed producers, there were several reasons for this decision: sensitization was made about the derivative products, the good taste of the storage root, the quality of the *gari* made in association with cassava, its ability to enrich soils, the diversity of products made from its processing, and for its nutritive value.

Others who have also seen the crop were reluctant to crop it. The main reasons given were the absence of market to sell it, the lack of knowledge of the uses of yam bean, and cooking problems compared with other root and tubers.

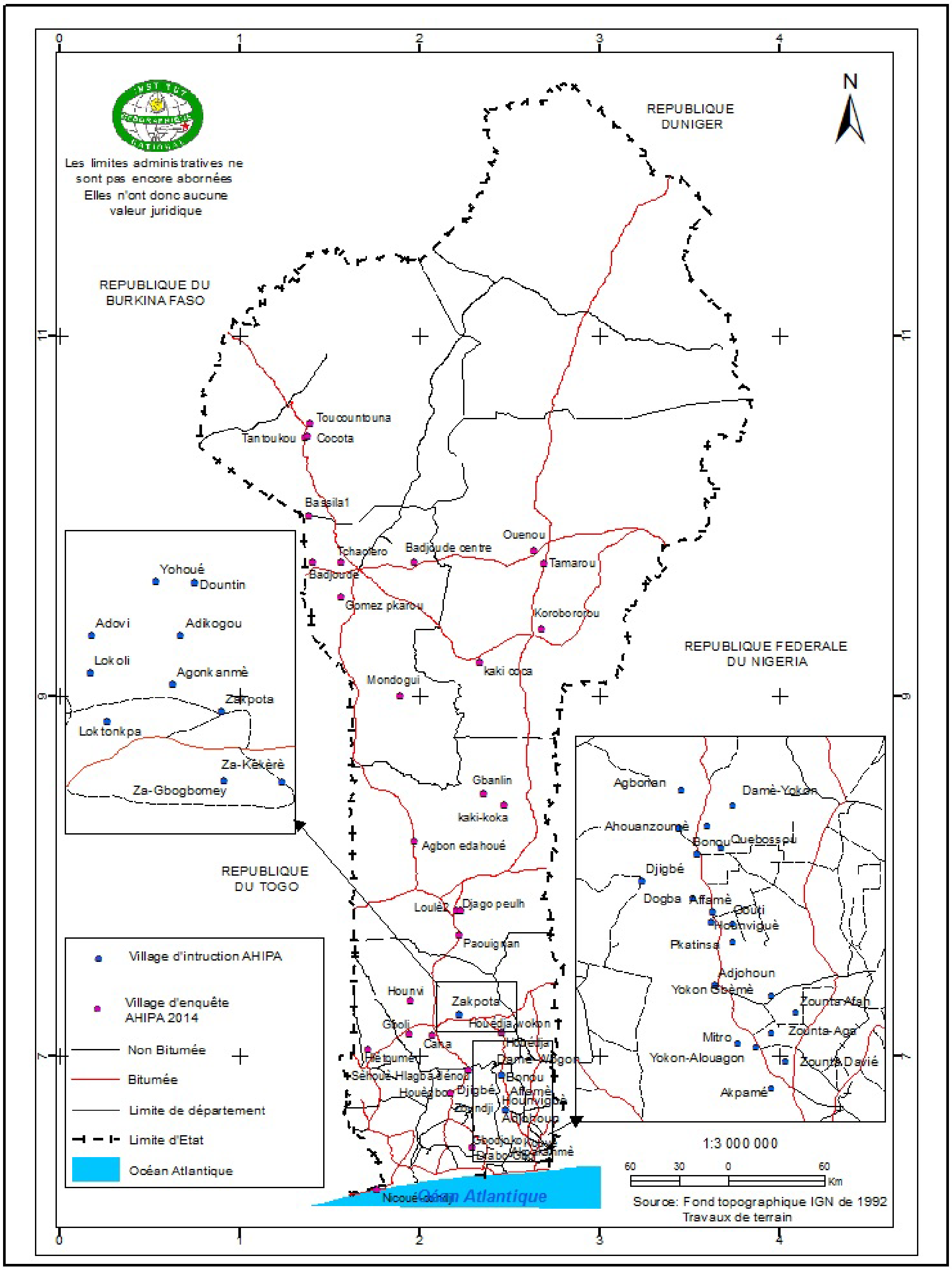


Figure 6. Dissemination of yam bean and OFSP in Benin.

Uses of yam bean

Producers have used yam bean storage roots in very different ways (Table 15). Most of the producers have processed the tubers into *gari* mixed with cassava. They have also used it to feed animals in certain villages.

Table 15 Different uses of yam bean

Use	No. of Producers	Producers (%)
Processing	8	30.8
Animal feed	4	15.4
Other uses (raw, juice, alcohol etc.)	7	26.9
Total	**19**	**73.1**

Source: Results, survey May 2014.

In fact, the yam bean storage roots are very appreciated by consumers because of its good taste when raw. Many farmers plan the cultivation to improve soil fertility through rotten upper biomass. According to farmers, the crop can give strength to people who consume it and improve the health condition of any animal.

5.7 PERCEPTIONS OF YAM BEAN PRODUCERS

Table 16 gives an overview of the main advantages of the yam bean perceived by the surveyed producers.

Table 16 Prioritization of advantages related to the cultivation of yam bean

Advantage	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Score*
Obtaining *gari* mixed with cassava	5	21	13	2	8	7.07
Good organoleptic, energetic, and nutritional quality	20	30	16	7	20	7.02
Low production cost	0	27	9	18	8	6.13
As fodder in animal feed	2	7	28	19	22	5.76
Other advantages	17	0	17	13	20	5.53

Source: Results, survey May 2014.

Table 16 shows that the three main advantages are obtaining *gari* after mixing it with cassava; the good organoleptic, energetic, and nutritional quality; and its low production cost. Despite all the advantages of yam bean, several constraints were mentioned and are related to its cultivation as well as its consumption (Table 17).

Table 17 Majors constraints to yam bean cultivation

Constraints	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Score*
Hard cropping operations	32.5	40	17.5	5	5	0	4.9
Tedious tilling	30	27.5	20	17.5	5	0	4.6
Non-mastery of planting techniques	32.5	17.5	22.5	17.5	7.5	2.5	4.42
Lack of knowledge of processing processes	0	2.5	7.5	20	35	35	2.07
Difficulty to dig holes to put stakes	0	0	7.5	10	37.5	45	1.8
Non-availability of seeds	5	12.5	25	30	10	17.5	3.2

Source: Results, survey May 2014.

The analysis reveals that there are three main constraints: hard cropping operations of yam bean, tedious tilling, and non-mastery of planting techniques.

6. CONCLUSIONS, PERSPECTIVES, AND IMPLICATIONS

This study analyzes the dissemination and adoption of yam bean cultivation in Benin. The results show that, despite a self-dissemination of yam bean, its current adoption rate is 47%.

In all AEZ, crop rotation has a particular interest. It is practiced by all surveyed producers in the Depression zone and in the Fisheries zone. The market share of yam bean processed is currently 5.2%, with raw yam bean root having the smallest market share (0.98%). This is an interesting aspect since in the Americas and Asia the yam bean market is only for raw yam bean storage root. For Benin we conclude that the cultivation of yam bean can only be profitable for producers when the crop is processed. As to the average sales price, it is relatively low for raw yam bean root (20 Fcfa/kg), but for the processed storage roots it seems to be high (1,630 Fcfa/kg).

The main advantages related to the cultivation of *P. erosus* yam bean are fourfold: (1) *gari* obtained from mixing it with cassava, (2) good organoleptic taste, (3) energetic and nutritional quality, and (4) its low production cost. Despite all the advantages related to yam bean, several constraints were mentioned and are related to its cultivation and its consumption: (1) hard cropping operations of yam bean, (2) tedious tilling, and (3) non-mastery of planting techniques.

Most of the farmers highly wish/appreciate training courses on ahipa processing and are looking for markets to sell the product. Yet most ignore ahipa processing techniques. Therefore, we consider training on processing as a key to introduce ahipa into the local diet of Benin. For the introduction of such a new crop in farmers' fields, we recommend to the CIP project the methodology of INRAB and that national development structures be informed and/or associated in each cropping zone.

7. ACKNOWLEDGMENT

At the end of the activities carried out and the results achieved, we sincerely thank CIP for its decisive financial support for the implementation of this study. The technical and administrative support from the National Agricultural Research Institute of Benin (INRAB) was indispensable in conducting this study. We express our gratitude to all its managers. Our sincere thanks also go to the surveyed producers in the different AEZs for their frank collaboration.

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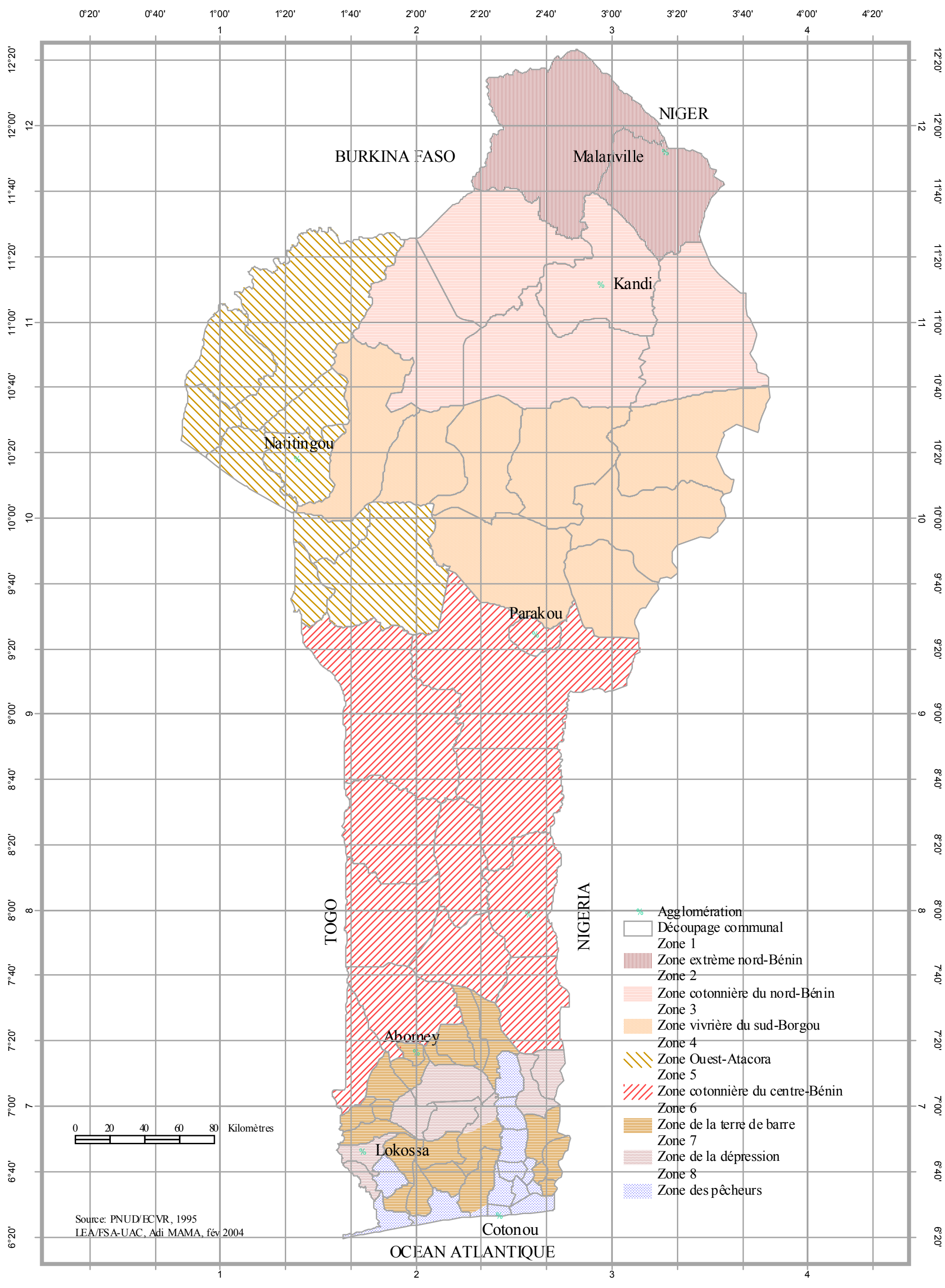
ANNEX 1: AGRO-ECOLOGICAL ZONES IN BENIN



ANNEX 2: DETAILS ON THE NUMBER OF PARTICIPANTS IN THE DISSEMINATION AND SURVEYS ACCORDING TO THE AEZ, THE COMMUNE, AND THE VILLAGE IN BENIN

AEZ	Commune	Village	Geographic Coordinates			Participating in the dissemination phase 2011	Participating in the dissemination phase 2012	Participating in the dissemination phase 2013	Interviewed in 2014
			Longitude	Latitude	Altitude (masl)				
Food Crop zone of South Borgou	N'dali	Gomez pkarou	09°32.920	001°33.991	333	2	4	0	1
		Ouenou	09°48.251	002°37.988	352	0	1	0	1
		Tamarou	09°44.075	002°41.751	381	1	0	0	1
	Bembèrèkè	Gando Paris Peulh				0	1	0	0
		Bore				0	1	0	0
	Nikki	Nikki				0	1	0	0
	Subtotal zone	**6**				**3**	**8**	**0**	**3**
West-Atacora zone	Ouaké	Badjoude	09°44.694	001°24.379	429	0	1	0	1
		Badjoude centre	09°44.673	001°58.393	429	0	5	0	5
	Toucountouna	Cocota	10°26.067	001°21.844	390	0	5	0	5
		Tantoukou	10°26.485	001°22.830	420	1	1	1	1
		kaki coca	09°11.168	002°20.161	289	0	2	0	1
		Toucountouna	10°30.610	001°23.659	489	0	3	0	0
	Natitingou	Natitingou				0	4	0	4
	Copargo	Tchaclero	09°44.337	001°33.991	437	0	1	0	1
	Subtotal zone	**8**				**1**	**22**	**1**	**18**
Cotton zone of Center Benin	Ouèssè	Gbanlin	08°27.438	002°21.628	240	3	1	0	3
	Bassila	Mondogui	08°59.985	001°53.524	324	4	5	0	4
		Dépani				0	3	0	0
		Camp pionnier				0	5	0	0
		Wannou				0	4	0	0
		Alédjo NGO ADRIA				0	8	0	0
		Bassila1	08°59.745	001°23.224	337	1	4	0	1
	Parakou	Korobororou	09°22.348	002°40.917	354	1	0	0	1

AEZ	Commune	Village	Geographic Coordinates			Participating in the dissemination phase 2011	Participating in the dissemination phase 2012	Participating in the dissemination phase 2013	Interviewed in 2014
			Longitude	Latitude	Altitude (masl)				
	Tchaourou	kaki-koka	08°23.468	002°28.169	332	2	0	0	2
	Bantè	Agbon edahoué	08°11.350	001°58.393	241	1	6	0	1
	Dassa	Paouignan	07°40.350	002°13.410	198	2	11	8	12
		Loulè2	07°48.346	002°12.452	201		5	0	2
		Djago peulh	07°48.299	002°13.592	196		1	0	0
		Djago	07°48.299	002°13.592	196		1	0	1
	Djidja	Hounvi	07°18.310	001°57.248	184		21	6	15
	Aplahoué	Hlétoumè	07°02.005	001°43.051	252		3	0	2
	Glazoué	Assanté				3	5	0	0
		Okoroto				1	7	0	0
	Savè	Ouogui				5	5	0	0
	Subtotal zone	**19**				**23**	**95**	**14**	**44**
Zone of the *terres de barre*	Zogbodomey	Cana (Gandjè kpindji)	07°07.045	002°04.182	122	2	5	2	5
	Agbangnizoun	Gboli	07°07.125	001°56.582	202	1	11	2	9
	Abomey-Calavi	Drabo-Gbo	06°29.582	002°17.471	32		5	1	4
		Glo-kpossouhué CALAVI				0	1	0	0
		Gbodjoko	06°35.009	002°19.227	73		4	3	4
	Missrété	Akpakanmè	06°31.278	002°29.344	63		2	0	0
		Kouvè	06°34.112	002°33.599	51		2	0	2
		Zoundji	06°44.033	002°25.603	59		5	0	0
	Za-Kpota	Kodota					1	1	0
		Za-Kpota centre					2	2	0
		Djoyitin					1	1	0
		Zakékéré					2	2	0
		Zazoumè					1	1	0
		Agbogbomè					1	1	0
		Adikogon					5	5	0
		Lontonkpa					5	5	0

AEZ	Commune	Village	Geographic Coordinates			Participating in the dissemination phase 2011	Participating in the dissemination phase 2012	Participating in the dissemination phase 2013	Interviewed in 2014
			Longitude	Latitude	Altitude (masl)				
		Houangon					1	1	0
	Subtotal zone	**18**				**3**	**53**	**27**	**24**
Depression zone	Toffo	Houègbo	06°47.478	002°10.436	155	1	0	0	1
		Guémè-Sèhouè	06°55.418	002°16.232	84		1	0	1
		Sèhouè Hlagba dénou	06°55.418	002°16.232	84		1	0	0
	Subtotal zone	**3**				**1**	**2**	**0**	**2**
Fisheries zone	Grand-popo	Nicoué-condji	06°15.578	001°46.083	6		7	0	2
	Ouinhi	Houédja	07°07.689	002°27.475	28	6	7	1	6
		Houédja wokon	07°04.938	002°28.351	41	2	0	0	2
	Bonou	Akpaloko					2	2	0
		Sèdjè					1	1	0
		Assrossa					2	2	0
		Ouibossou					1	1	0
		Ahouanzoumè					3	3	0
		Sècodji					1	1	0
		Bonou-centre					1	1	0
		Agbonan					8	8	0
	Dangbo	Zounta-aga					3	3	0
		Gbémintofi					1	1	0
		Akokponawa					1	1	0
		Mitro					1	1	0
		Yokon-gbémè					1	1	0
		Saï-lazare					1	1	0
		Yokon					1	1	0

AEZ	Commune	Village	Geographic Coordinates			Participating in the dissemination phase 2011	Participating in the dissemination phase 2012	Participating in the dissemination phase 2013	Interviewed in 2014
			Longitude	Latitude	Altitude (masl)				
		Zounguè					1	1	0
		Akpamè					3	3	0
		Djigbé					3	3	0
		Hozin					1	1	0
		Hondji					3	3	0
	Subtotal zone	**23**				**8**	**53**	**40**	**8**
Total	**27**	**75**				**39**	**231**	**82**	**101**

APPENDIX 7

FINAL REPORT BØRNEFONDEN (BENIN)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: Report on Ahipa production at BØRNEfonden-Benin Development Unities (June 2012 to May 2014)

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: NESTOR ALOKPAI - BØRNEFONDEN-BENIN

J U N E 2 0 1 4

CONTENTS

ABSTRACT

BØRNEfonden-Benin, a nongovernmental organization (NGO), has been working for about two years (2012–2014) with the yam bean in intervention areas in Benin (Bonou, Adjohoun, Dangbo, and Zakpota; southern part of Benin, northeast of Cotonou and northwest of Porto Novo; about 100 km from Lagos, Nigeria). The use of the yam bean by the NGO started after the national partner the National Agricultural Research Institute of Benin (INRAB) had shown that the crop is well adapted to the growing conditions of Benin and that the new crop can be processed into a various foods (gari, juice, yogurt, liqueur/alcohol, chips, and flour). Crop yields of the storage roots are remarkably high, with 25.0, 16.7, 15.8, and 14.6 t/ha across farms in the areas of Bonou, Adjohoun, Dangbo, and Zakpota. In total, 71 farmers reported their harvests. Awareness campaigns were undertaken to promote processed food products from yam beans. Access to markets by promoting yam bean products and make people in Benin more aware of them would make the crop more profitable to farmers.

We believe that the crop would require only two years of moderate investments (about US $10,000–20,000/year) to really take off in the southeastern part of Benin, close to the Nigerian border. The major advantage of this new root crop—apart from yield, processing options, and nutritional quality—is that it is relatively easily to supply seed to farmers who made our on-farm success possible. That is, during the project period, we could supply only 8 farmers with orange-fleshed sweetpotato planting material, compared with 80 farmers with yam bean seed for 500 m^2 per farm). BØRNEfonden-Benin considers the project to be very successful and will continue to work with the crop for at least two years on its own funds. However, the most critical part for farmers are buyers and markets to achieve a sustainable adoption of the crop in the target region of southeast Benin.

1. INTRODUCTION

This report is the second and the final report on the cooperation of BØRNEfonden-Benin with the Ahipa project (2013–2014), as stated in the letter of agreement between BØRNEfonden-Benin and the International Potato Center (CIP) with respect to ahipa on-farm trials.

The Ahipa project has involved 80 producers at BØRNEfonden-Benin Development Unities and BØRNEfonden-Benin intervention areas. At the time of reporting, 71 farmers have already achieved the production process up to harvesting. This report highlights the yam bean harvesting and the different uses from yam bean processed products.

2. AHIPA HARVESTS

The yam bean trials were harvested from 1 to 30 November 2013. Harvest was supervised by the field advisors recruited by BØRNEfonden in the framework of the project.

The result of the production yield shows that the trials were more successful in 2013 than in 2012. The average storage root yield across all producers in the BØRNEfonden-Benin intervention areas was 25 t/ha in the area of Bonou; 16.7 t/ha in Adjohoun; 15.8 t/ha in Dangbo; and 14.6 t/ha in the area Zakpota (see Annex 1).

The highest root yields obtained was about 49.7 t/ha (in Bonou), whereas the lowest was 3.6 t/ha (in Zakpota). This year, as we have started the production process earlier, the farmers' selection and required technical procedures were strictly followed up so that activities fit into the growing season. The timing for cultivation was the best possible, and we did not face any drought as we did with the bad weather in 2012. A seed production trial covered about 100m² per farm, but it was a bit difficult to estimate precisely because some farmers had hidden some part of their products in order to plant them next year or to sell. More detailed information on the ahipa trials in 2013–2014 are provided in the questionnaire survey that we implemented and shared with CIP.

3. AHIPA SALES PRICES DEFINED FOR FARMERS

The market price for ahipa has been aligned with the one defined last year (i.e., **150 CFA F/kg and compared with cassava**, which is the reference product). This is a good price (1 kg of cassava is sold at 75 CFA F). However, ahipa cultivation is twice as difficult than cassava production, but it can allow for **two harvests per year**. It is mainly the pruning operation required for ahipa that is the more difficult operation mentioned by the farmers. This has a huge impact on the cost of ahipa production compared with cassava production. However, farmers are aware that ahipa has **more options than cassava** with respect to processed products likely to be more valued at markets.

4. OPERATIONS TO PROMOTE YAM BEAN

In 2013–2014 about 50% of the whole yam bean production has been processed for advertising and marketing (this activity will be ongoing in 2014/15 based on own funds of BØRNEfonden-Benin). About 50% was used as food for families, in kindergartens, and during nutritional sessions with nursemaids and children.

About 1,000 persons have tasted the crop during three public sessions in the communities where BØRNEfonden is working (see Annex 2) and during a local fair organized by BØRNEfonden. About 30% of the total production has been processed in various products such as *gari*, juice, yogurt, liqueur (alcohol), chips, and flour and sold at this fair. In advance of the fair, the farmers (men and women) who have abilities in food processing have been trained by Dr. Wilfried Padonou. After the training sessions, the farmers and others who were trained did a great job by producing many ahipa-processed products especially for the fair and the tasting sessions. The yam bean products have been very appreciated by the participants at the fair and at the tasting sessions. In addition, eating fresh ahipa was also very appreciated, especially with roasted groundnuts.

In the kindergartens and through the nutritional sessions, about 300 children and mothers have eaten ahipa products. Producers are advised to organize ahipa consumption sessions in their home and villages. For the tasting sessions, two videos were produced and many photos were taken during those sessions. Although these actions helped to promote ahipa, the crop remains largely unknown by the general public. Moreover, the producers do not have opportunities to sell it on the market because we did not attend to any fair and did not have tasting sessions in the big towns such as Porto-Novo, Cotonou, and Bohicon.

However, with the production level of this year (2014), we greatly need this kind of promotion in urban markets. We plan to organize further ahipa marketing in our largest towns. BØRNEfonden is also planning to contact some customers in Cotonou (restaurants and individual consumers) and in the harbor.

5. OFSP PRODUCTION

With respect to OFSP production, we received some planting materials (vines) in December 2013, for eight famers in the area of Bonou; trials are going very well so far. Actually, Bonou is the largest area of sweetpotato cultivation in Benin and farmers are used to this crop. The OFSP accessions received from CIP-Ghana are Lanwara, Ejumura, and Carote-C.

6. CONCLUSION

In general, yam bean trials on-farms in BØRNEfonden's area of intervention were very successful in 2013–2014. The objectives of BØRNEfonden the next year are to help farmers to gain access to markets by promoting ahipa products and making ahipa and OFSP production better known to the people of Benin and more profitable. BØRNEfonden also plans to introduce yam bean consumption into the eating habits of the rural communities and in the towns, especially for children and young people, and help train some women and men on yam bean processing.

Finally, we thank CIP for the financial support given to BØRNEfonden for implementing the ahipa project. We hope to continue the collaboration

ANNEX 1: STORAGE ROOT YIELDS FOR AHIPA PRODUCTION TRIALS AT DANGBOBONOU, AND ZAKPOTA

1: Commune	Name	Accession	Cultivated area (m^2)	Quantity (kg)/1,000m²	Yield (t/ha)
Adjohoun	Agoundjo Rahmane	EC 533	500	1880	18,80
	Ahissou Vlavonou	EC 533	500	1640	16,40
	Aïhoubo Robert	EC 533	500	2050	20,50
	Akotegnon Justin	EC 533	500	1840	18,40
	Dah Zoundji Sylvère	EC 533	500	2380	23,80
	Djossinou Didier	EC 533	500	1324,5	13,25
	Dossou Daniel	EC 533	500	1470	14,70
	Lavinon Ezechiel	EC 533	500	880	8,80
	Sossou Sylvain	EC 533	500	1750	17,50
	Soton Théodore	EC 533	500	1850	18,50
	Vossanou Edgard	EC 533	500	1100	11,00
	Zoclaclounon Valère	EC 533	500	1880	18,80
Bonou	Average Adjohoun	EC 533	500	-	16,70
	ADANLIENKLOUNON Anicet	EC 533	500	1300	13,00
	Aglo Dossou	EC 533	500	1320	13,20
	Agossou Mathias	EC 533	500	2220	22,20
	ALLOMASSO Alain	EC 533	500	4235	42,35
	Atcha Martin	EC 533	500	3010	30,10
	AYIMASSE Jean	EC 533	500	2400	24,00
	Dah-Sefan Eusèbe	EC 533	500	2596	25,96
	Dohou Janvier	EC 533	500	2505	25,05
	DOHOU Thimotée	EC 533	500	1035	10,35
	Dossou Victorin	EC 533	500	2830	28,30
	Doutchemey Gaétan	EC 533	500	3348	33,48
Dangbo	FAGNON Laurent	EC 533	500	2980	29,80
	Hountondji Tchègoun	EC 533	500	1760	17,60
	KOUDENOUKPO Jean	EC 533	500	3050	30,50
	Mevegni René	EC 533	500	1765	17,65
	SEGBE François	EC 533	500	4970	49,70
	Sonon Jacob	EC 533	500	1985	19,85
	Tougou Michel	EC 533	500	1730	17,30
	Average Bonou	EC 533	500	-	25,02
	Akouègnihodé Lobaloké	EC Kew	500	1520	15,20
	Atchonoude Djimon	EC Kew	500	2250	22,50
	Dahovinon Daniel	EC Kew	500	2734	27,34
	Fagnibo Joseph	EC Kew	500	2200	22,00
	Fassinou Jean-Baptiste	EC Kew	500	2093	20,93
	Gbénou André	EC Kew	500	3500	35,00
	Gbetoho Joachim	EC Kew	500	830	8,30

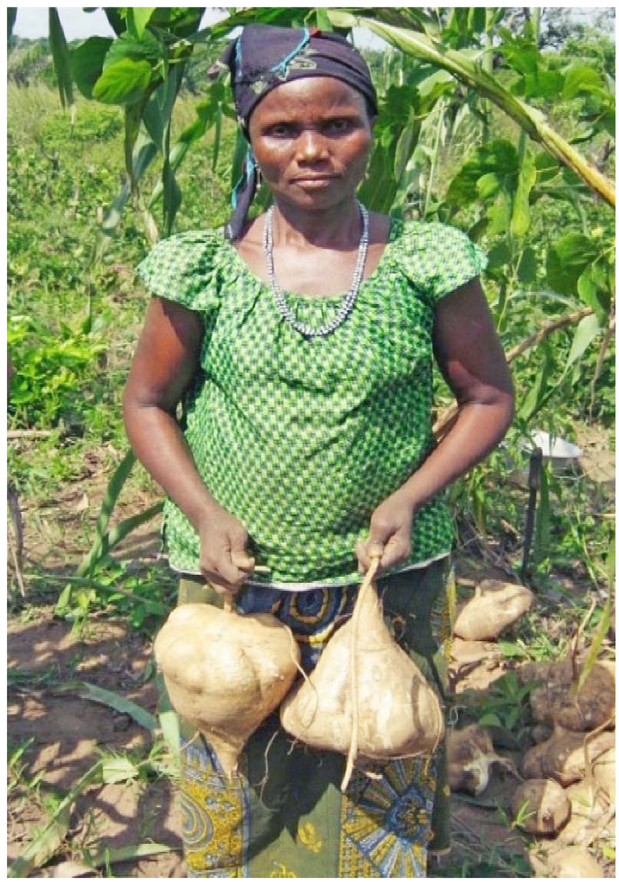
1: Commune	Name	Accession	Cultivated area (m^2)	Quantity (kg)/1,000m²	Yield (t/ha)
	Guidi Euloge	EC Kew	500	790	7,90
	Hountondji Houndévè	EC Kew	500	2035	20,35
	Kounasso Narcisse	EC Kew	500	1680	16,80
	Koussa Pierre	EC Kew	500	1570	15,70
	Monnou Charles	EC Kew	500	1671	16,71
	Nouatin Dossou	EC Kew	500	1250	12,50
	Soton Daniel	EC Kew	500	1906	19,06
	Tossou Hotèkpo	EC Kew	500	1180	11,80
	Vignon Justin	EC Kew	500	1550	15,50
	Fagnibo Joseph	EC Kew	500	765	7,65
	Yehouenou Lobayo	EC Kew	500	495	4,95
	Average Dangbo	EC Kew	500	-	15,80
	ADOGO Célestin	EC 533	500	1893,75	18,94
	AGADA François	EC 533	500	3018,75	30,19
	AGBANOU Edith	EC Kew	500	2562,5	25,63
	AHISSIN Ernest	EC Kew	500	700	7,00
	AHOGNIGNON Napoléon	EC 533	500	1656,25	16,56
	Akpado Honorine	EC 533	500	1756,5	17,57
	ALLAHIA Sévérin	EC 533	500	362,5	3,63
	ANICHEOU Mélanie	EC Kew	500	618,15	6,18
	ASSEKOU Parfait	EC 533	500	681,25	6,81
	DEDJIDJA Louis	EC Kew	500	2512,5	25,13
	DEMAGBEYAOU Azonsi	Ec Kew	500	1175	11,75
	DJEME Bienvenu	EC Kew	500	1637,5	16,38
	Dovonon Paulin	EC Kew	500	1937,5	19,38
	ETCHO Elisabeth	EC 533	500	1012,5	10,13
	GBOGBO Justin	EC Kew	500	2100	21,00
	Hazounmè Alfred	EC 533	500	2243,5	22,44
	LOUHA Sébastien	EC 533	500	3181,25	31,81
	TOUGAN Alossi	EC Kew	500	687,5	6,88
	Tougan Jean	EC Kew	500	550	5,50
	TOUGAN Véronique	EC Kew	500	612,5	6,13
	VIGAN Alexis	EC Kew	500	537,5	5,38
	WANHOUE Cyriaque	EC Kew	500	562,5	5,63
	Average Zakpota	EC Kew/EC 533	500	-	14,55

ANNEX 2: AHIPA PRODUCTION AND PROCESSING PHOTOS

A farmer prunes his ahipa crop.

A farmer poses with the stacks on his ahipa farm.

A farmer during stacking of her ahipa crop.



A farmer poses with her harvested ahipa.

A farmer harvests ahipa on his farm.

A farmer poses with his harvested ahipa.

A farmer poses with stacks of ahipa on his farm.

Ahipa processing training sessions.

Ahipa processing training sessions.

Some ahipa processed products exposed during a local fair at Adjohoun.

People visiting and buying ahipa products during a local fair at Adjohoun.

APPENDIX 8

FINAL REPORT UCL (BELGIUM)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: UCL—"Provide New Diversity to Use Yam Bean Seed (YBS) for Human Consumption"

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: UCL—UNIVERSITÉ CATHOLIQUE DE LOUVAIN/BELGIUM

M A Y 2 0 1 4

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: May 30, 2014

Methods to determine toxic compounds in yam bean seed at Université Catholique de Louvain (UCL)/Belgium under AHIPA project.
On behalf of UCL

written by:
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CONTENTS

ABSTRACT

The yam bean is a legume root crop in the genus *Pachyrhizus* and the sub-tribe *Glycininae* with high storage root yields and very wide adaptation (in Mexico, the crop is known as jicama, and in Peru and Bolivia as ahipa). In addition to storage root yields, the yam bean has high seed yields, but the seeds cannot be used due to toxic compounds. Three new methods were developed to determine rotenone and pachyrrhizine in yam bean seed. In the first, a high performance liquid chromatography (HPLC) system was used as a reference method. The second, faster methodology is using microwave extraction and U-HPLC, and the third method is based on near infrared spectroscopy (NIRS) on milled yam bean seed. In total, 227 seed samples from Peru, Uganda, and Burundi were quantified for rotenone and 127 for pachyrrhizine. In-vivo tests clearly showed that the toxicity of yam bean seed is not only due to rotenone and pachyrrhizine. In-vivo toxicity tests allowed us to identify these potential compounds as 12-hydroxypachyrrhizone, munduserone, 12-hydroxydolineone, and dehydroneotenone. The *P. tuberosus* accession CIP-209054 with very low rotenone content did not contain any 12-hydroxypachyrrhizone and was not toxic when it was tested in vivo at the dose where other samples were.

1. OBJECTIVE AND BACKGROUND

1.1 OBJECTIVE

The Université Catholique de Louvain (UCL) contributed to the specific objective 6 of the Ahipa project—namely, "to provide new diversity to use yam bean seed (YBS) for human consumption," and particularly search for genotypes with low/no rotenone or other toxic/anti-nutritional factors in their seeds in order to allow human/animal consumption.

1.2 BACKGROUND

The yam bean is a legume root crop in the genus *Pachyrhizus* and the sub-tribe *Glycininae* with high storage root yields and very wide adaptation (in Mexico the crop is known as jicama, and in Peru and Bolivia as ahipa). In addition to storage root yields, the yam bean has high seed yields: Zanklan et al. (2007) reported a seed yield of 5.7 t/ha (and remarkably 4.7 t/ha under drought-stress conditions) across 14 *P. erosus* accession in Benin, West Africa. However, YBS are only used to propagate the crop because they are toxic. At the beginning of the project, the assumption was that the toxicity of the yam bean is due to rotenone (a potentially toxic isoflavonoid). This is reported in several publications, but most are traced back to Santos et al. (1996). No detailed studies have been conducted that makes YBS toxic; however, it appears that YBS protein and oil are quite similar to soybean protein and oil (Santos et al. 1996; Grüneberg et al. 1999). Note that there are very few reports about fatal cases of YBS toxicity (Narongchai et al. 2005), although the crop is widely grown and used as a root fruit and/or root vegetable in Central America and Asia.

1.3 REFERENCES

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Zanklan, A.S, S. Ahouangonou, H.C. Becker, E. Pawelzik, and W.J. Grüneberg. 2007. Evaluation of the Storage Root-forming legume Yam Bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Science* 47: 1934–1946.

2. ACTIVITIES

The project at UCL had 10 activities carried out from 2009 to 2014: (1) establish analytical method to quantify rotenone in YBS; (2) develop a fast through-put methodology using microwave extraction and U-HPLC to quantify rotenone in YBS; (3) develop reference methods and fast through-put methodology by NIRS; (4) screen seed samples from different species and accessions, and grown in different environments (227 seed samples screened); (5) test feasibility of using food processing to decrease the rotenone content of YBS; (6) determine whether pods at different development stages and leaves can be used as human food or animal feed; (7) develop an in-vivo model for global toxicity of YBS; (8) determine other toxic compounds in YBS; (9) purify the more toxic fraction in YBS; and (10) develop a concept note for a new project proposal for YBS. Each activity is discussed below.

Note: After Activity 7, the activities changed compared with the original project plan. No large-scale screening among mutation lines were carried out. Instead, the activities focused on the identification of the compounds which make YBS more toxic as expected due to their rotenone and pachyrrhizine content.

Activity 1. Establish an analytical method to quantify rotenone in YBS. To find accessions with low/no rotenone (a potentially toxic isoflavonoid in YBS) content, it was necessary to quantify it in seeds. A first analytical method was developed for its quantification. This three-step method was fully validated and was simple enough to be transferable in any laboratory equipped with an HPLC system (see abstract of Publication 1).

Activity 2. Develop fast through-put methodology to quantify rotenone in YBS. Owing to the high number of samples to quantify, a faster methodology using microwave extraction and U-HPLC was developed and validated. Moreover, it allowed simultaneous quantification of rotenone and pachyrrhizine, a known phenyl furanocoumarin whose cytotoxicity is reported to be lower than rotenone but also potentially toxic to human being (see abstracts of Publications 2 and 3).

Activity 3. Develop reference methods and fast through put methodology by NIRS. These validated methods gave reference values for the development and calibration of a fast through-put quantification method by NIRS on milled YBS, which will be used in Peru to screen a high number of samples (publication in preparation).

Activity 4. Screen seed samples from different species and accessions and grown in different environments. After the development of quantification methods, they were applied at UCL for the screening of seed samples from different species and accessions, and grown in different environments. A total of 227 seed samples from Peru, Uganda, and Burundi were quantified for rotenone and 127 for pachyrrhizine.

Activity 5. Test feasibility of using food processing to decrease the rotenone content of YBS. To determine the feasibility of using food processing to decrease the rotenone content of YBS and allow their use in food, six different technological processes applicable to African local environments were studied in terms of their ability to degrade rotenone in the YBS (see abstract of Publication 4). The toxicity of the extracts resulting from these degraded samples was compared with the extracts of the initial seeds in vitro on two different cell lines (CHO and WI38) and in in-vivo experiments.

Activity 6. Determine whether pods at different development stages and leaves can be used as human food or animal feed. To determine whether pods and leaves could also be used as human/ animal food, the analytical method was modified in order to measure rotenone and pachyrrhizine content in pods and leaves. Six different accessions from the three species *P. erosus, P. tuberosus,* and *P. ahipa* were cultivated in Uganda. Their pods were collected at three different maturity levels while the leaves were collected and divided in two batches: one just freeze dried and the other sundried and freeze dried.

Activity 7. Develop an in-vivo model for global toxicity of YBS. To study the global toxicity of the seeds from different accessions, an in-vivo model was developed: Wistar female rats of 200 g were fed by oral gavage with YBS using oil as a vehicle.

Activity 8. Determine other toxic compounds in YBS. To identify other toxic compounds in YBS, toxic extracts were fractionated by different chromatographic techniques, and the cytotoxicity in vitro and toxicity in vivo of fractions obtained were determined.

Activity 9. Purify the more toxic fraction in YBS. The compounds of the more toxic fraction were further purified and their structure identified by up-to-date techniques (high-resolution mass spectrometry and nuclear magnetic resonance).

Activity 10. Develop a concept note for a new project proposal for YBS. A concept note for a new project proposal to make YBS available for human consumption (potential funding by International Atomic Energy Agency in Austria) was written.

3. MAJOR FINDINGS

Rotenone values found in the different analyzed samples (227 for rotenone and 127 for pachyrrhizine) of YBS were between **0.6 and 3.5 mg/g** (pachyrrhizine values between 0.2 and 3.3 mg/g). One seed sample from Peru was found to have a quantity of rotenone lower than the lower limit of quantification (***P. ahipa*, accession CIP-209038**) and one seed sample from Burundi was found to have a quantity of rotenone lower than the lower limit of quantification (***P. tuberosus*, accession CIP 209054**). We also observed that rotenone and pachyrrhizine content may vary according to environmental factors, so this low content has to be verified in different cultivation areas, before being considered as safe for human consumption.

We also observed on in-vivo experiments that the **toxicity of YBS is mainly located in its lipidic fraction**, so the protein content of the seed could still be valorized after the extraction of the toxic fraction. For example, we were able to extract more than 70% of rotenone from YBS flour with a local alcohol.

If seeds and flour could be used for human consumption after food processing, we tested different thermic/cooking processes to lower rotenone content. This compound is sensitive to temperature: **drying and roasting** of whole seeds seem to be the more effective processes **allowing a degradation of up to 70% of the initial content of rotenone**. Moreover, it was observed that the toxicity (in vitro and in vivo) decreased with rotenone content.

The study on the pods was meant to provide data on a part of the plant already used as a food in some areas of Asia. The study on the leaves was meant to provide data for farmers willing to use the leaves as fodder. It was shown that both the pods and the leaves had rotenone content lower than in the seeds: **leaves—between 0.3 mg/g and up to 1.6 mg/g of rotenone; pods—between levels so low that they were under the limit of detection and levels higher than 0.8 mg/g of rotenone**. Surprisingly, sun drying did not lower the rotenone content in the leaves. We also observed that rotenone content was increasing with the maturity level of the pods.

In-vivo tests realized to determine the acute toxicity of YBS clearly showed that their toxicity is not only due to rotenone and pachyrrhizine, but at least also to one or more additional lipophilic compound(s). In fact, YBS were shown to be far more toxic than what was expected based on their rotenone contents. Fractionations followed by **in-vivo toxicity tests allowed us to identify these potential compounds as 12-hydroxypachyrrhizone, munduserone, 12-hydroxydolineone, and dehydroneotenone**. In a previous study by Nath et al. (1980), the activity of 12-hydroxypachyrrhizone and 12-hydroxydolineone on inhibition of in-vitro respiration has been compared to the activity of rotenone. It was observed that at weak concentrations ($0,5.10^{-7}$ M), these compounds were less toxic than rotenone, 12-hydroxypachyrrhizone being more toxic than 12-hydroxydolineone. At higher concentration (1.10^{-6} M), they were more active on NADH-oxydoreductase than rotenone. Moreover, it was reported that, as the rotenoids metabolism is essentially oxidative, hydroxyled rotenoides are detoxified more slowly. Munduserone has been reported to be less active than rotenone (Crombie et al. 1992), whereas no data were found on dehydroneotenone's toxicity. From literature data it seems that the six toxic compounds are also biosynthetically linked (Fig. 1). It is hypothesized that there are close genetic correlations among these compounds in yam beans (so far it has been shown that rotenone and pachyrrhizine concentrations in YBS are correlated; Lautié et al. 2013).

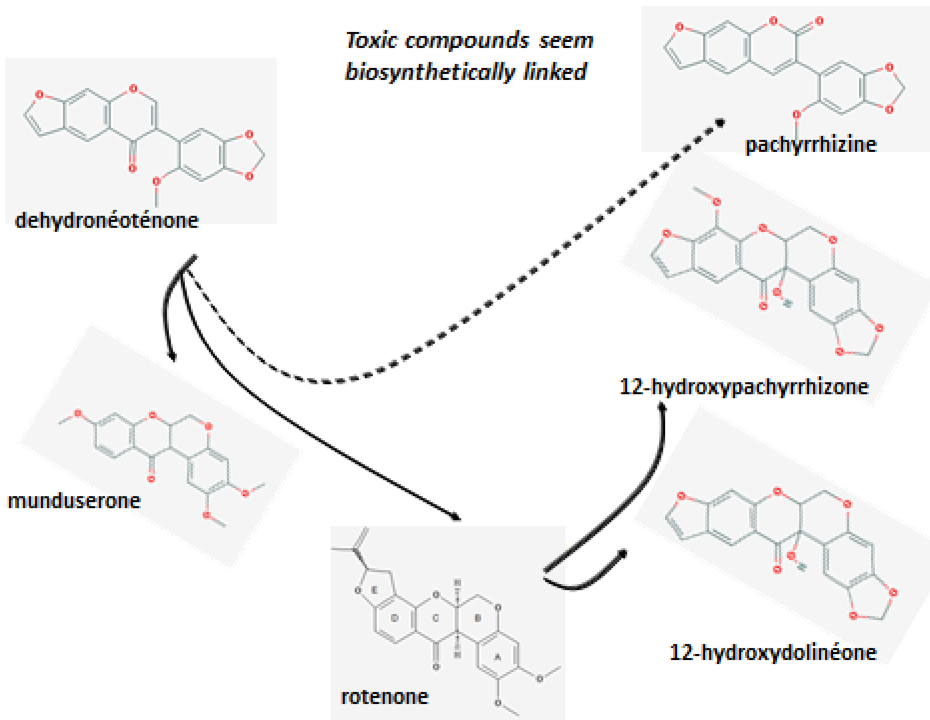

Figure 1. Current hypothesis of biosynthetical pathway of potentially toxic rotenoids in YBS.

We observed that the accession of interest from ***P. tuberosus*** **(CIP-209054) with very low rotenone content did not contain any 12-hydroxypachyrrhizone** and was not toxic when it was tested in vivo at the dose where other samples were. No toxicity was either detected for the same accession dried 7 h at 100°C. **These results confirm that (1) one accession with low rotenone content has no acute toxicity (chronic toxicity should be tested further), and (2) this biosynthetical pathway can be interrupted without damaging the plant and without an accumulation of rotenone if it is one of its precursors**.

However, when the flour from the seeds of this accession (CIP-209054) is supplemented with rotenone at a resulting level inferior to rotenone NOAEL, a toxicity is observed. This toxicity is nevertheless lower than the one exerted by a *P. erosus* accessions (EC 533) at the same rotenone concentration. These results make us think that rotenone has an important role in the acute toxicity of YBS, but its action is reinforced by the presence of the other rotenoids. The pathway leading to these compounds has to be interrupted if we want to make YBS available for human consumption.

Our project will not reach the target to screen yam bean mutation lines generated in this project for these six compounds. **So far, NIRS (as a fast through-put method) has been calibrated to detect rotenone and pachyrrhizine in milled YBS samples but not for the other derivatives**. In total there are about 5,000 M2 lines in generation M3 available to be screened for the six toxic compounds, and additionally about 20,000 M2 single seeds. We hope some of them could show very low/no rotenoid content to allow human consumption.

New diversity to use YBS for human consumption has been provided, but so far no material is available that can be disseminated for human consumption. However, our results have increased the chances of success of a new project allowing the use of YBS for human consumption.

REFERENCES

Crombie, Leslie, Jonathan L. Josephs, Jane Cayley, John Larkin, and John B. Weston. 1992. The rotenoid core structure: modifications to define the requirements of the toxophore. *Bioorganic & Medicinal Chemistry Letters* 2(1): 13–16.

Nath, M., Venkitasubramanian, T.A., and Krishnamurti, M. 1980. Action and structure –Activity relationship of rotenoids as inhibitors of respiration in vitro. *Bull. Environm. Contam. Toxicol.* 24: 116–123.

4. ABSTRACT OF ARTICLES PUBLISHED IN THE FRAMEWORK OF THE PROJECT

4.1 PEER-REVIEWED JOURNALS

Publication 1:

Lautié, E., Rozet, E. , Hubert, P. , and Quetin Leclercq, J. 2012. Validated SPE HPLC-UV quantification of rotenone in seeds of different yam bean (*Pachyrhizus* sp.). *Food Chemistry* 131(4): 1531–1538.

Abstract: This study describes the development of a validated method for the quantification of rotenone in yam bean. The milled seeds were submitted to a Soxhlet dichloromethane extraction which allowed extracting 90% of the seeds rotenone. Elimination of the lipids was obtained via solid phase extraction. Rotenone was eluted with dichloromethane/methanol and the solution dried under vacuum and solubilised directly in methanol before injection in HPLC. The whole process was realised as much as possible protected from light and at temperatures lower than 40°C which allowed high recovery rates of spiked rotenone. Total error was used as criterion for the validation process and accuracy profiles drawn. The method allows the quantification of rotenone in yam bean seeds from 0.07% up to 1.25% (w/w). This method was applied to the quantification of rotenone in the seeds of several accessions of *Pachyrhizus erosus* and *P. ahipa*. The results range from 1.13 to 2.76 mg/g dry material.

Publication 2:

Lautié, E., Rasse, C., Rozet, E. , Mourgues, C., Vanhelleputte, J.P., and Quetin Leclercq, J. 2013. Fast microwave assisted extraction of rotenone for its quantification in seeds of yam bean (*Pachyrhizus* sp.). *Journal of Separation Science* 36: 758–763.

Abstract: The aim of this study was to find if fast microwave assisted extraction could be an alternative to the conventional Soxhlet extraction for the quantification of rotenone in yam bean seeds by solid phase extraction and HPLC-UV. For this purpose, an experimental design was used to determine the optimal conditions of the microwave extraction. Then the values of the quantification on three accessions from two different species of yam bean seeds were compared using the two different kinds of extraction. A microwave extraction of 11 min at 55°C using methanol/dichloromethane (50:50) allowed rotenone extraction either equivalently or more efficiently than the 8h Soxhlet extraction method and was less sensitive to moisture content. The selectivity, precision, trueness, accuracy and limit of quantification of the method with microwave extraction were also demonstrated.

Publication 3:

Lautié, E., Rozet, E., Hubert, P., Vandelaer, N., Billard, F., zum Felde, T., Grüneberg, W.J., and Quetin-Leclercq, J. 2013. Fast method for the simultaneous quantification of toxic polyphenols applied to the selection of genotypes of yam bean (*Pachyrhizus* sp.) seeds. Talanta 117: 94–101.

Abstract: The purpose of the research was to develop and validate a rapid quantification method able to screen many samples of yam bean seeds to determine the content of two toxic polyphenols, namely

pachyrrhizine and rotenone. The analytical procedure described is based on the use of an internal standard (dihydrorotenone) and is divided in three steps: microwave assisted extraction, purification by solid phase extraction and assay by UHPLC. Each step was included in the validation protocol and the accuracy profiles methodology was used to fully validate the method. Finally the validated dosing intervals range from 0.25 mg to 5 mg pachyrrhizine per gram of seeds and from 0.58 mg/g to 4 mg/g for rotenone. More than one hundred samples from different accessions, locations of growth and harvest dates were screened. Pachyrrhizine concentrations ranged from 3.29 mg/g to lower than 0.25 mg/g while rotenone concentrations ranged from 3.53 mg/g to lower than 0.58 mg/g. This screening along with PCA and DA analyses allowed the selection of the more interesting genotypes in terms of low concentrations of these two toxic polyphenols.

Publication 4:

Catteau, L., Lautié, E., Koné, O., Coppé, M., Hell, K., Pomalegni, C.B., and Quetin-Leclercq, J. (*forthcoming*). Degradation of rotenone in yam bean seeds (*Pachyrhizus* sp.) through food processing. *Journal of Agricultural and Food Chemistry* (DOI: 10.1021/jf402584k).

Abstract: The purpose of this research is to screen different processes, which could potentially decrease or even eliminate rotenone, a toxic isoflavonoid, from Pachyrhizus seeds. These seeds have very interesting nutritional characteristics, especially their high proteins and lipids contents, and could potentially increase food security in under-nourished populations. Different processes (drying, roasting, boiling, frying, alcohol extraction), tegument-removal and traditional Beninese culinary recipes were tested and rotenone was quantified in end-products by a validated method, associating microwave extraction, solid phase extraction (SPE) and HPLC-UV. With these processes rotenone removal of up to 80% was obtained. The most effective methods were the drying and roasting of the seeds and the maceration of their flour in local alcohol. The rotenone degradation and elimination was confirmed by cytotoxic assays, effectively inducing a decrease in sample toxicity.

4.2 OTHER SCIENTIFIC COMMUNICATIONS

4.2.1 ORAL COMMUNICATIONS

Lautié, E., Mbarga Dimbeck, A.M.S., Van Helleputte, J. P., Colak, R., Tumwegamire, S., Grüneberg, W. J., and Quetin-Leclercq, J. 2013. Toxic polyphenols in aerial parts of yam bean (*Pachyrhizus* sp.). *Forum of Pharmaceutical Sciences*, Spa, Belgium.

Abstract: The yam bean (*Pachyrhizus* sp.) is a legume crop originating from the Americas but also cultivated in Asia and some parts of Africa. It is grown almost exclusively for its nutrient rich storage roots because seeds contain toxic polyphenols . Anyway young pods have been reported to be used as food in Mexico, Thailand or Indonesia. The valorization of the aerial parts of the plant is also important in order to extend its use as an alternative legume crop in countries of West- and Central Africa. So we decided to quantify the content of rotenone and pachyrrhizine, two toxic compunds, in yam bean pods and also to evaluate the impact of the maturity of pods on these concentrations. For this purpose, pods from two accessions of the three cultivated *Pachyrhizus* species were grown in Uganda. The quantification procedure was modified from a validated method. It used an internal standard and consisted of three steps: a microwave assisted extraction, a purification by solid phase extraction and the assay itself by UHPLC-DAD. Concentrations ranged from 0.123 to 0.808 mg/g dry material for rotenone and from 0.060 to 0.802 mg/g dry material for pachyrrhizine. The results were between 3 and 5 times lower in pods than those reported in seeds alone. The study revealed also that the lower the level of maturity, the lower the amounts of both compounds. Genotype and environmental effects on the production of these compounds by the plant were also detected. Finally, one *P. tuberosus* accession

(209054) seemed to be very interesting because of its very low content of pachyrrhizine and rotenone at every levels of maturity.

Lautié, E., zum Felde, T., Heider, B., Tumwegamire, S., Grüneberg, W.J., and Quetin-Leclercq, J. 2013. Valorization of the nutrient-rich yam bean (*Pachyrhizus* sp.) for Central and West Africa (*Pachyrhizus sp*. congress of AFERP, Brussels, Belgium.

Abstract: This international and multidisciplinary project aimed at showing that this underutilized and highly nutritious legume root crop, showing a wide adaptation and high yield potential, can lead to greater food supply, more sustainable farming systems and new options for generating income in the rural and urban poor Central and West Africa. During this four-year initiative main results were obtained in:

1. Improving the availability of yam bean germplasm for Central and West Africa especially high-yielding genotypes
2. Developing the *gari* processing of storage roots
3. Studying the chemical content of seeds, pods, and leaves in order to provide a diversity of use of these by-products.

While YBS are known to contain a toxic isoflavonoid, different strategies were developed in order to make them usable for consumption in a close future as pods are consumed in Asia. First different genotypes were screened using different kinds of analytical tools as microwave assisted extraction-solid phase extraction-ultra high performance liquid chromatography or near infrared spectroscopy to identify the less toxic ones. Then the feasibility of decreasing the amount of toxic compounds through food processing was studied and, in-vitro and in-vivo models were used to test the toxicity of different samples. The influence of the maturity of the seed containing pods was also studied.

Lautié, E. 2013. Rotenone: the limiting factor to yam bean (*Pachyrhizus* sp.) seeds valorization? Seminar of the Louvain Drug Research Institute, Ecole de pharmacie de l'université catholique de Louvain, Bruxelles, Belgium.

Lautié, E. 2010. Yam bean seeds (*Pachyrhizus* sp.) and rotenone. Seminar of the Louvain Drug Research Institute, Ecole de pharmacie de l'université catholique de Louvain, Bruxelles, Belgium.

Lautié, E., Rozet, E. , Hubert, P. , and Quetin Leclercq, J. 2010. A validated method combining SPE and HPLC-UV for the quantification of rotenone in seeds of yam bean (*Pachyrhizus* sp.). *Drug Analysis*, Anvers, Belgium.

Abstract: Due to the nutritional content of its roots and seeds as well as its agronomical yields and the resistance of the plant itself, there is a great deal of interest for the yam bean (*Pachyrhizus* sp.). The seeds are especially interesting as they contain several minerals, essential amino acids and a high amount of proteins and lipids. Nevertheless, in order to be used as a food crop, it is necessary to obtain seeds as poor as possible in potentially toxic compounds such as rotenone. This compound which is known to be present in these seeds has been shown to inhibit the complex I of the mitochondrial respiratory chain and was formerly used for its insecticidal activity. Its toxicity linked with dopaminergic neuronal degeneration causes many features of Parkinson's disease in animal models and may contribute to this disease in man as well. Thus we developed a method to quantify rotenone in yam bean seeds. In this study, 1 g of seeds flour from Peruvian *P. erosus* was submitted to Soxhlet dichloromethane extraction. A process of 80 cycles (about 8 hours of extraction) allowed extracting about 87.5% of the rotenone present in the seeds. The lipids of the extracts were cleared up using solid phase extraction (SPE) on silica and rotenone was then eluted with dichloromethane/methanol (98:2), dried under vacuum and solubilised directly in methanol before its injection in HPLC. The whole process

was realised as much as possible protected from light and at temperatures lower than 40°C. The recovery of spiked rotenone for the total process rated above 95%. Total error was used as criterion for the validation process and accuracy profiles drawn. The method was found to be selective, linear, accurate, true and precise from at least 25 µg/mL to 75 µg/mL which allowed the quantification of 1.18% down to 0.14% (w/w) rotenone in yam bean seeds. The methodology described was shown to be convenient for routine analysis and is meant to be used as a selection tool of less toxic seeds between a large panel of accessions of *Pachyrhizus*.

4.2.2 Poster Presentations

Lautié, E., Rozet, E., Hubert, P., Vandelaer, N., Billard, F., zum Felde, T., Grüneberg, W.J., and Quetin-Leclercq, J. 2013. Simultaneous quantification of toxic polyphenols applied to the selection of genotypes of yam bean (*Pachyrhizus* sp.) seeds. Congress of AFERP, Brussels, Belgium.

Lautié, E., Claeys, M., and Quetin-Leclercq, J. 2012a. Analysis of rotenone degradation products by electrospray mass spectrometry. 8th joint congress of AFERP, ASP, GA, PSE, and SIF on Natural Products Research. New York, USA. *Planta Medica* 78: PJ141.

Lautié, E., Claeys, M., and Quetin-Leclercq, J. 2012b. Structure characterization of rotenone fragments and thermal degradation products using electrospray mass spectrometry. Joint congress of the Belgium society of mass spectrometry (BSMS) and of the Dutch association of mass spectrometry (NVMS), Rolduc, Netherlands.

Lautié, E., Catteau, L., and Quetin-Leclercq, J. 2012. Thermic degradation of potentially toxic compounds of yam bean seeds flour (*Pachyrhizus* sp.) KVCV symposium "Mass spectrometry in Food and Feed," Gand, Belgium.

Lautié, E., Zekri, S., Chataigné, G., and Quetin-Leclercq, J. 2010. HPLC-MS identification of toxic compounds from the yam bean seeds (*Pachyrhizus erosus* L.) Annual congress of the Belgium society of mass spectrometry (BSMS), Bruxelles, Belgium.

5. CONCEPT NOTE FOR A NEW PROJECT PROPOSAL FOR YAM BEAN SEED

We focus here on required research activities in the future to proof that YBS from a mutation breeding program could be used in human consumption. CIP and its partners (one of which was UCL), funded by the Belgium Development Corporation, have introduced the yam bean into six African countries in the framework of a five-year project (2009–2014). Through the project, which ends in June 2014, information has been gathered on the yam bean's potential for food production in West and Central Africa.

In addition to the feasibility of using yam bean storage roots for food production, important results with respect to the YBS for human consumption has been obtained:

1. Improved understanding of the compounds which make YBS toxic. In-vivo tests realized on YBS clearly showed that their acute toxicity is not only due to rotenone and pachyrrhizine, but to at least one additional lipophilic compound. This could be 12-hydroxypachyrrhizone, munduserone, 12-hydroxydolineone, and/or dehydroneotenone. Furthermore, these compounds as well as rotenone could be biosynthetically linked, which make them good candidates for elimination by mutation screening.
2. The development of two types of quantification methods for rotenone and pachyrrhizine in YBS. A cheap and fast through-put method with NIRS for the screening of great numbers of seeds and an accurate method with UV-UHPLC for precise results for the best seeds candidates. A method

for the separation of the other potentially toxic rotenoids has already been developed, which is a step further for their future quantification.

3. One mutation with very low rotenone content has been identified and tested in vivo. It showed no signs of acute toxicity at a dose where other accessions showed acute toxicity. This indicates that in addition to the storage root, the YBS might also have a potential for human consumption. Furthermore, no 12-hydroxypachyrrhizone has been detected (by a very sensitive LC-MS method) in this last genotype. It allows us to think that these kinds of compounds are not essential to the plant's development and that some/most of them could be eliminated/not produced without damaging its development.
4. It is known that the production of secondary metabolites by a plant can be influenced by the environment (climate, presence of parasites, nature of soils, etc.). We observed during the project, for leaves, that the content of rotenone could differ in function of locations.
5. From our point of view, two targets/axes of research detailed below should be investigated to allow seeds to be used for human consumption. They can be done in parallel as they can both give an interesting feedback to each other. Moreover, some of the investigation of target 1 can also be realized during cultivation periods of target 2.

5.1 TARGET 1: IDENTIFICATION OF THE TARGETED COMPOUNDS TO ELIMINATE/AVOID FOR SAFE CONSUMPTION OF YBS AND IMPROVED UNDERSTANDING OF HOW THE TOXICITY OF YBS IS EXERTED

1. To end the characterization of the toxic compounds in YBS, another fraction has to be investigated. This other fraction was identified as slightly toxic during the initial fractionation of *P. erosus*, which led to the identification of 12-hydroxupachyrrhizone, 12-hydroxy dolineone, munduserone, and dehydroneotenone. The compounds responsible for the toxicity of this other fraction have to be identified as well, even if their toxicity is probably less important. More precisely, this fraction results from the fractionation by vacuum liquid chromatography of the hexane Soxhlet extract eluted with hexane/dichloromethane (50:50).
2. Isolation/hemisynthesis of 100 mg or g quantities of potentially toxic lipophilic compounds and evaluation of their toxicity alone, in vitro and in vivo.
3. Comparison of the different toxic compounds at the mechanistic level:
   - Are all compounds exerting their toxicity through the inhibition of NADH-oxydoreductase? Or are the other mechanisms of action of rotenone involved too in the acute toxicity as the inhibition of ornithine decarboxylase, the induction of apoptose, or the modification of the microtubules organization (genotoxicity)? This information could be obtained by in-vitro models existing in the literature.
   - If the isolated compounds do not act by the same mechanism, identification of this mechanism, in-vitro or in-vivo models should perhaps be developed, depending on the findings obtained.
   - Does the acute toxicity result from the addition of the activity of all toxic compounds, or is there a synergetic action between compounds (meaning that the suppression of one compound would lead to a higher decrease of the toxicity)? In-vitro and in-vivo tests in combination will have to be performed.
   - How does the rat model fit the metabolism of these compounds in the human being? How transferable are the results? This will need metabolic analysis and analytical method development.

Once these questions have been answered, the “targets” for the mutation breeding will be correctly defined.

5.2 TARGET 2: SELECTION OF NON-TOXIC GENOTYPES/MUTATIONS OF YBS

1. A calibration of the fast through-put quantification method by NIRS for rotenone and the other “target compounds” should be established for the screening of great numbers of seeds generated by the mutation breeding. For this aim, the validation of a reference method by UV-UHPLC should be realized previously. The feasibility of using NIRS for fast screening on rotenone and pachyrrhizine has been demonstrated by the previous Ahipa project (2009–2014). This will allow the selection of 25 genotypes of interest with low quantities of rotenone and other target compounds.
2. These genotypes will be then quantified accurately by the reference method. The seven best genotypes will be chosen on the basis of analytical results.
3. These seven genotypes will be multiplied in different environments and re-evaluated by the reference method to be sure that no conditions lead to the production of the targeted compounds through the activation of another inter-related pathway. The presence/absence of other agronomic traits (root yield, for example) can intervene at this level. A maximum of five genotypes should last at the end this process.
4. In-vivo tests will be realized on these genotypes:
   — First, the absence of acute toxicity needs to be checked (24–48 h): survival and evaluation of signs of pain will be assessed.
   — Then, short-term chronic toxicity should be evaluated (2–3 months) through the assessment of:
      - behavioral studies (looking for signs of pain)
      - follow-up of the body mass and the food intake
      - feces analyses for the follow-up of rotenone elimination
      - blood analyses (assay of hepatic enzymes, renal toxicity)
      - histological analysis of the different organs withdrawn after the sacrifice of animals.

   These experiments should lead to the selection of the three genotypes showing best results in terms of toxicity.
5. In-vivo tests will be realized on these genotypes for the evaluation of medium-term chronic toxicity (6 months) through the assessment of:
   — Behavioral studies with the ROTAROD test after 6 months treatment: looking for signs of neurologic affection as rotenone is suspected to play a role in dopaminergic neuronal degeneration causing features of Parkinson disease. Sherer et al. (2003) reported that animals with dopaminergic lesions showed a reduced activity, a bent posture and in some cases stiffness.
   — Follow-up of the body mass and the food intake
   — Blood analyses (assay of hepatic enzymes, renal toxicity)
   — Histological analysis of the different organs withdrawn after the sacrifice of animals.

   Finally, if no toxicity at all is found for one or several mutations, other studies depending on the legislation of the country in which the seeds would be utilized should be conducted in order to register these YBS as a new food. Guidance should be taken with the U.S. Food and Drug Administration (www.fda.gov), the Belgian AFSCA (federal agency for food security, www.afsca.be), or other similar agencies. This final stage should be subcontracted or realized by a specialized laboratory.

5.3 REFERENCE

Sherer, T.B., Kim, J-H., Betarbet, R., and Greenamyre, J.T. 2003. Subcutaneous rotenone exposure causes highly selective dopaminergic degeneration and [alpha]-synuclein aggregation. *Experimental Neurology* 179(1): 9–16.

APPENDIX 9

FINAL REPORT MAKERERE UNIVERSITY (UGANDA)

FINAL REPORT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

Sub-component: Graduate Training and Research at Makerere University

SUBMITTED TO: THE INTERNATIONAL POTATO CENTER

SUBMITTED BY: MAKERERE UNIVERSITY

J U N E 2 0 1 4

FINAL AHIPA PROJECT REPORT

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Report submitted: 20 June 2014
1st revision, 15 September 2014
2nd revision, 27 October 2014
Graduate training and research at Makerere University under AHIPA project

On behalf of Makerere University

written by:
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CONTENTS

1. OBJECTIVE AND BACKGROUND

1.1 OBJECTIVE

The Makerere University in Uganda contributed to the specific objective 8 of the project "Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa" (the AHIPA project)—namely, to promote awareness, communication, training, and capacity building.

1.2 BACKGROUND

The training component of the AHIPA project at Makerere University is focused on identification of adapted high-yielding yam bean accessions and development of yam bean storage root products appropriate for East and Central Africa. The activities comprised course work; field/laboratory research; and dissemination of information in genetics, breeding, agronomy, and utilization of *Pachyrhizus* spp. in East and Central Africa.

2. STUDENTS

The project had nine full-time postgraduate students, all registered at the College of Agricultural Sciences and Environmental Sciences, Makerere University. The students are distributed according to the following programs and disciplines: two PhD students in plant breeding, four MSc students in agronomy, two MSc students in food science/technology, and one MSc student in plant genetic resources (Table 1).

Moreover, there were three undergraduate students (fourth-year students finalists) pursuing their BSc in agriculture: Gloria Asingwire, Elias Oyesigye and James Muhangi. They were supported by the AHIPA project (Table 1). They successfully completed field work of their special project component, including writing up their studies, which have been submitted for examination. These three BSc students have graduated (Table 2).

A number of PhD, MSc, and BSc students gathered with some of their supervisors and other stakeholders during the AHIPA workshop held in December 2013, at Makerere University (Fig. 1).

Table 1 Information on the PhD and MSc students supported by the AHIPA project

Name	Country	Discipline	Supervisors
Jean Ndirigue	Rwanda	Plant breeding	Prof. P Rubaihayo, Dr. P. Tukamuhabwa
Rolland Agaba	Uganda	Plant breeding	Dr. P. Tukamuhabwa, Prof. P. Rubaihayo
Charles Andiku	Uganda	Agronomy	Dr. James Ssebuliba, Dr. Hebert Talwana
David Onyuta	Uganda	Agronomy	Dr. James Ssebuliba, Dr. Jenifer Bisikwa
Ernest Vyizigiro	Burundi	Agronomy	Dr. Hebert Talwana, Prof. David Osiru
Kilongo Bulambo	DR Congo	Agronomy	Dr. Hebert Talwana, Dr. James Ssebuliba
Lydia Nakagiri	Uganda	Food science and technology	Prof. John Muyonga, Dr. Agnes Namutebi
Abbas Kisambira	Uganda	Food science and technology	Prof. John Muyonga, Dr. Yusuf Byaruhanda
Godwin Nkwasibwe	Uganda	Plant genetic resources	Dr. P. Tukamuhabwa, Prof. Elly Sabiiti

Not all PhD and MSc students have completed their thesis. The progress in thesis work made by student is summarized in Table 3.

Table 2 Information on the BSc agriculture students supported by the AHIPA project

Name	Country	Title of Project	Supervisors
Gloria Asingwire	Uganda	Consumer acceptability of yam bean salads in Kampala	Ms. Harriet Kyomugisha
Elias Oyesigye	Uganda	Morphological diversity of African yam bean (*Sphenostylis stenocarpa*) Winged bean (*Psophocarpus Tetragonolobus*) and other legume forming tubers	Dr. Phinehas Tukamuhabwa
James Muhangi	Uganda	Cost Benefit Analysis Of Processing Yam Bean Into Flour Used To Make *Atap*/*Ugali* Food Products In Serere and Luwero Districts	Ms. Elizabeth Balirwa

All the supervisors for the BSc students were from the Departments of Agricultural Production and Food Technology and Nutrition at the Makerere University. All students completed their study and graduated.

Figure 1. The AHIPA project-sponsored students, together with some of their supervisors and other participants at AHIPA meeting, Makerere University, 18–20 December 2013.

Table 3 Progress of PhD and MSc work by student and country of origin

Name	Country	Program	Stage of Thesis Development
Jean Ndirigue	Rwanda	PhD*	Final field research (year 3); 1st manuscript written (required 2 submitted manuscripts to peer-reviewed journals)
Rolland Agaba	Uganda	PhD*	Final field research; (year 3); 1st manuscript written (required 2 submitted manuscripts to peer-reviewed journals)
Charles Andiku	Uganda	MSc	MSc awarded
David Onyuta	Uganda	MSc	Draft of thesis completed and under final revision
Ernest Vyizigiro	Burundi	MSc	Draft of thesis completed and under final revision
Kilongo Bulambo	DR Congo	MSc	Draft of thesis completed and under final revision
Lydia Nakagiri	Uganda	MSc	Completed field work and draft of thesis, but abruptly left and is no longer involved in the program
Abbas Kisambira	Uganda	MSc	MSc awarded
Godwin Nkwasibwe	Uganda	MSc	Submitted thesis for examination

* This work received after the end of the AHIPA project; further support by CIP from the CGIAR Research Program Roots, Tubers, and Bananas until at least June 2015.

3. GERMPLASM ACQUISITION AT MAKERERE UNIVERSITY

Makerere University has built up a germplasm collection of storage root-forming legumes currently being conserved at its Agricultural and Research Institute at Kabanyolo (MUARIK) genebank. (The received germplasm is summarized in Table 4 and shown in Fig. 2.) The collection currently holds 39 accessions of *Parchyrhizus* spp. (yam beans) received from CIP. Other storage root-forming legume species/accessions, such as *Psophocarpus* spp., *Sphenostylis stenocarpa*, and *Vigna vexillata*, were received from AVRDC (World Vegetable Center), the International Institute of Tropical Agriculture (IITA), the International Center for Tropical Agriculture (CIAT), and the Botanical Garden in Meise/ Belgium.

Table 4 Germplasm and source of storage root-forming legume accessions held by Makerere University Agricultural and Research Institute at Kabanyolo (MUARIK)

Species	Common Name	Source	No. of Accessions Being Conserved
Pachyrhizus spp.	Yam bean	CIP	39
Vigna vexillata	Mung bean	CIAT	4
Sphenostylis stenocarpa	African yam bean	IITA	3
Psophocarpus tetrago spp.	Winged bean	AVRDC	3
Vigna vexillata	Mung bean	Meise Botanical Garden	2

A significant amount of germplasm is held at MUARIK for *Pachyrhizus* spp., comprising *P. ahipa*, *P. tuberosus*, and *P. erosus.* For other storage root-forming legumes, only a limited number of accessions could be obtained, despite considerable efforts to obtain more. This reflects the availability of *Sphenostylis stenocarpa*, *Psophocarpus tetragonolobus*, and storage root-forming *Vigna vexillata* for agricultural research. No accessions were obtained for storage root-forming legume *Tylosema esculentum* (origin Southern Africa), *V. lobatifolia* (origin Southern Africa), *Pueraria* (origin India), *Flemingia* (origin India), *Apios* (origin North America), and *Psoralea* (Australia and North America). All of these, however, are wild species and not domesticated.

Figure 2. Student field exercise on storage root-forming legumes at the AHIPA workshop at MUARIK, Makerere University, December 2013.

4. INDIVIDUAL STUDENT PROGRESS

4.1 GROUP A STUDENTS

The students in Group A are pursuing their PhD thesis. They have successfully defended their proposals, have acquired full admission to Makerere University, and are in final stages of field research (year 3).

Student 1: Jean Ndirigue (PhD)—Crop Science (plant breeding)

Title of PhD thesis: Adaptation and genetic analysis for earliness and yield of yam bean (*Pachyrhizus* spp.) through *P. ahipa* x *P. tuberosus* interspecific hybrids in Rwanda

Objectives:

- Evaluate yam bean accessions for adaptation to different agro-ecological zones in Rwanda (field trials completed).
- Determine inheritance of earliness and its components in yam bean through nine *P. ahipa* x *P. tuberosus* interspecific hybrid populations (field trials in year 3).
- Determine heritability of root yield and its components in yam bean through nine *P. ahipa* x *P. tuberosus* interspecific hybrid populations (field trials in year 3).

Progress:

- Twenty-three yam beans for adaptability in three agro-ecological zones of Rwanda have been evaluated.

- F1 hybrids received from CIP for field evaluations and genetic analysis are now at F3 stage in the field (Fig. 3).

Challenges

Late arrival of the F1 populations mean that the student will require more time to establish field trials, data correction, and thesis writing. This calls for an extension of Mr. Ndirigue's fellowship by at least one academic year. Fortunately, this challenge is being followed up by CIP (support at least until June 2015).

Since we do not have the equipment to analyze the populations for micronutrients (Fe, Zn, and Ca), the objective to determine these nutrients was discontinued from the study as recommended by the graduate committee. The committee's aim was to help Mr. Ndirigue to be able to complete his PhD without unnecessary delays.

Figure 3. Discussion with Jean Ndirigue (PhD student) in his F2 populations at Rubona, in November 2013, Rwanda.

Student 2: Rolland Agaba (PhD)—Crop Science (plant breeding)

Title of PhD thesis: Genetic improvement of yam bean (*Pachyrhizus* spp.) for storage root dry matter, starch and protein through *P. erosus* x *P. tuberosus* interspecific hybrids in Uganda

Objectives:

- Determine genetic variation in yam bean germplasm for dry matter, starch, and protein contents in Uganda (field trials completed).
- Determine number of genes and mode of gene action controlling inheritance of dry matter content in yam bean through nine *P. erosus* x *P. tuberosus* interspecific hybrid populations.
- Determine response to selection for high dry matter content in yam bean through estimates in nine *P. erosus* x *P. tuberosus* interspecific hybrid populations.

Progress:

- Testing of 40 accessions of yam beans at Namulonge, Kabanyolo, and Soroti has been completed.
- F1 hybrids received from CIP have been advanced to F3 and are to be planted in a trial at Namulonge once the rains get started in 2014.
- Mr. Agaba was trained in use of near infrared spectroscopy equipment at NaCRRI and gained skills that he is already applying in analysis of F1s data and the germplasm used for objective 1.

Challenges

As mentioned with Jean Ndirigue, Mr. Agaba will also require an extension of the fellowship for at least one academic year to enable him to complete the study successfully. Fortunately, this challenge is being followed up by CIP (support at least until June 2015).

4.2 GROUP B STUDENTS

In this category we have two students who have completed their studies, defended their thesis, and have graduated.

Student 1: Kisambira Abbas (MSc)—Food Science and Technology

Title: Physico-Chemical Characteristics of Yam Bean (Pachyrhizus) Seed Flour and Protein.

Objectives:

- Determine the composition of seeds from three cultivated yam bean species *(P. erosus, P. ahipa, and P. tuberosus)*.
- Determine the functional and pasting properties of defatted yam bean seed flour (*P. erosus*).
- Determine the characteristics of yam bean seed protein (*P. erosus*).

Conclusions

The study shows that yam bean seed is a good source of protein, fat, and carbohydrates. *P. tuberosus* exhibits the highest protein content, *P. erosus* the highest fat content, and *P. ahipa* the highest total carbohydrate content. Functional properties of both flour and isolate indicate that both have potential to be used in food systems as well as in a variety of industrial applications (e.g., adhesives, paper, textiles, bioplastics, biodiesel, and composites). However, yam bean seed protein was seen to have average score in emulsion and foaming capacities and may not be suitable for application where these properties are required, such as in mayonnaise.

The study indicated that yam bean seed protein has a high in-vitro protein digestibility, which contributes to its protein quality. The study shows that albumin is the most dominant protein fraction in yam bean seed; this suggests that the seeds can be a good source of high nutritional quality protein. Further research is needed to establish the safety of the defatted flour and the isolate to promote utilization for food and feed. It is necessary to determine the performance of yam bean seed flour and isolate as ingredients in food and non-food industrial applications. There is also need to undertake breeding activities for rotenone-free seeds to fully utilize the seeds of the crop.

Student 2: Charles Andiku (MSc)—Crop Science (agronomy)

Title: Evaluation of yam bean (*Pachyrhizus* spp.) accessions for root yield and nutritional quality under growing conditions of Uganda

Objectives:

- Determine storage root yield performance and stability of selected yam bean accessions across different agro-ecological zones in Uganda.
- Determine storage root yield components of selected yam bean accessions.
- Assess the storage root nutritional quality of yam bean accessions under different growing conditions of Uganda (Fig. 4).

Observations and Recommendations

Genotype CIP-209018 was the most stable accession. The most suitable yam bean genotype to be grown in Uganda appears to be CIP-209017, followed by CIP-209018, CIP-209016, CIP-209052, and CIP-209050. With respect to the environments used in this study, it was observed that Uganda can be divided into two mega-environments for yam bean production.

Conclusions

Storage root fresh yields were significantly different across the different locations. Across all accessions it was found that Namulonge–Lake Victoria zone appears to be the most ideal environment (10.1 t/ha across accessions used) for yam bean production. This was followed by Serere–North Uganda (8.0 t/ha across accessions used), and Kachwekano–West Uganda mountains, a low-performing location (3.1 t/ha across accessions used). *P. tuberosus* accessions especially were not adapted to this location. Note that in this study, Serere was the most stable environment for yam bean production.

Figure 4. Plot yield of accession UY 823 from Charles Andiku's yield experiment at Namulonge, Uganda.

4.3 GROUP C STUDENTS

The students in this category have completed course work and field research and have submitted their theses for final examination.

Student 1: Godwin Nkwasibwe (MSc)—Plant Genetic Resources

Title: Morphological Characterization of Legume Root Crop Germplasm for Utilization and Conservation in Uganda

Objectives:

- Characterize legume root crop germplasm in Uganda using morphological traits.
- Determine the yam bean seed storage properties for long-term conservation.

Observations

A significant amount of germplasm is held at MUARIK for *Pachyrhizus,* comprising *P. ahipa*, *P. tuberosus*, and *P. erosus.* However, for other storage root-forming legumes, only a very limited number of accessions could be obtained for this study (see also Table 4). With respect to agronomic and morphological traits, there is significant genetic variation among the yam bean accessions, which can be used to distinguish accessions and useful for improvement through breeding. It was observed that yam bean seed can be desiccated to 5% without damage, suggesting that yam beans can stored for the long term for conservation. It was noted that seed stored at 7% moisture content at room temperature maintained the highest viability.

4.4 GROUP D STUDENTS

The students in this category have completed their research work and are finalizing writing of the theses; they are enrolled for MSc in different fields.

Student 1: David Onyuta Alinaitwe (MSc)—Crop Science (agronomy)

Title: Farmer participatory evaluation of storage root forming legume yam bean (*Pachyrhizus* spp.) in selected areas of Uganda

Objectives:

- Determine the agronomic and quality traits of 14 yam bean accessions on farmers' fields in Luwero and Serere.
- Compare yield performance of selected yam bean accessions under farmers' field practices.
- Identify key socioeconomic attributes that could enhance acceptability of yam bean by farmers and consumers.

Observations and Recommendations

There was significant difference in the performance of the yam bean accessions using different agronomic practices. Farmer participation in evaluation of the accessions might speed up identification of high-utility yam bean accessions. The determination of the agronomic performance of the yam bean accessions should offer a basis for adoption and further research in Uganda. There is need to explore postharvest traits and market value of yam bean storage roots for wide-scale acceptability.

Student 2: Ernest Vyizigiro (MSc)—Crop Science (agronomy)

Title: Effect of different plant populations and manure application levels on the yield of yam bean (*Pachyrhizus* spp.) in Burundi

Overall objective:

To promote the adoption of yam bean varieties in major farming systems of Burundi for food yield and diversity.

Specific objectives:

- Identify an optimum plant population for high and stable yields of yam bean in Burundi.
- Determine the effect of cattle manure on growth and yield of selected yam bean accessions in Burundi (Fig. 5).

Conclusions

The accessions used in this study were significantly different for storage root fresh yields but not across location used in Burundi. Plant population, spacing, and organic manure had no significant effect on storage root yield. The highest yielding genotype was CIP-209017, with storage yields up to 73.1 t/ha, followed by genotype CIP-209054 (15.5 t/ha) and CIP-209031 (14.7 t/ha). It appears that the yam bean is well adapted to Burundi.

Figure 5. Field trial of Mr. Ernest Vyizigiro in Burundi to investigate population and manure treatment levels in yam bean.

Student 3: Pacifique Kilongo Bulambo (MSc)—Crop Science (agronomy)
Title: Effect of agronomic practices on growth and yield of yam bean in Eastern Democratic Republic of the Congo (DRC)

Objectives:

- Investigate the effect of harvesting date on yam bean tuber yield.
- Determine the effect of type of seed bed preparation on yam bean storage root growth and yield.
- Determine the effect of intercropping yam bean with maize under farmers conditions in South Kivu, DRC.

Progress

In June 2014 the trials of Mr. Bulambo are in the field (second season, first season completed) and data collection is ongoing. During the defense of his proposal, the graduate committee suggested that he conducts two season of experimentation to achieve more reliable results. Note that Mr. Bulambo had to take intensive English classes to improve his language skills in order to attend courses and to write his thesis.

Figure 6. Mr. Bulambo, yam bean student from DRC, is showing leaf spots on yam beans to his supervisor, Dr. Hebert Talwana, in his field trial at Bukavu, DRC.

4.5 GROUP E STUDENT

The student in this category is at high risk of not finalizing her thesis.

Student 1: Lydia Nakagiri (MSc)—Food Science and Technology

Title: Participatory development of nutrient enriched yam bean (*Pachyrhizus* spp.) products and recipes in Uganda

Objectives:

- Determine the current food consumption and processing patterns in Serere and
- Luwero District of Uganda.
- Develop and test acceptability of different yam bean based products and recipes with farmers in Serere and Luwero District of Uganda.
- Assessment of the nutritional content of the developed yam bean based products.

Progress

Lydia Nakagiri has completed all field research work and has submitted a completed draft of her thesis to her supervisors, Prof. John Muyonga and Dr. Agnes Namutebi. The writing was quite good for a first MSc thesis draft, and in one to two months of she could have submitted her final thesis.

Challenges

Lydia Nakagiri has been staying in Ghana for more than a year. This has limited her from having a close interaction with her supervisors to complete her work. Unfortunately, the program and project have had no contact with her during that time; and to the best of our knowledge, nor have her supervisors.

4.6 GROUP F STUDENTS

The students in this category are undergraduate/BSc students, who were not in the letter of understanding between CIP and Makerere University in the framework of the AHIPA project. The three BSc students were working on studies with yam bean in Uganda and have completed their study and graduated.

Student 1: James Muhangi (BSc)–Agriculture

Title: Cost Benefit Analysis of Processing Yam Bean into Flour used to make *Atap*/*Ugali* Food Products in Serere and Luwero Districts of Uganda

Student 2: Gloria Asingwire (BSc)–Agriculture

Title: Consumer acceptability of yam bean salads in Kampala

Student 3: Elias Oyesigye (BSc)–Agriculture

Title: Morphological diversity of African yam bean (*Sphenostylis stenocarpa*) Winged bean (*Psophocarpus Tetragonolobus*) and other legume forming tubers

5. PUBLICATIONS IN PEER REVIEWED JOURNALS

Only one paper has been published as part of the yam bean program at the Makerere University:

Kisambira, A., J. H. Muyonga, Y.B. Byaruhanga, P. Tukamuhabwa, S. Tumwegamire, and W. Grüneberg. 2014. Physicochemical Characteristics of Yam Bean (*Pachyrhizus erosus*) Seed Proteins. *Journal of Food Research* 3(6): 168–178.

One manuscript has been submitted to HortScience and under review:

Andiku, C., P. Tukamuhabwa, J. M. Ssebuliba, H. Talwana, S. Tumwegamire, R. Eyzaguirre, B. Heider, and W. J. Grüneberg. Evaluation of the American Yam Bean (*Pachyrhizus* spp.) for Storage Root Yield across Varying Ecogeographic Conditions in Uganda.

We expect further publications from the PhD students since two accepted manuscripts in a peer-reviewed journal are a prerequisite to award the PhD degree.

6. ATTACHMENT

Appendix 11: Yam Bean Photo Gallery for Uganda presents several photos associated with the work described in Appendix 9.

APPENDIX 10

YAM BEAN PHOTO GALLERY FOR PERU

THE AHIPA PROJECT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

FINAL AHIPA PROJECT REPORT

Yam Bean Photo Gallery for Peru (PE)
Taken during the AHIPA project

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Funded by the Belgium Development Cooperation (2009–2014)

ABSTRACT

The yam bean is a legume root crop in the genus *Pachyrhizus* and the sub-tribe *Glycininae* with high storage root yields and very wide adaptation. In Mexico the crop is known as jicama and in Peru and Bolivia as ahipa. This is part III of the photo gallery taken as part of the AHIPA project, "Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa."

Part III shows photos taken during the recollection of high dry matter (DM) yam bean in the area of the river Ucayali and river Tambo, as proposed by Grüneberg et al. (2003). Also carried out were evaluation, conservation, and repatriation of genetic resources; introgression of *P. erosus* x *P. tuberous* and *P. ahipa* x *P. tuberous* to create high DM yam bean; mutation breeding to eliminate toxics compounds in the yam bean seed (this root crop is propagated by true seeds); and processing of yam bean storage roots with emphasis on the determination of plant iron of storage roots and processed products, including iron bioavailability. The International Potato Center (CIP) holds in trust about 120 yam bean accessions, including 18 segregating populations from the introgression of *P. erosus* x *P. tuberous* and *P. ahipa* x *P. tuberous* to create high DM yam bean. Nine accessions are recommended for demonstration trials: 209013, 209017, 209018, 209035, 209036, 209037, 209041, and 209054.

REFERENCE

Grüneberg, W.J., P. Freynhagen-Leopold, and O. Delgado-Váquez. 2003. A new yam bean (*Pachyrhizus* spp.) interspecific hybrid. *Genetic Resources and Crop Evolution* 50: 757–766.

PERU (PE) GROUP 1 CIP PHOTOS:

Recollection, Evaluation, and Conservation of Genetic Resources for *Pachyrhizus* spp. *(P.* tuberosus and *P. ahipa*) in Peru. Note that all photos in Groups 1 and 2 were taken by Ing. Elisa Romero of the AHIPA project (2010–2013).

Yam bean PE Group 1 Photo 1: Participation in the XXIV Congress of the Central Ashaninka of the river Tambo (CART) on 18–20 August 2010.

Yam bean PE Group 1 Photo 2: Travel on the river Tambo to assist at the XXIV Congress of the Central Ashaninka of the river Tambo (CART) on 18–20 August 2010.

Yam bean PE Group 1 Photo 3: Mother and child participating at the XXIV Congress of the Central Ashaninka of the river Tambo (CART) on 18–20 August 2010.

Yam bean PE Group 1 Photo 4: Sra. Ana Diaz Faquín, a farmer conserving *Pachyrhizus* spp., in the native community of Caco, during the 1st collection trip of *Pachyrhizus* spp. between Pucallpa and Atalaya, in 2010.

Yam bean PE Group 1 Photo 5: Sra. Sonia Soto, farmer conserving *Pachyrhizus* spp., in the native community of Nueva Ahuaypa, during the 1st collection trip of *Pachyrhizus* spp. between Pucallpa and Atalaya, in 2010.

Yam bean PE Group 1 Photo 6: Refreshment, during the XXIV Congress of the Central Ashaninka of the river Tambo (CART) on 18–20 August 2010.

Yam bean PE Group 1 Photo 7: Evaluating plants of the 1st collection trip in a screenhouse at San Ramón, 2010–2011.

Yam bean PE Group 1 Photo 8: Plants of 12 accessions maintained (BEH1, BEH2, BEH5A, BEH5B, BEH6, BEH7, BEH8, BEH10A, BEH10B, BEH13A, BEH13B, and BEH14) and their multiplication during 2011–2012 at San Ramón.

Yam bean PE Group 1 Photo 9: Seeds generated from accessions obtained during the 1st collection trip between Pucallpa and Atalaya (2010–2011) at San Ramón.

Yam bean PE Group 1 Photo 10: Elisa Romero traveling by boat on the river Tambo to meet and coordinate with the institute of the native community of Betania in 2011.

Yam bean PE Group 1 Photo 11: Meeting with the native community of Yarina in the city Constitución in 2012 during a collection trip of *Pachyrhizus* spp.

Yam bean PE Group 1 Photo 12: Luis Ortiz Ballesteros and Eduardo Ortiz Espíritu sign a letter of understanding about the AHIPA project in the native community of Tsachopen, Oxapampa.

Yam bean PE Group 1 Photo 13: Pruning of plants on the 2nd ahipa collection trip under screenhouse conditions at San Ramón during 2012–2013.

Yam bean PE Group 1 Photo 14: Green pods of *P. tuberosus* (Ashipa) of accession BEH14 in a screenhouse at San Ramón.

Yam bean PE Group 1 Photo 15: Pods, seeds, and storage roots of the accession *P. tuberosus* (BEH5B) grown under screenhouse conditions at San Ramón.

Yam bean PE Group 1 Photo 16: Leaves, pods, and storage roots of *P. tuberosus* accession (BEH5A) grown under screenhouse conditions at San Ramón.

Yam bean PE Group 1 Photo 17: Storage roots of *P. ahipa* accession CIP-209032 from experimental field plots in Lima during 2010–2011.

Yam bean PE Group 1 Photo 18: Storage roots of *P. erosus* grown in experimental plots at San Ramón.

Yam bean PE Group 1 Photo 19: Dry pods from the 2nd collection of ahipa after harvest campaign 2012–2013.

Yam bean PE Group 1 Photo 20: Visit of Sr. Arnaldo Cruz, head of UNAY, in the screenhouses to multiply ahipa at the experimental station Asan Ramón during 2011.

Yam bean PE Group 1 Photo 21: Carlos and Luis prune plants in multiplication of *P. ahipa* after flowering under screenhouse conditions at San Ramón.

Yam bean PE Group 1 Photo 22: Plant, flower, and pods of *P. ahipa*.

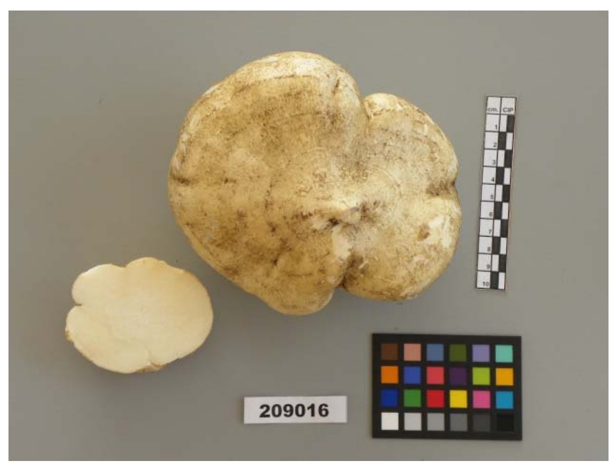
Yam bean PE Group 1 Photo 23: Plant, of *P. tuberosus* before flowering.

Yam bean PE Group 1 Photo 24: Inflorescence of *P. tuberosus*.

Yam bean PE Group 1 Photo 25: Purple inflorescence and small pods of *P. erosus*.

Yam bean PE Group 1 Photo 26: Purple inflorescence of *P. erosus.*

Yam bean PE Group 1 Photo 27: Seeds of *P. ahipa* (CIP-209026) after germination.



Yam bean PE Group 1 Photo 28: Storage root of *P. erosus* accession CIP-209016.

Yam bean PE Group 1 Photo 29: Green pods of *P. tuberosus.*

Peru (PE) Group 2 CIP Photos:
Recollection, Evaluation, and Conservation of Genetic Resources for *Pachyrhizus* spp. (*P. tuberosus* and *P. ahipa*) in Peru.

Yam bean PE Group 2 Photo 1: Harvest of experimental plots: Dr. Grüneberg, Dr. Thomas, and Gabriela Burgos at the experimental station La Molina, Lima, 2010.

Yam bean PE Group 2 Photo 2: Ing. Édison (docent at ITS in Betania) demonstrating plants of *P. tuberosus* at the Instituto Tecnológico Superior in the native community of Betania.

Yam bean PE Group 2 Photo 3: Students of the Instituto Tecnológico Superior in the native community of Betania at a science fair.

Yam bean PE Group 2 Photo 4: Plants of *P. erosus* accession CIP-209018 (in front) and *P. tuberosus* in a field trial to obtain storage roots for processing studies.

Yam bean PE Group 2 Photo 5: Field observations in experimental plots planted for processing studies of *Pachyrhizus* spp. by Dr. Heider in San Ramón.

Yam bean PE Group 2 Photo 6: Germination of seeds of *Pachyrhizus* spp. sown in sand before planting.

Yam bean PE Group 2 Photo 7: Crossing *P. erosus* (EC) x *P. tuberosus* (TC) at San Ramón.

Yam bean PE Group 2 Photo 8: CIP technicians are crossing *P. ahipa* (AC) *x P. tuberosus* (TC) high DM Chuin type in a screenhouse at San Ramón.

Yam bean PE Group 2 Photo 9: CIP technicians are crossing *P. tuberosus* (TC) high DM Chuin type *x P. erosus* (EC) in a screenhouse at San Ramón*.*

Yam bean PE Group 2 Photo 10: Plants prepared for crossing.

Yam bean PE Group 2 Photo 11: Storage root of interspecific hybrid derived from crossing *P. tuberosus* (TC) high DM Chuin type *x P. erosus* (EC) (CIP-209014 x CIP-209019) grown under screenhouse conditions in pots at San Ramón.

Yam bean PE Group 2 Photo 12: Storage root of interspecific hybrid derived from crossing *P. ahipa* (AC) *x P. tuberosus* (TC) high DM Chuin type (CIP-209004 x CIP-209014) grown under screenhouse conditions in pots at San Ramón.

Yam bean PE Group 2 Photo 13: Storage root of interspecific hybrid derived from crossing *P. ahipa* (AC) *x P. tuberosus* (TC) high DM Chuin type (CIP-209022 x CIP-209013A) grown under screenhouse conditions in pots at San Ramón.

Yam bean PE Group 2 Photo 14: Storage root of interspecific hybrid derived from crossing *P. erosus* (EC) *x P. ahipa* (AC) (CIP-209016A x CIP-209014) grown under screenhouse conditions in pots at San Ramón.

Yam bean PE Group 2 Photo 15: Pods and seeds of interspecific hybrid EC x TC (CIP-209031 x CIP-209022) grown under screenhouse conditions in pots at San Ramón and La Molina, Peru.

Yam bean PE Group 2 Photo 16: Pods and seeds of interspecific hybrid EC x TC high DM Chuin type (CIP-209016A x CIP-209013A) grown under screenhouse conditions in pots at San Ramón and La Molina, Peru.

Yam bean PE Group 2 Photo 17: Stiple of hybrid (CIP-209016 x CIP-209018) in screenhouse at La Molina, Lima.

Yam bean PE Group 2 Photo 18: Stiple of high DM hybrid (CIP-209015 x CIP-209004) in screenhouse at La Molina, Lima.

Yam bean PE Group 2 Photo 19: Mature pods of hybrid EC x TC high DM Chuin type (CIP-209018 x CIP209014) under screenhouse conditions of La Molina, Lima.

Yam bean PE Group 2 Photo 20: Pods of inter-specific hybrid EC x TC high DM Chuin type (CIP-209018 x CIP209014) under screenhouse conditions of La Molina, Lima.

Yam bean PE Group 2 Photo 21: Completely mature pods of hybrid AC x TC high DM Chuin (CIP-209031 x CIP-209013A) under screenhouse conditions of La Molina, Lima.

Yam bean PE Group 2 Photo 22: Working group of the AHIPA project at San Ramón in Peru: Ing. E. Romero, C. Tasso, Tec. V. Aliaga, Sr. C. Flores, and L. Ulloa.

Yam bean PE Group 2 Photo 23: Sowing in pots # 4 for experiment Yam bean Mosaic Virus (YBMV) under screenhouse conditions of San Ramón.

Yam bean PE Group 2 Photo 24: *Pachyrhizus* spp. plantlets before transplanting to the field plots.

Yam bean PE Group 2 Photo 25: *Pachyrhizus* spp. plantlets for the YBMV experiment to be planted in two replications.

Yam bean PE Group 2 Photo 26: Inoculation of *Pachyrhizus* spp. leaves with YBMV.

Yam bean PE Group 2 Photo 27: Ing. C. Tasso preparing membranes with samples of ahipa accessions for posterior analysis of YBMV.

Yam bean PE Group 2 Photo 28: Harvest of storage roots of accession 209015 in replication R-I in the YBMV experiment.

Yam bean PE Group 2 Photo 29: Commercial and noncommercial storage roots in replication R-I in the YBMV experiment.

Yam bean PE Group 2 Photo 30: Experiment to characterize 83 accessions of *Pachyrhizus* spp. at San Ramón, Peru.

Yam bean PE Group 2 Photo 31: Plants of *P. ahipa, P. erosus*, and *P. tuberosus* in the experiment to characterize 83 accessions of ahipa at San Ramón, Peru.

Yam bean PE Group 2 Photo 32: Luis Ortiz Ballesteros and Eduardo Ortiz Espíritu visit the experiment to characterize 83 accessions of ahipa in San Ramón, Peru.

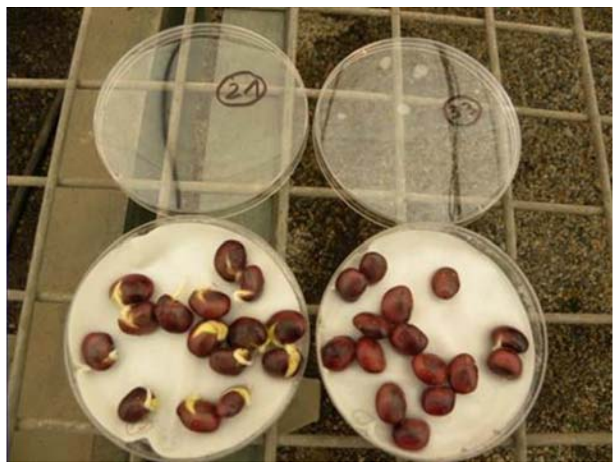
Yam bean PE Group 2 Photo 33: Seed fair for ahipa with farmers/conservationist of the native community of Tsachopen, Oxapampa.

Peru (PE) Group 3 CIP Photos:

New Genetic Resources for *Pachyrhizus* spp. *(P.* tuberosus and *P. ahipa*) Mutation Breeding in Peru.

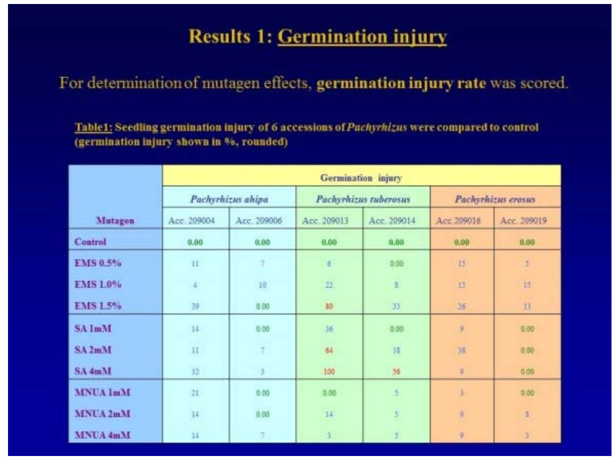
(Photos taken by Ing. Carolina Tasso and Ing. Elisa Romero in the AHIPA project, 2010–2013.)

Yam bean PE Group 3 (Mutation Breeding) Photo 1: Treatment of yam bean seed (CIP-209004, CIP-209006, CIP-209013, CIP-209014, CIP-209016, and CIP- 209019) with the mutagen compounds ethyl methanesulfonate (EM: 0.5%, 1%, 1.5%), sodium azide (SA: 1 Mm, 2 Mm, 4 Mm), and N-Nitroso-N-methylurea (MNUA: 1 Mm, 2 Mm, 4 Mm) (photo by C. Tasso, 2010).



Yam bean PE Group 3 (Mutation Breeding) Photo 2: Germination injury after treatment of yam bean seed mutagen compounds (photo by C. Tasso, 2010).

Yam bean PE Group 3 (Mutation Breeding) Photo 3**: Mutagen treatments of seeds is a risk to staff, especially young women (photo by C. Tasso, 2010).

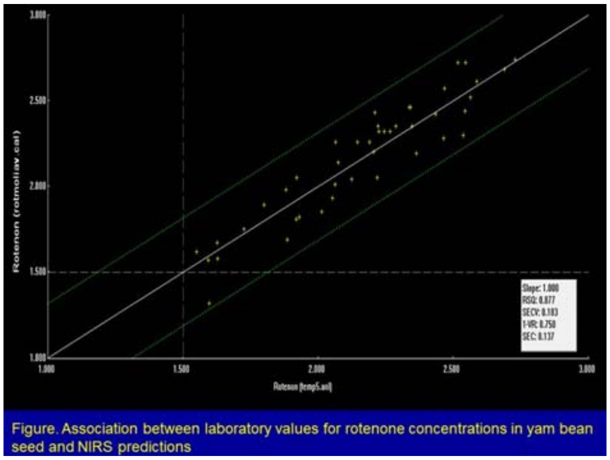


Mutagen	Germination injury					
	Pachyrhizus ahipa		*Pachyrhizus tuberosus*		*Pachyrhizus erosus*	
	Acc. 209004	Acc. 209006	Acc. 209013	Acc. 209014	Acc.209016	Acc. 209019
Control	0.00	0.00	0.00	0.00	0.00	0.00
EMS 0.5%	11	7	6	0.00	15	5
EMS 1.0%	4	10	22	8	15	15
EMS 1.5%	39	0.00	80	33	26	13
SA 1mM	14	0.00	36	0.00	9	0.00
SA 2mM	11	7	64	18	38	0.00
SA 4mM	32	3	100	36	9	0.00
MNUA 1mM	21	0.00	0.00	5	3	0.00
MNUA 2mM	14	0.00	14	5	9	8
MNUA 4mM	14	7	3	5	9	3

Yam bean PE Group 3 (Mutation Breeding) Photo 4: Observed germination injury results from mutagen treatments of yam bean seeds presented at the annual AHIPA project meeting in Burundi 2011 (photo by C. Tasso, 2011).

Yam bean PE Group 3 (Mutation Breeding) Photo 5: Jan Olenizak and Carolina Tasso handling M1 plant (plants germinated from mutagen treated seeds) (photo by E. Romero, 2011).

Yam bean PE Group 3 (Mutation Breeding) Photo 6: A M2 *Pachyrhizus* spp. plant derived from seed produced on a M1 plant. Seeds of M2 plant become M2 lines in M3, which is the test unit to evaluate for low rotenone and derivatives by dividing the seed harvest of M2 lines in 50% for the lab and 50% remaining seed to maintain the lines (photo by C. Tasso, 2012).



Yam bean PE Group 3 (Mutation Breeding) Photo 7: NIRS shows its feasibility to be used as a fast through-put approach to screen for rotenone content in milled yam bean seed (from T. zum Felde's AHIPA project report, 2012).

Yam bean PE Group 3 (Mutation Breeding) Photo 8: Mutation experiment to eliminate toxic rotenone and derivatives in yam bean true seed—plants before flowering at San Ramón (photo by E. Romero, 2011).

Yam bean PE Group 3 (Mutation Breeding) Photo 9: Persons in charge of the mutation experiment (photo by E. Romero, 2011).

Yam bean PE Group 3 (Mutation Breeding) Photo 10: Inflorescence of P. tuberosus (Ashipa) in the mutation experiment (photo by E. Romero, 2011).

Yam bean PE Group 3 (Mutation Breeding) Photo 11: Packing seed of M2 after harvest of M1 plant (photo by E. Romero, 2012).

Yam bean PE Group 3 (Mutation Breeding) Photo 12: One mutation found without (or at least very low) rotenone and derivatives—*P. tuberosus* (CIP-209054) low storage root DM—low rotenone and pachyrrhizine contents and no 12-hydroxypachyrrhizone in yam bean seed (not acute toxic at 0.7 g/200 g in animal studies). Poster presented by Emmanuel Lautie at the final AHIPA project meeting in Uganda 2014 (photo by W. Grüneberg, 2014).

Peru (PE) Group 4 CIP Photos:

Processing *Pachyrhizus* spp. *(P. erosus, P. tuberosus*, and *P. ahipa*), including processing under laboratory conditions to avoid non-plant iron and zinc contamination to determine iron bioavailability of yam bean food products. (Photos taken by Rosemary Carpio, Ing. Carolina Tasso, and Ing. Elisa Romero in the AHIPA project, 2010–2013).

Yam bean PE Group 4 Photo 1: Grading *P. ahipa, P. erosus*, and *P. tuberosus* storage roots to process flour (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 2: Grading *P. ahipa, P. erosus*, and *P. tuberosus* storage roots with a grader to process flour (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 3: Samples of *P. ahipa, P. erosus*, and *P. tuberosus* after grading and extracting the juice (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 4: Sun drying of graded samples of *P. ahipa, P. erosus*, and *P. tuberosus* (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 5: Oven-drying graded samples of *P. ahipa, P. erosus*, and *P. tuberosus* (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 6: Starch extracted from storage root samples of *P. ahipa, P. erosus*, and *P. tuberosus* (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 7: Flour from *P. erosus* (CIP-209018) and *P. tuberosus* (CIP-209014) (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 8: Starch from *P. tuberosus* (CIP-209013A) and *P. erosus* (CIP-209018) (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 9: Juice of *Pachyrhizus* spp. after grading (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 10: Production of "*chichi*" made from ahipa in the native community of Yarina (photo by E. Romero, 2011).

Yam bean PE Group 4 Photo 11: "*Mazamorra*" of ahipa and coconut at the seed fair (photo by E. Romero, 2013).

Yam bean PE Group 4 Photo 12: Cake made from ahipa and common wheat (photo by E. Romero, 2013).

Yam bean PE Group 4 Photo 13: Bread made from ahipa, sweetpotato (pro-vitamin A-rich variety 'Beauregard'), and common wheat flour at probe taste presentations in the native community of Tsachopen, Oxapampa (photo by E. Romero, 2012).

Yam bean PE Group 4 Photo 14: Bread made from ahipa, sweetpotato, and common wheat at probe taste presentations in the native community of Tsachopen, Oxapampa (photo by E. Romero, 2012).

Yam bean PE Group 4 Photo 15: Blga. Monica Santayana presents products made from ahipa and ahipa x sweetpotato at "The Field Day" at the experimental field station in San Ramón (photo by E. Romero, 2012).

Yam bean PE Group 4 Photo 16: During ahipa root laboratory processing in Lima, Peru, selection and cleaning process of the ahipa roots (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 17: During ahipa root laboratory processing, ahipa roots without their skin are grated on a stainless steel grater to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 18: During the ahipa mash preparation for dewatering, a researcher puts the sample in a cotton mesh and then into a stainless steel cylinder with holes drilled to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 19: During the ahipa mash preparation for dewatering, a researcher puts the sample in a cotton mesh and then into a stainless steel cylinder with holes drilled to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 20: During the dewatering mash into wet cake, ahipa mash is pressed in the hydraulic press to remove excess water in order to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by Ing. C. Tasso, 2012).

Yam bean PE Group 4 Photo 21: The wet ahipa cake after the pressing under laboratory processing to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 22: Drying of the wet ahipa cake. It shows the broken wet cake in small pieces (grits), placed in petri plates, and then put in drying oven to determine plant iron and zinc of processed ahipa products without non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 23: Milling of yam bean *gari*, showing the harder particles being ground with a pestle and mortar. The grits had to be milled to a specific size. Processing was conducted under conditions avoiding non-plant iron and zinc contamination (photo by Ing. C. Tasso, 2012).

Yam bean PE Group 4 Photo 24: Sieving of the *gari*, showing the separation of excess fiber that was eliminated. Processing was conducted under conditions avoiding non-plant iron and zinc contamination (photo by research assistant, R. Carpio, 2012).

Yam bean PE Group 4 Photo 25: Three products processed under laboratory conditions avoiding non-plant iron and zinc contamination: *gari* with sieving, *gari* without sieving, and fiber under laboratory conditions. These products are made for nutritional analysis (photo by Biol. J. Gavidia, 2012).

Yam bean PE Group 4 Photo 26: The toasting of the yam bean *gari* in a conventional process. It shows the fermented wet cake ready to be toasted in a pan. Processing was conducted avoiding non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 27: Toasting of the yam bean *gari* in a conventional process. It shows the wet cake toasted in small pieces in a pan to obtain a dry and crispy final product. Processing was conducted under conditions avoiding non-plant iron and zinc contamination (photo by research assistant R. Carpio, 2012).

Yam bean PE Group 4 Photo 28: Final product in two presentations: crispy *gari* and hydrated *gari* made under conventional process. Processing was conducted under conditions avoiding non-plant iron and zinc contamination. Results from Cornell University (personal communication, Raymond Glahn, 2014) reveal quite good iron bioavailability in our yam bean products. No non-plant iron contamination was confirmed as no aluminum content was found in samples done by inductively coupled plasma from the University of Adelaide (photo by research assistant R. Carpio, 2012).

APPENDIX 11

YAM BEAN PHOTO GALLERY FOR UGANDA

THE AHIPA PROJECT

Enhancing the nutrient-rich yam bean
(*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

FINAL AHIPA PROJECT REPORT

Yam Bean Photo Gallery for Uganda (UG)
Taken during the AHIPA project

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Funded by the Belgium Development Cooperation, 2009–2014

ABSTRACT

The yam bean is a legume root crop in the genus *Pachyrhizus* and the sub-tribe *Glycininae* with high storage root yields and very wide adaptation. In Mexico the crop is known as jicama and in Peru and Bolivia as ahipa. This is part I of the photo gallery taken as part of the project "Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa" (AHIPA project). Part I show photos taken during the introduction, germplasm evaluation of yam bean on-station and on-farm in Uganda, and the option to process local food products from yam bean storage roots.

As demonstrated by Zanklan et al. (2007) for West Africa, the crop is also well adapted to Central Africa and can be processed into several local food products such as *atapa*, *ugali*, porridge, and pancakes (also in mixture with other crops such as maize or bananas). Moreover, yam bean's low dry matter (DM) is appreciated by farmers for its refreshing taste as it is in many countries of the Americas and Asia. Two high-yielding, low DM yam beans can enter into the variety release process in Uganda. Eighteen breeding populations to select for high DM yam bean varieties from introgressions of *P. erosus* x *P. tuberosus* and *P. ahipa* x *P. tuberosus* crosses are still under selection at Makerere University.

REFERENCE

Zanklan A.S, S. Ahouangonou, H. C. Becker, E. Pawelzik, and W. J. Grüneberg. 2007. Evaluation of the Storage Root-forming legume Yam Bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Science* 47: 1934–1946.

Group 1 Photos:

Yam Bean at Serere and Luwero, Uganda, and product Porridge and Fufu (2011–2012). (NB: Photos 1–5 by Silver Tumwegamire; photos 6 and 7 by Wolfgang Grüneberg)

Yam bean UG Group 1 Photo 1: Mr. Eugine Ekinyu inspects yam bean on-farm demonstration field at Abuket village, Kyere Sub-county, Serere district in Uganda, 2012.

Yam bean UG Group 1 Photo 2: Women weed their yam bean on-farm demonstration field at Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda, 2011.

Yam bean UG Group 1 Photo 3: Farmers grate yam bean roots using a motorized grater before squeezing out water and drying at Abuket village, Kyere Sub-county, Serere district in Uganda, 2011.

Yam bean UG Group 1 Photo 4: A school child is excited by the gift of yam bean root from the CIP-Uganda team at Abuket village, Kyere Sub-county, Serere district in Uganda, 2012.

Yam bean UG Group 1 Photo 5: A farmer displays and is excited by the gift of yam bean root from the CIP-Uganda team at Abuket village, Kyere Sub-county, Serere district in Uganda, 2012.

Yam bean UG Group 1 Photo 6: Close to Namulonge—yam bean on-farm trials (photo by W. Grüneberg, 2011).

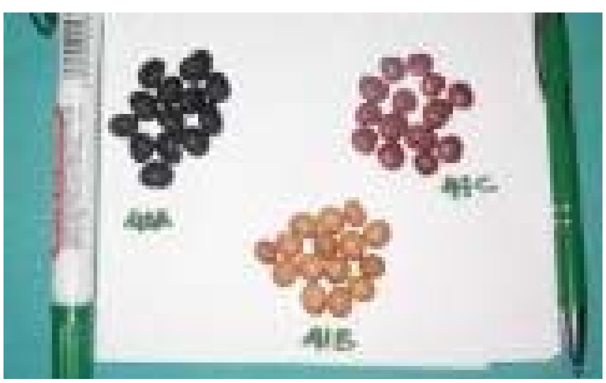
Yam bean UG Group 1 Photo 7: At Makerere University during the annual Yam Bean project meeting (photo by W. Grüneberg, 2012).

Uganda (UG) Group 2 Photos:

Yam bean at the National Crops Resources Research Institute (NaCRRI – Namulonge, Luwero, Makerere University, Kampala, KZARDI. (NB: Except where noted otherwise, all photos taken by Silver Tumwegamire, 2010–2012.)

Yam bean UG Group 2 Photo 1: At NaCRRI, Namulonge in Uganda. Yam bean plants growing in a screenhouse to produce seeds for distribution to other countries, Rwanda, Democratic Republic of the Congo (DRC), and Burundi.

Yam bean UG Group 2 Photo 2: At NaCRRI, Namulonge in Uganda. Yam bean plants of different genotypes growing in the field to produce seeds for local needs (i.e., student trials at Makerere University and on-farm production demonstration fields) in Uganda.



Yam bean UG Group 2 Photo 3: At NaCRRI, Namulonge in Uganda. Three different seed colors associated with accession 209060. The original seeds were black.

Yam bean UG Group 2 Photo 4: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. Joweria Ssekiyanja, a lady farmer, weeds her yam bean garden with her colleague looking on.

Yam bean UG Group 2 Photo 5: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. A woman farmer on routine flower pruning of all the yam bean plants in the on-farm production demonstration plots.

Yam bean UG Group 2 Photo 6: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. Using a hand hoe, a woman farmer harvests yam beans during on-farm field evaluations.

Yam bean UG Group 2 Photo 7: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. Women farmers collect and clean soil from yam bean roots after harvesting.

Yam bean UG Group 2 Photos 8a: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. A breast-feeding mother eats and enjoys raw yam bean root. She preferred the purple-fleshed *P. ahipa* types.

Yam bean UG Group 2 Photos 8b-c: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. A breast-feeding mother eats and enjoys raw yam bean root. She preferred the purple-fleshed *P. ahipa* types.

Yam bean UG Group 2 Photo 9: At the CIP-Uganda office in Kampala. Ms. Sarah Mayanja, a CIP staff, eats and enjoys her fruit-yam bean root salad, which she had packed and brought from home.

Yam bean UG Group 2 Photo 10: At Kachewekano Agricultural Zonal Research Institute (KZARDI). Roots of other better performing *P. erosus* types at KZARDI (≥ 2,300 masl) after 7 months in the field.

Yam bean UG Group 2 Photo 11: At NaCRRI, Namulonge in Uganda. Participants of the 2012 annual project meeting visit a field trial for a PhD student, Rolland Agaba, at NaCRRI.

Yam bean UG Group 2 Photo 12: Phinehas Tukamuhabwa, AHIPA project coordinator at Makerere University, explains yam bean seed multiplication activities in the screenhouse at Makerere University Agricultural Research Institute, Kabanyolo (photo by IT person at Makerere University, Kampala, 2010).

Yam bean UG Group 2 Photo 13: Participants at annual project meeting view the first yam bean roots from the seed multiplication plants at NaCRRI, Namulonge.

Yam bean UG Group 2 Photo 14: Participants of the annual project meeting at MAK (photo by IT person at Makerere University, Kampala, 2012).

Uganda (UG) Group 3

Yam Bean Product Development Pictures: Yam bean at Serere and at Makerere University, Kampala, Uganda. (Photos taken by Silver Tumwegamire, Lydia Nakagiri, and Isaac Migisa, 2011–2012.)

Yam bean UG Group 3 Photo 1: At Abuket village, Kyere Sub-county, Serere district in Uganda, women in the village peel and wash clean yam bean roots before they are grated (photo by S. Tumwegamire, 2012).

Yam bean UG Group 3 Photo 2: At Abuket village, Kyere Sub-county, Serere district in Uganda, Lydia Nakagiri, MSc student at Makerere University, spreads yam bean grated material onto a rack for sun proper and fast sun drying (photo by S. Tumwegamire, 2011).

Yam bean UG Group 3 Photo 3: At Abuket village, Kyere Sub-county, Serere district in Uganda, Lydia Nakagiri, Silver Tumwegamire, and farmers work together to spread yam bean grated material onto a rack for sun proper and fast sun drying (photo by I. Migisa, CIP Driver, 2011).

Yam bean UG Group 3 Photo 4: At Abuket village, Kyere Sub-county, Serere district in Uganda. In the green bag is the dried grated yam bean material from one of the high-yielding *P. erosus* accession 209017 (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 5: At Abuket village, Kyere Sub-county, Serere district in Uganda, farmers measure and mix all ingredients agreed on to incorporate in order to make yam bean-based *atapa* or porridge (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 6: At Abuket village, Kyere Sub-county, Serere district in Uganda. Farmers mill the mixed yam beam and other ingredients using a hammer mill to obtain composite flour. Also farmers milled only dry grated yam bean material (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 7: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda, women sieve yam bean flour after pounding the dry grated material (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 8: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. Pure yam bean flour obtained after sieving or milling using a hammer mill (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 9: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. A woman carries a plate of *ugali* made from composite flour 50% yam bean and 50% maize (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 10: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. The *ugali* is sliced into smaller pieces for serving (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 11: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. Porridge made from composite flour 50% yam bean and 50% maize (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 12: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. A group of women, men, and children tastes porridge made from composite flour 50% yam bean and 50% maize (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 13: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. On a big plate are raw pan cakes sliced from dough made from ripe dessert banana and yam bean flour (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 14: At Mayilikiti village, Nyimbwa Sub-county, Luwero district in Uganda. A frying pan with boiling oil and pancakes made from dough made from ripe dessert banana and yam bean flour (photo by L. Nakagiri, 2012

Yam bean UG Group 3 Photo 15: At Mayilikiti village, Nymbwa Sub-county, Luwero district in Uganda. Fried pancakes made from dough made from ripe dessert banana and yam bean flour (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 16: At Abuket village, Kyere Sub-county, Serere district in Uganda. *Atapa* made from yam bean, cassava, sweetpotato, and sorghum is being mixed in a pan on the cooking stove (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 17: At Abuket village, Kyere Sub-county, Serere district in Uganda. *Atapa* made from yam bean, cassava, sweetpotato, and sorghum is being served by a woman for consumer taste acceptance (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 18: At Abuket village, Kyere Sub-county, Serere district in Uganda. A group of women, men, and children tastes porridge made from composite flour 50% yam bean and 50% maize (photo by L. Nakagiri, 2012).

Yam bean UG Group 3 Photo 19: Jean Ndirique from Rwanda explains during the Ahipa exhibition at Makerere during the 2012 annual project meeting (photo by IT person at Makerere University, 2012).

Yam bean UG Group 3 Photo 20: Participants taste different yam bean-based products during the Ahipa exhibition at Makerere during the 2012 annual project meeting (photo by IT person at Makerere University, 2012).

Yam bean UG Group 3 Photo 21: Yam bean root salad during the Ahipa exhibition at Makerere during the 2012 annual project meeting (photo by IT person at Makerere University, 2012).

Yam bean UG Group 3 Photo 22: Participants taste different yam bean-based products during the AHIPA Project exhibition at Makerere during the 2012 annual project meeting (photo by IT person at Makerere University, 2012).

Yam bean UG Group 3 Photo 23: Lydia Nakagiri, MSc student Makerere University–Rwanda, explains during the AHIPA Project exhibition at Makerere during the 2012 annual project meeting (photo by IT person at Makerere University, 2012).

Yam bean UG Group 3 Photo 24: At Abuket village, Kyere Sub-county, Serere district in Uganda. Chicken and guinea fowls eat a raw yam bean root (photo by L. Nakagiri, 2012).

APPENDIX 12

YAM BEAN PHOTO GALLERY FOR BENIN

THE AHIPA PROJECT

Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa

FINAL AHIPA PROJECT REPORT

Yam Bean Photo Gallery for Benin (BE)
Taken during the AHIPA project

Official project name: "Enhancing the nutrient-rich yam bean (*Pachyrhizus spp.*) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa"

Funded by the Belgium Development Cooperation, 2009–2014

ABSTRACT

The yam bean is a legume root crop in the genus *Pachyrhizus* and the sub-tribe *Glycininae* with high storage root yields and very wide adaptation. In Mexico the crop is known as jicama and in Peru and Bolivia as ahipa. This is part II of the photo gallery taken as part of the AHIPA project "Enhancing the nutrient-rich yam bean (*Pachyrhizus* spp.) storage roots to improve food quality and availability and sustainability of farming systems in Central and West Africa." Photos in Part II were taken during on-station and on-farm trials in Benin, on-farm processing into products for local markets, and awareness and dissemination campaigns.

Zanklan et al. (2007) have shown that the yam bean is well adapted to West Africa, tolerates drought stress, and can be processed into *gari*. But the crop remained unknown to farmers in Benin. In the AHIPA project, which fortunately means "to the market" in the local language, the yam bean was disseminated to farmers in Benin by INRAB and the NGO BØRNEfonden. *Gari*, juice/bottle refreshments, alcohol, and snacks are products that received most awareness by consumers and producers. Introduction of a new crop is quite a cumbersome task, even if it is high yielding. Most important appears to be road shows to show farmers what can be made with the new crop. However, the low dry matter (DM) type of the yam bean is also appreciated by farmers in Benin for its refreshing taste, as it is in many countries of the Americas and Asia. Processing to *gari* from low DM yam bean needs to be combined with juice to merit efforts. The products are iron dense and have quite good iron bioavailability; this holds true for *gari* as well as juice (see yam bean photo gallery part III for Peru). High DM yam beans appear to have advantages for *gari* processing, with a conversion rate of around 19%. The crop was disseminated to 300 farmers and might be grown today by thousands of farmers in Benin. However, farmers need to make income, so linking farmers and buyers of yam bean still appears to be a challenge in establishing the new crop in Benin and West Africa.

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Zanklan, A.S, S. Ahouangonou, H. C. Becker, E. Pawelzik, and W. J. Grüneberg. 2007. Evaluation of the Storage Root-forming legume Yam Bean (*Pachyrhizus* spp.) under West African Conditions. *Crop Science* 47: 1934–1946.

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Padonou, S.W., A.K. Hounyèvou, J-L Ahounou, A. P. Houssou, P. Fandohan, K. Aïhou, A. Adjanohoun, K. Hell, P.Y. Adégbola, G. A. Mensah, and D.O. Koudande. 2013. Yam bean (*Pachyrhizus erosus*) tuber processing in Benin: production and evaluation of the quality of yam bean-gari and yam bean-fortified gari. *Int. J. Biol. Chem. Sci*. 7(1): 247–259.

Benin (BE) Group 1 INRAB Photos:

Yam Bean cultivation and processing in Benin. (Photos taken by Wilfrid Padonou, Léandre Dahoundo, Camille Bankolé, and Epiphane Guédou, 2010–2013.)

Yam bean BE Group 1 INRAB Photo 1: *Gari* processed on-station with different percentage of yam bean and cassava (photo by W. Padonou, 2010).

Yam bean BE Group 1 INRAB Photo 2: Yam bean effluent extraction by pressing the grated mash (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 3a: Yam bean flour obtained after milling the dried yam bean pulp (photo by W. Padonou, 2011)spp. between Pucallpa and Atalaya, in 2010.

Yam bean BE Group 1 INRAB Photo 3b: Yam bean flour obtained after milling the dried yam bean pulp (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 4: BSc student explains his observations during an on-station yam bean cultivation trial at the Agricultural Research Centre of Savè/INRAB (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 5: Farmer tells scientists from INRAB and CIP his findings from his yam bean cultivation trial at Bossouvi (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 6: Yam bean pods, seeds and processed products presented at World Food Day 2011 in Benin (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 7: People tasting the yam bean processed products presented at World Food Day 2011 in Benin (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 8: Former Ministry of Agriculture of Benin (2011–2013) tastes yam bean-processed products presented at World Food Day 2011 in Benin (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 9: The general director of INRAB (blue shirt and white cap), the representative of FAO in Benin (woman with blue cap), and visitors taste yam bean products at World Food Day 2011 in Benin (photo by W. Padonou, 2011).

Yam bean BE Group 1 INRAB Photo 10: Yam bean seeds, storage roots, and processed products presented at a mini-fair organized by INRAB during the national agricultural researchers meeting at AfricaRice campus on 11 November 2011 (photo by C. Bankolé, 2011).

Yam bean BE Group 1 INRAB Photo 11: The president of the parliament of Benin (2007–2011 and 2011–2015) and other officials in contact with yam bean products at the mini-fair organized by INRAB during the national agricultural researchers meeting at AfricaRice campus on 11 November 2011 (photo by C. Bankolé, 2011).

Yam bean BE Group 1 INRAB Photo 12: Liquor extraction from fermented yam bean effluent (photo by W. Padonou 2011).

Yam bean BE Group 1 INRAB Photo 13: Sun-drying of grated and pressed yam bean mash before milling into flour (photo by W. Padonou 2011).

Yam bean BE Group 1 INRAB Photo 14: Bottled and ready-to-drink yam bean juice processed at on-station scale at INRAB (photo by W. Padonou 2012).

Yam bean BE Group 1 INRAB Photo 15: Snack *atchonmon* obtained from yam bean flour. The processing was done as on-station trial at INRAB (photo by W. Padonou 2012).

Yam bean BE Group 1 INRAB Photo 16: Manual bottle capper fabricated by INRAB to cover bottles filled with yam bean juice (photo by W. Padonou 2013).

Yam bean BE Group 1 INRAB Photo 17: Yam bean juice processing: Bottles filling and capping demonstration during a training session of BØRNEfonden's farmers and processors (photo by E. Guédou, 2013).

Yam bean BE Group 1 INRAB Photo 18: Yam bean juice processing: Pasteurization of yam bean juice at on-farm scale demonstrated during a training session of BØRNEfonden's farmers and processors (photo by E. Guédou, 2013).

Yam bean BE Group 1 INRAB Photo 19: Leandre Dahoundo (CIP-Ghana technician) giving yam bean dry chips to children in a village of Abomey-Calavi (South Benin) (photo by W. Padonou, 2013).

Yam bean BE Group 1 INRAB Photo 20: Yam bean fortified-*gari* processing at a *gari* processing unit at Hounvi (Central Benin) with women toasting yam bean fortified-*gari* (photo by L. Dahoundo, 2013).

Yam bean BE Group 1 INRAB Photo 21: Wilfrid Padonou shows farmers in Mondogui (Central of Benin) processed products from yam bean and explains advantages of yam bean cultivation, processing, and consumption (photo by L. Dahoundo, 2013).

Yam bean BE Group 1 INRAB Photo 22: Wilfrid Padonou at the professional training centre in Parakou (North Benin) with yam bean-processed products. He held a class session with girls on yam bean processing (photo by L. Dahoundo, 2013).

Yam bean BE Group 1 INRAB Photo 23: Wilfrid Padonou shows yam bean-processed products during a class session at the professional training centre in Parakou (North Benin) (photo by L. Dahoundo, 2013).

Yam bean BE Group 1 INRAB Photo 24: Wilfrid Padonou (INRAB staff at left) in a discussion on yam bean cultivation and processing with farmers in Gomez Kparou village (N'Dali, North Benin) (photo by L. Dahoundo, 2013).

Yam bean BE Group 1 INRAB Photo 25: Breads made with mix yam bean–wheat flour at laboratory scale at INRAB (photo by W. Padonou, 2012).

Yam bean BE Group 1 INRAB Photo 26: Screw press and yam bean pressing demonstration for juice extraction at on-farm scale at Dangbo (South Benin) (photo by W. Padonou, 2013).

Yam bean BE Group 1 INRAB Photo 27: Goats eat yam bean peels in Benin (photo by W. Padonou, 2012).

Yam bean BE Group 1 INRAB Photo 28: Animal production scientist, Charles Pomalegni, pulls up two giant snails (*Archachatina* spp.*)* to show to CIP researchers. Here they were thriving on yam bean. In parts of Africa and Asia, these snails are raised by small-scale producers in plots behind their home or work compounds (photo by Graham Thiele, 2011).

Yam bean BE Group 1 INRAB Photo 29: Along with the giant snails (see also *ScienceDaily*, November 20, 2009: Let Them Eat Snail: Nutritional Giant Snails Could Address Malnutrition), the AHIPA project in Benin has been undertaking feeding trials with nursery fish and a highly prized rodent called a grasscutter. “The grasscutter has meat that is rich in protein, low in fat, and appreciated for its taste and tenderness. The yam bean’s potential as livestock feed or for local processing may bring even greater added value to small-scale farmers,” said Graham Thiele, an economist and director of CGIAR Research Program on Roots, Tubers, and Bananas (photo by G. Thiele, 2011).

Yam bean Benin (BE) Info—NGO BØRNEfonden Group 1 Photos:

Yam bean at NGO BØRNEfonden in Benin. (Photos taken by Mathieu Dovonou, Théophile Djossa, Aristide Akpa, Joseph Larou, Lys Lobote, Lucien Amoussou, and Houenon Rodrigue, 2012–2013.)

Yam bean BE NGO BØRNEfonden Group 1 Photo 1: During ahipa tasting session in Zakpota commune. It shows from right to left: Dr. Padonou's assistant; Dr. Padonou presenting information on ahipa processing to the participants; Nestor Alokpaï, who is responsible for agriculture and animal breeding sector of Zakpota (state agency); and two chiefs of DU. In front are the products made from ahipa processing (photo by M. Dovonou, a family advisor in charge of income-generating activities at Development Unit: DU 423 of BØRNEfonden-Benin, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 2: Ahipa tasting session in Zakpota commune; ahipa juice in bottle made for the tasting session (photo by M. Dovonou, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 3: During ahipa tasting session in Zakpota commune; ahipa liqueur made for the tasting session (photo by M. Dovonou, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 4: During ahipa tasting session in Bonou commune; ahipa yoghurt, made for the tasting session (photo by T. Djossa, Chief of Development Unit: DU 434 of BØRNEfonden-Benin, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 5: During ahipa tasting session in Bonou commune; fresh ahipa made for the tasting session (photo by T. Djossa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 6: Tasting of fresh ahipa with roasted peanuts in Bonou at the DU 434 of BØRNEfonden-Benin. At this session, we have Nestor Alokpaï, who is in charge of the AHIPA project at BØRNEfonden-Benin head office; Théophile Djossa, chief of Development Unit: DU 434 of BØRNEfonden-Benin; and the family advisors of his staff (photo by Aristid Akpa, farmers' advisor on the project, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 7: During ahipa tasting session in Dangbo commune. It shows ahipa liqueur, ahipa juice, snack made from ahipa, ahipa dried small strips, and ahipa storage roots. These products were made for the tasting session (photo by Joseph Larou, chief of Development Unit: DU 431 of BØRNEfonden-Benin, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 8: During ahipa tasting session in Zakpota commune. Woman tastes ahipa yoghurt (photo by M. Dovonou, 2012).

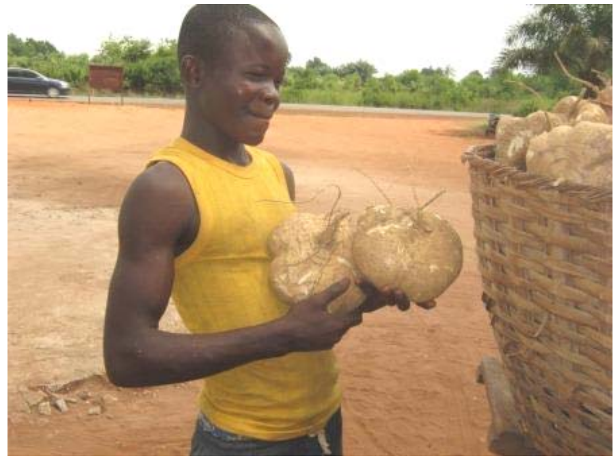
Yam bean BE NGO BØRNEfonden Group 1 Photo 9: During ahipa harvesting in Zakpota. Two ahipa farmers (women) carry the ahipa to their house (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 10: During ahipa harvesting in Zakpota, woman displays her largest ahipa roots (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 11: At ahipa harvesting in Zakpota, woman harvests ahipa on her farm (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 12: At ahipa harvesting in Zakpota, woman poses with the ahipa roots harvested on her farm (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 13: At ahipa harvesting in Dangbo, a man transports ahipa roots on his bicycle (photo by Lys Lobote, farmers' advisor on AHIPA project, 2012).



Yam bean BE NGO BØRNEfonden Group 1 Photo 14: At ahipa harvesting in Dangbo, young man poses with ahipa roots (photo by L. Lobote, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 15: At ahipa harvesting in Bonou, ahipa storage roots stored in plastic sacks (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 16: Farmer harvests ahipa at Dangbo (photo by L. Lobote, 2012).

Yam bean BE NGO BØRNEfonden Group 1 Photo 17: Woman farmer weeding on her farm (photo by Lucien Amoussou, family advisor in DU 434 Bonou, 2013).

Yam bean BE NGO BØRNEfonden Group 1 Photo 18: Farmer weeds his ahipa fields on his farm (photo by Houenon Rodrigue, family advisor in DU 422 Zakpota, 2013).

Yam bean Benin (BE) Info–NGO BØRNEfonden Group 2 Photos:

Yam bean at NGO BØRNEfonden in Benin. (Photos taken by Epiphane Guedou, Gontrand Alladassi, Houenon Rodrigue, Bessan François, Aristide Akpa, Leopold Mahoukpo, and Lys Lobote, 2013–2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 1: During pruning operation at Bonou in Benin, man and his son prune yam bean flowers on their farm to increase storage root yields (photo by Epiphane Guedou, farmer's advisor on AHIPA project at BØRNEfonden-Benin, 2013).

Yam bean BE NGO BØRNEfonden Group 2 Photo 2: Ahipa harvesting at Dangbo in Benin; man transports his ahipa storage roots on his bicycle (photo by L. Lobote, 2012).

Yam bean BE NGO BØRNEfonden Group 2 Photo 3: Farmer harvests ahipa on his farm at Adjohoun (photo by Gontrand Alladassi, family advisor in DU 433 Adjohoun in Benin, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 4: In Zakpota, farmer puts ahipa roots after harvest in a bag to transport them home (photo by H. Rodrigue, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 5: In Zakpota, farmer shows his ahipa storage roots after harvesting (photo by Bessan François, family advisor in DU 421 Zakpota, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 6: In Zakpota, woman harvests ahipa on her farm (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 2 Photo 7: At local fair at Adjohoun, woman explains to visitors about ahipa-processed products that she is selling (ahipa juice, snacks from ahipa, fresh consumption of ahipa,

Yam bean BE NGO BØRNEfonden Group 2 Photo 8: In Zakpota, woman presents her largest ahipa storage roots (photo by A. Akpa, 2012).

Yam bean BE NGO BØRNEfonden Group 2 Photo 9: At ahipa harvest in Zakpota, woman poses with her ahipa roots (photo by B. François, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 10: At local fair at Adjohoun, ahipa-processed products (juice, snack, fresh, and liqueur) for sale during the fair (photo by E. Guedou, 2014).

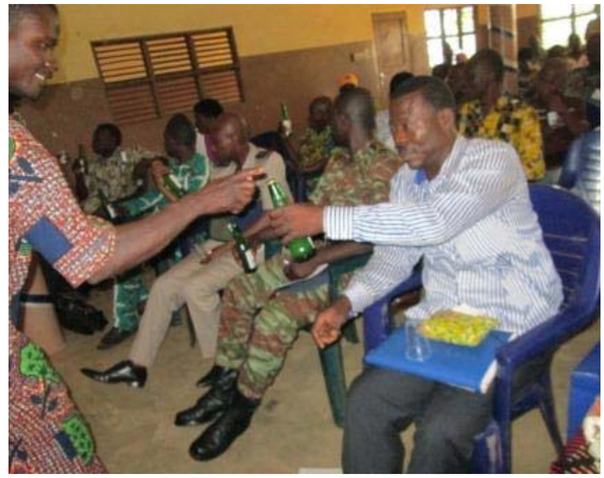
Yam bean BE NGO BØRNEfonden Group 2 Photo 11: At local fair at Adjohoun, some ahipa-processed products for sale in the front of a stand during the fair (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 12: Farm operations at Adjohoun: farm with a part of staked ahipas to enhance true seeds production (photo by L. Lobote, 2013).

Yam bean BE NGO BØRNEfonden Group 2 Photo 13: Farmer weeds his ahipa field (photo by H. Rodrigue, 2013).

Yam bean BE NGO BØRNEfonden Group 2 Photo 14: Farmer weeds her farm (photo by B. François, 2013).

Yam bean BE NGO BØRNEfonden Group 2 Photo 15: After ahipa harvest in Bonou, ahipa storage roots stored in bags (photo by A. Akpa, 2013).



Yam bean BE NGO BØRNEfonden Group 2 Photo 16: At tasting session organized by the DU, some participants taste ahipa juice (photo by L. Amoussou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 17: At local fair in Adjohoun, participants buy ahipa products (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 18: T At local fair in Adjohoun, producers pose with their ahipa-processed products (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 19: At local fair in Adjohoun, a major visiting ahipa stand (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 20: At local fair in Adjohoun, some ahipa-processed products (flour, snacks, and chips) (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 21: At local fair in Adjohoun, ahipa-processed products (flour, snacks, chips, and juice) (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 22: At local fair in Adjohoun, participants buy ahipa products (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 23: At local fair in Adjohoun. Ahipa products exposed for sale (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 24: At tasting session in Dangbo, participants share ahipa products (photo by Leopold Mahoukpo, family advisor at DU 430 Dangbo of BØRNEfonden-Benin, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 25: At tasting session in Dangbo, participants drink ahipa juice (photo by L. Mahoukpo, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 26: At local fair in Adjohoun, producers display their ahipa-processed products for sale (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 27: At local fair in Adjohoun, participants buy and drink ahipa juice (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 28: Ahipa processing training by Dr. Wilfrid Padonou in Zakpota. Participants peel and clean fresh ahipa storage roots (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 29: Ahipa processing training by Dr. Wilfrid Padonou in Dangbo. Participants press fresh ahipa peeled with a manual press tool (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 30: Ahipa processing training by Dr. Wilfrid Padonou in Dangbo. Participants press fresh ahipa peeled with a manual press tool (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photos 31 and 32: Ahipa processing training by Dr. Wilfrid Padonou in Dangbo. Participants bottle ahipa juice (photo by E. Guedou, 2014).

Yam bean BE NGO BØRNEfonden Group 2 Photo 33: Ahipa processing training by Dr. Wilfrid Padonou in Bonou. Participants practice preparing ahipa snacks (photo by E. Guedou, 2014).

Yam bean BE NGO Bjoern Group 2 Photo 34: Ahipa processing training by Dr. Wilfrid Padonou in Adjohoun. Participants practice packaging ahipa snacks with an electric packaging tool (photo by E. Guedou, 2014).

The International Potato Center (known by its Spanish acronym CIP) is a research-for-development organization with a focus on potato, sweetpotato, and Andean roots and tubers. CIP is dedicated to delivering sustainable science-based solutions to the pressing world issues of hunger, poverty, gender equity, climate change and the preservation of our Earth's fragile biodiversity and natural resources.
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