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Nutritional improvement of yam bean and sustainability of farming systems in Central and West Africa

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Abstract American yam bean (*Pachyrhizus* spp.), a storage root forming legume, is currently disseminated in five West and Central African countries to investigate its food production potential. The genetic base of yam bean germplasm under custody by the International Potato Center (CIP) was broadened by seed acquisition and interspecific hybridization. Multi-environmental trials (METs) were established to evaluate agronomic performance and storage root composition. Average storage root yields were 4.9 t ha^{-1} for *P. ahipa*, 31.8 t ha^{-1} for *P. erosus*, 25.4 t ha^{-1} for *P. tuberosus*, and 15 t ha^{-1} for hybrid varieties. Iron (Fe) contents on root dry matter basis ranged from 19 to 52 ppm. Zinc (Zn) content was on average 9 ppm. Starch contents also on dry matter basis varied from 20.7% in *P. erosus* to 78.8% in a hybrid. Processed products included: fresh and cooked roots, starch, flour, chips, and *gari*. Results demonstrate the agronomic and nutritional potential of American yam bean.

Key words: Chips, Fe, *gari*, *Pachyrhizus* spp., Zn

Introduction

American yam bean (*Pachyrhizus* spp.) is a storage root forming legume of which three cultivated species can be distinguished: *P. ahipa*, *P. erosus*, and *P. tuberosus*. The crop produces heavy storage roots and large seeds, but only storage roots are consumed due to the toxic compound, rotenone, contained in seeds (Sørensen, 1996). In the frame of the yam bean project *Pachyrhizus* spp. has been introduced into Africa and is currently disseminated in five African countries in order to investigate its potential for food production in West- and Central Africa.

Ahipa is one of the most important legume roots and tuber crops (FAO, 1979). However, to date, only a small fraction of *Pachyrhizus* spp. diversity is used more intensively. The objective of the on-going American yam bean research is to improve availability of (*Pachyrhizus* spp.) germplasm, identify adapted high yielding yam bean accessions, and develop yam bean storage root products for West- and Central Africa.

Material and Methods

The International Potato Center (CIP) is leading a four year initiative (2009-2012) encompassing a series of research activities designed to unlock the full potential of the American yam bean. A collecting mission was carried out from 19-28th of November 2010 in Peru travelling the Ucayali River upstreams from Pucallpa to Atalaya. During this trajectory 15 native communities belonging to the Shipibo, Ashaninka, and Jine were visited, and 15 accessions were collected of which eleven were successfully multiplied and stored at CIP genebank in Lima, Peru for long term conservation purposes. A copy of the collection is maintained at the Instituto Nacional de Inovación Agraria (INIA) in Pucallpa, Peru.

Multi-environmental trials (METs) including three *Pachyrhizus* species were established in Uganda, Rwanda, Burundi, D.R. Congo and Peru. Germplasm was evaluated for agronomic performance and storage root composition (protein, dry matter, iron, zinc, and starch). Preliminary results from Peru were subjected to a one-way analysis of variance (ANOVA) using SAS-STAT 9.1.

In order to broaden the genetic base of yam bean available at CIP, a cross breeding experiment was established in 2010. The experiment was designed as a completely diallelic cross between three *P. ahipa* and three *P. tuberosus* accessions and between three *P. erosus* und three *P. tuberosus* s accessions (Table 1).

Results and Discussion

The genetic base of yam bean germplasm under custody by CIP was broadened by seed acquisition and interspecific hybridisation. The number of accessions maintained at CIP- genebank was increased from 42 to 68. Seven new *P. erosus* accessions and 8 new *P. tuberous* accessions were obtained by germplasm exchange from CATIE/Costa Rica and 11 new *P. tuberosus* accessions were collected in collection missions in the Peruvian Amazon. The new collection comprises of three varieties of *P. tuberosus:* purple Chuin (9 acc.), white Ashipa (1) and yellow Ashipa (1) (data not shown).

Table 1. Number of flowers crossed, number of pods obtained for six cross combinations among *P. ahipa* (CIP-Acc. 209004, 209022, 209031), *P. tuberosus* (CIP-Acc. 209013, 209014, 209015), and *P. erosus* (CIP-Acc. 209016, 209018, 209019).

Groups	Cross combinations	# flowers crossed	# pods
	P. ahipa (AC) x *P. tuberosus* (TC)		
1	AC x AC	323	17
2	TC x TC	71	24
3	AC x TC	788	63
4	TC x AC	384	27
5	auto-pollinization AC	448	91
6	auto-pollinization TC	106	72
	P. tuberosus (TC) x *P. erosus* (EC)		
1	EC x EC	1710	275
2	TC x TC	1869	89
3	EC x TC	4051	250
4	TC x EC	1796	84
5	auto-pollinization EC	242	212
6	auto-pollinization TC	253	210

Interspecific hybridisation resulted in 18 F1 interspecific and 12 F1 intraspecific cross populations. Nine *P. ahipa* x *P. tuberosus* chuin F1 cross populations as well as 9 *P. erosus* x *P. tuberosus* chuin F1 cross populations were developed. Theses population will be used to generate a large number of F2 lines that serve to select genotypes with high dry matter, high starch, and adaptation to the environmental conditions of the Central African highlands or the savanna zones of West, Central, and Southern Africa. Since the beginning of the crossbreeding experiment a total of 2120 (AC x TC) and 9921 (EC x TC) pollinations were made, of which 294 and 1120, respectively were successful and seeds harvested (Table 1). The hybrid populations of *P. ahipa* x *P. tuberosus* chuin and *P. erosus* x *P. tuberosus* chuin will broaden the very narrow genetic diversity of high dry matter *Pachyrhizus* spp.

Results from comprehensive METs in Peru showed considerable variation in dry matter content (11.4-38%) with maximum values found for *P. tuberosus* (Table 2). Average storage root yields were 4.9 t ha^{-1} for *P. ahipa*, 31.8 t ha^{-1} for *P. erosus*, 25.4 t ha^{-1} for *P. tuberosus*, and 15 t ha^{-1} for hybrid varieties. Iron contents on dry matter basis ranged from a minimum accession of 19 ppm in *Pachyrhizus ahipa* and *P. erosus,* to a maximum of 51.5 ppm in *Pachyrhizus tuberosus*. Zinc content was on average 9 ppm across all accessions. *P. ahipa* and *P. erosus*

Table 2. Storage root yield and quality of *Pachyrhizus* spp. evaluated at two environments in Peru 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^{-1})	4.9	1.4	13.6
	Dry matter (%)	19.1	17.2	20.5
	Protein (%)	7.7	6.3	9.4
	Starch (%)	53.4	37.9	62.9
	Fe mg (kg^{-1})	24.1	19.0	31.0
	Zn mg (kg^{-1})	9.9	7.6	14.0
P. erosus (N= 5)	Yield t (ha^{-1})	31.8	24.4	39.6
	Dry matter (%)	13.7	11.4	16.1
	Protein (%)	8.3	6.6	10.4
	Starch (%)	35.3	20.7	50.5
	Fe mg (kg^{-1})	21.8	19.0	23.5
	Zn mg (kg^{-1})	11.2	10.0	13.5
P. tuberosus (N= 8)	Yield (t ha^{-1})	25.4	4.9	49.2
	Dry matter (%)	26.5	13.2	38.0
	Protein (%)	6.4	4.7	8.9
	Starch (%)	59.4	24.4	78.0
	Fe mg (kg^{-1})	37.0	21.5	52.0
	Zn mg (kg^{-1})	7.4	5.7	11.4
P. tuberosus x *P. ahipa hybrids* (N = 8)	Yield (t ha^{-1})	15.0	7.0	21.5
	Dry matter (%)	30.7	27.0	37.2
	Protein (%)	7.2	4.7	11.4
	Starch (%)	68.7	51.1	78.8
	Fe mg (kg^{-1})	33.6	24.0	49.5
	Zn mg (kg^{-1})	8.9	6.1	11.7

are clearly two yam bean species with low dry matter storage root contents. However, starch contents on dry matter basis of up to 60% can be found in these two species. *P. tuberous* and *P. tuberosus* chuin x *P. ahipa* hybrids exhibit high storage root dry matter (up to 38%), and high starch contents on storage root dry matter basis (up to 78%). Average storage root protein contents among *Pachyrhizus* species (6.4–8.3%) are three times as high as the average found in cassava germplasm, and dry matter and starch contents of *P. tuberosus* and hybrids are within the same range as cassava (Ceballos *et al.*, 2010). The iron contents are twice as high as in cowpea (*Vigna unguiculata*) (Singh *et al.*, 2002) and correspond to iron levels of *Phaseolus vulgaris* genotypes, with intermedium iron content in seeds (Tryphone & Nchimbi-Msolla, 2002). The extreme wide range of dry matter and starch in *P. tuberosus* can be explained by the fact that low dry matter *P. tuberosus* accessions were evaluated together with high dry matter *P. tuberosus* accessions.

Product development efforts resulted in a number of products processed from yam bean roots: fresh storage roots as raw or cooked vegetable, starch, flour, chips and *gari*. *Gari* prepared from yam bean using a traditional cassava procedure had a much browner colour as compared to cassava *gari*. However, protein, calcium and zinc levels in yam bean *gari* were two to three times higher than that of cassava *gari* (Wassens, 2011). Protein on dry matter basis ranged between 3.7% (EC-533) and 4.7% (EC-KEW). On average, 6.3 mg Fe and 1.2 mg Zn were observed in 100 g of *gari* made from EC-KEW while 8.8 mg Fe and 2.1 mg Zn were found in *gari* prepared from EC-533 (Table 3). However, Wassens (2011) noted that output/input ratios of yam bean *gari* developed from *P. erosus* are 50–75% lower than those of cassava.

Food processing studies within the yam bean research effort have shown that the output/input ratios of food products are much higher for *P. tuberosus* chuin accessions compared to *P. erosus* or *P. ahipa* accessions. However, fresh storage root yields of *P. erosus* are impressive in the savannas of West Africa (Zanklan *et al.*, 2007). These results were confirmed for Benin and Central Africa in the savannas of Uganda (data not shown).

Table 3. Yield and quality parameters of traditionally processed *gari*.

Quality parameters	EC-Kew *gari*	EC-533 *gari*
Fresh matter yield (t ha^{-1})	88.4	89.9
Gari yield (t ha^{-1})	4.2	2.4
Fe mg /100 g *gari*	6.3	8.8
Zn mg /100 g *gari*	1.2	2.1
Protein (% DM)	4.7	3.7

Source: Wassens, 2011.

Present preliminary project results demonstrate the potential of American yam bean to adapt to a wide range of environmental conditions, produce high yields and be processed successfully into local food products. Particularly yam bean gari is a food product that could provide clearly more protein, iron, and zinc to the food supply than cassava *gari*.

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