ADVANCES IN SWEETPOTATO BREEDING FROM 1992 to 2012

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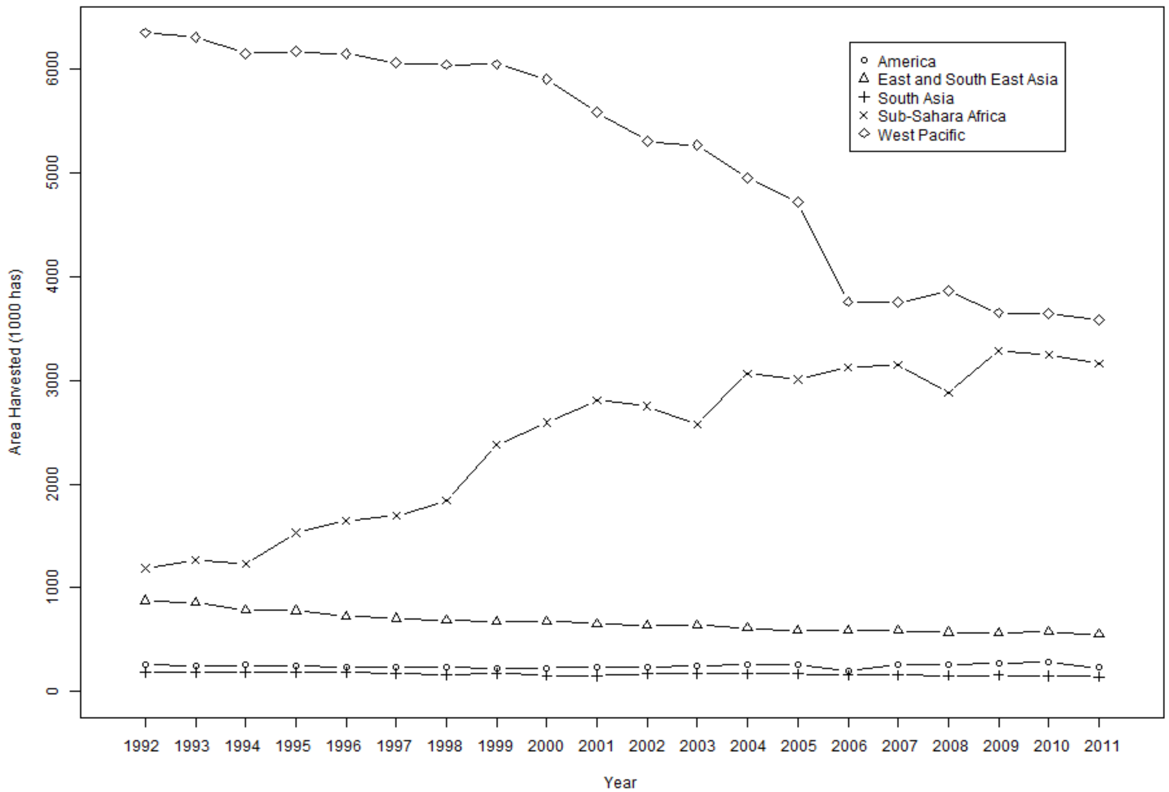
Importance & Distribution I – what is going on planting / harvested area?



The West Pacific (China, Korea, Japan) is using less and less sweetpotato as pig-feed

Sub-Saharan Africa (SSA) have had a huge increase in planting area during the past 20 year (to which extent this trend will continue?)

Declining trend in South East Asia (will Asia produce enough food on basis of rice, wheat and maize?)

Figure: Annual sweetpotato planting area by regions (FAO 2011)

America considering Argentina, Brazil, Cuba, Haiti, Peru and United States of America;

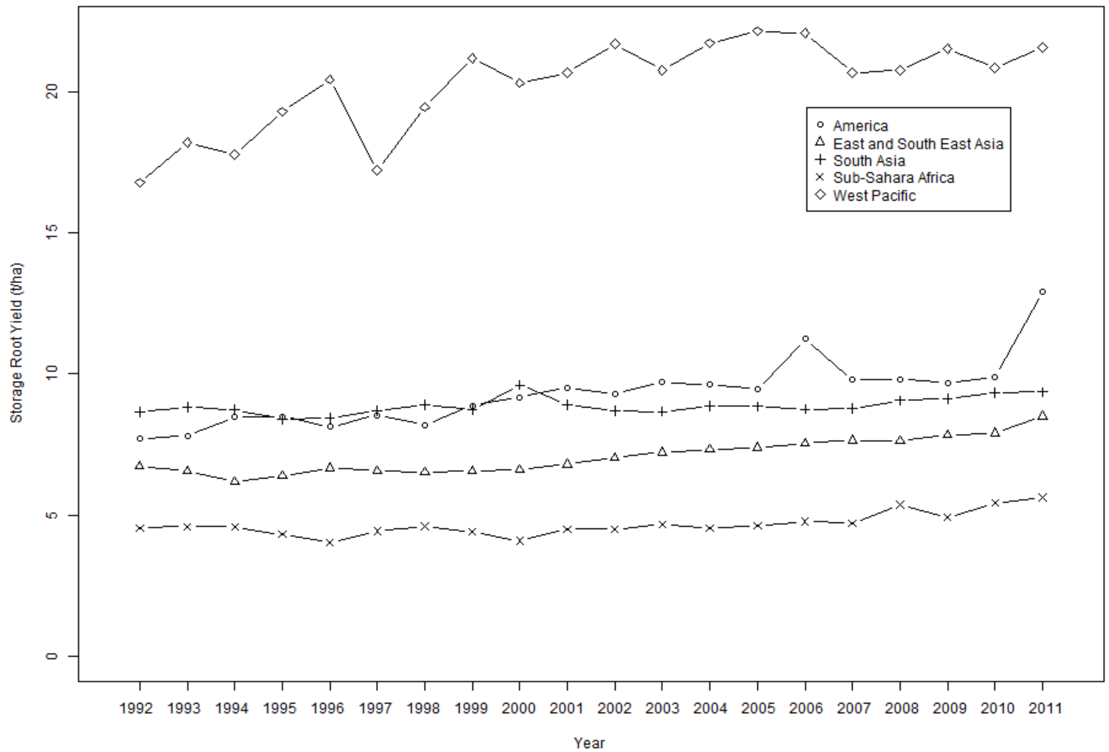
Sub-Saharan Africa considering East-Africa with Burundi, Ethiopia, Kenya, Rwanda, Uganda and United Republic of Tanzania, Southern Africa with Angola, Madagascar, Malawi, Mozambique, and Zambia, and West-Africa with Nigeria, Ghana and Mali;

South Asia considering Bangladesh and India;

East and South East Asia considering Indonesia, Papua New Guinea, Philippines and Viet Nam;

West Pacific considering China, Korea and Japan .

Importance & Distribution II - what is going on regarding yields t / ha?



Sub-Saharan Africa (SSA) still has the lowest yields compared to other world regions, but this varies extremely among countries in SSA

However, SSA had across the past 20 years <u>1% yield increase per year across all SSA countries, although a lot of marginal soils came into use.</u>

Figure: Annual sweetpotato storage root yields by regions (FAOSTAT 2011)

America considering Argentina, Brazil, Cuba, Haiti, Peru and United States of America

Sub-Saharan Africa considering East-Africa with Burundi, Ethiopia, Kenya, Rwanda, Uganda and United Republic of Tanzania, Southern Africa with Angola, Madagascar, Malawi, Mozambique, and Zambia, and West-Africa with Nigeria, Ghana and Mali;

South Asia considering Bangladesh and India;

East and South East Asia considering Indonesia, Papua New Guinea, Philippines and Viet Nam;

West Pacific considering China, Korea and Japan.

Importance & Distribution III – yield increase trend examples / can 2-3% be reached per year? Yes – but depends if you invest into real breeding

Production

Cultivated in now 117 countries of the world

30 countries contribute to >95% of world wide production

Yields & Yield Progress

4.5 %, 3.5 %, and 0.9% per year in Kenya, Mozambique and Uganda

Highest yields & potential yields

Senegal 33.3 t/ha in 2010

Israel 80 t/ha

Management ***– comprising weeding, clean planting material, & good varieties*** => 15 t/ha with currently available varieties

Country	2002	2009	2011
Argentina	14.6	13.8	15.1
China	21.7	21.6	21.7
Ghana	1.4	1.6	1.8
India	8.6	9.0	9.3
Indonesia	10.0	11.2	12.3
Japan	25.4	25.3	22.8
Kenya	**8.5**	**12.0**	**12.3**
Mali	15.8	19.1	18.8
Mozambique	**5.7**	**7.1**	**7.7**
Nigeria	3.0	2.9	2.9
Peru	16.1	16.4	18.1
Philippines	4.5	4.9	5.0
USA	17.4	22.5	23.3
Uganda	**4.4**	**4.5**	**4.8**
Zambia	17.0	15.4	18.4

Uses & Markets – rediscovery of the OFSP

Human consumption

Boiled & roasted

Flagship of the biofortification program

- 1st crop bio-fortified for pro-vitamin A

Animal feed

West Pacific (mainly China) & South East Asia (Vietnam, Papua)

Processed - Food & Starch Industry

West Pacific (China, Korea, Japan)

Americas (mainly USA) upcoming trend in South America (e.g. French fries)

In most OFSP varieties a piece (40 g - after boiling) contributes >50% to the recommended daily allowance (RDA) of pro-vitamin A

A piece eaten with rice and there would be no vitamin A deficiency (VAD) in Asia

New Uses & Markets => more needs from breeding

Mashed OFSP – for puree (+milk) or for bread

Bread made with a ratio of 66% wheat flour and 34% mashed OFSP in Mozambique 2009 => fortified bread

Selection for long stems & leaves (China 2008) – appears like young bean pods

OFSP processed to porridge (Serere – Uganda 2008

Sweetpootato upper biomass as animal feed (Canete – Peru 2007 the fodder crops at the Peruvian coast)

Wild Species and Centers of Genetic Diversity

Origin: Interspecific cross between a 2x and a 4x *Ipomoea* species in the section *Batatas* – new most likely domesticated independently in Central and South America – we can assume the 2nd parent will be known soon

Centers of Diversity: Central and South America (primary), the Pacific incl Papua New Guinea & Irian Jaya – new East Africa (secondary)

How can SP develop more rapidly genetic diversity than other crops? Answers by better knowledge from population genetics

Species (Accessions in CIP genebank)	**Polyploidy**
I. batatas (4,616)	4x, 6x
I. cordatotriloba (100)	2x
I. cynanchifolia (3)	2x
I. grandifolia (123)	2x
I. lacunosa (5)	2x
I. x leucantha (13)	2x
I. ramosissima (32)	2x
I. tabascana (1)	4x
I. tenuissima	2x
I. tiliacea (54)	4x
I. trifida (183)	**2x, 4x**
I. triloba (60)	2x
I. umbraticola (6)	2x

Origin = New World except I. littoralis (Australia)

Polyploidy & Population Genetics – fundamental publication by Gallais 2003

Sweetpotato hexaploid (6x) highly heterozygous hybrid

Seed set easily occurs

In-compatibility alleles – favor outcrossings

(6x) heterozygous F1 x (6x) heterozygous F1

⇒ Tremendous segregation in populations

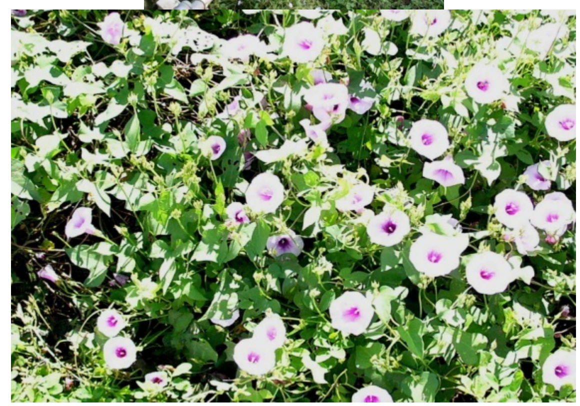
⇒ Tremendous difficulties to fix recessive inherited traits

⇒ The "genetic load" results in never ending "surprises"

Indication of trend in breeding populations towards more flowering, seed set, and self-compatibility

Population Genetics poorly represented – until recently Gallais published his text book 2003

We can say sweetpotato is a monster – how to handle it?



Escaped sweetpotato at San Ramon - natural selection favours abundant flowering

Polyploidy and Population Genetics

More genotypes compared to dipoids (simple case one locus and bi-allelism 6x = 7 genotypes; 2x = 3 genotypes)

Larger genetic load (unfavorable alleles) in 6x than in 2x

Genetic bottleneck have lower effects in 6x than in 2x; higher selection intensities can be used in 6x than 2x

Developing homozgous genotypes by selfing is an illusion

Heterozgous genotypes occur at much larger frequencies in 6x than in 2x (see **Fig. a**) => heterosis much more important (study heterosis in autopolyploides is very cumbersome) – for yield and yield stability we want highly heterozygous genotypes

Recessive inherited traits are quite difficult to fix (see **Fig. b**) – resistances or quality traits

=> The challenge for a breeder: achieve high level of heterozygousity for yield and biomass and inbreeding for resistances and quality

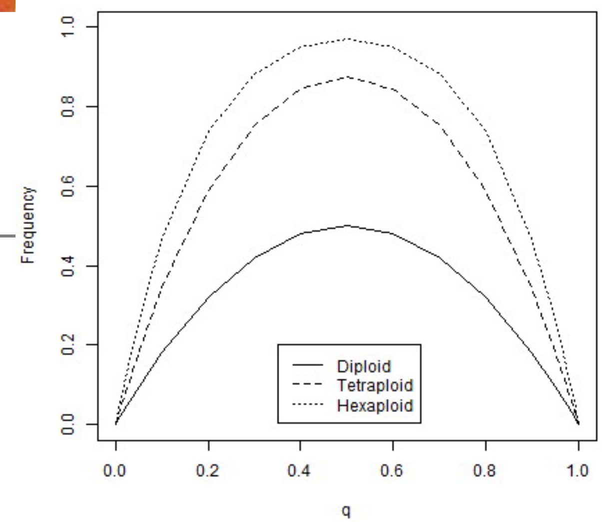


Fig a. Effect of ploidy level on the frequency of heterozygous genotypes

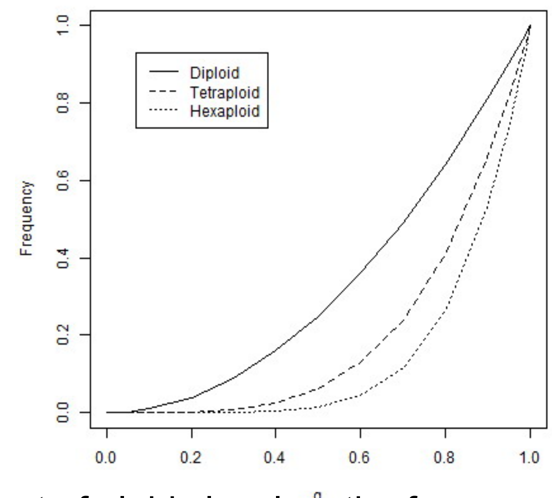


Fig b. Effect of ploidy level on the frequency of phenotypes expressing a one locus recessive inherited trait as a function of the allele frequency of the recessive allele.

Breeding Objectives I- generate by population new populations for major needs of users

Storage root yield as a breeding objective has highest priority (Uganda 2006)

<u>Overview on traits</u>

Yield, Stability & Adaptation

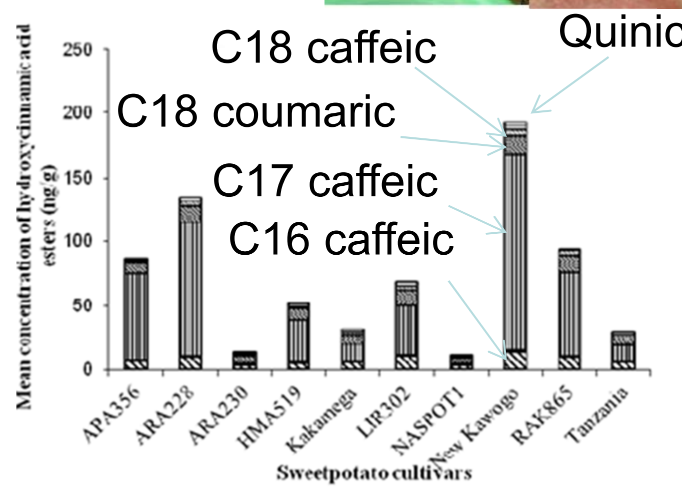
Taste & Nutrient density (beta-carotene, dry matter, Fe, Zn)

Farmers select varieties on basis of many more trait than only yield – those who do not realize this will learn it the hard way

Breeding Objectives II- generate by population improvement new populations for major needs of users

<u>**Overview on traits**</u>

Biotic & Abiotic Stress / Pest & Diseases:



Resistance to SP virus disease (SPVD) across regions - SP clorotic stunt virus (SPCSV) is the important component (generally SP is very resistant to virus but SPCSV breaks it down)

Resistance to weevil damage - all drought prone regions (Central and South America, SSA and SWCA) - storage roots deep in the soil and clearly tapering at top (Malawi & Mozambique) - latex in storage root skin / varieties like New Kawogo (Stevenson et al. 2009) from Uganda, Santo Amaro from Brazil, PZ06.120 from Peru are clearly less affected

Drought tolerance – sweetpotato is quite tolerant to drought but vine survival and adequate response to rains in genotypes adapted to drought prone areas are important

Variance Components – are much more used to determine breeding targets & strategies compared to the past

Table. Estimated means, minimum and maximum genotypic values, and variance components for yield and storage root quality traits (evaluation of 1174 clones across five 5 environments (different ecogeoraphic zones / Peru 2006- 2007).

Trait	mean	min	Max	Vg	Ve	Vgxe	Verror
RYLD, t ha^{-1}	19.0	0.0	55.5	**19.8**	27.2	**115.9**	48.3
FYLD, t ha^{-1}	22.6	0.0	67.8	**26.2**	110.6	**161.6**	79.3
DM, % FM†	**34.9**	**18.3**	**47.2**	**14.8**	4.2	**5.7**	3.0
Protein, % DM‡	4.3	2.7	8.9	0.3	6.2	0.7	0.5
Starch, % DM‡	66.0	**36.5**	**76.0**	**28.9**	6.0	**7.2**	3.8
Sucrose, % DM‡	10.3	**2.0**	**33.1**	**12.2**	0.7	**5.5**	3.0
Fructose, % DM‡	1.7	0.0	11.1	1.6	0.0	0.6	0.3
Glucose, % DM‡	2.2	0.0	16.0	3.0	0.1	1.0	0.5
β-carotene, ppm DM‡	143.7	**1.8**	**1220**	**14751**	2262	**4640**	1817
Iron, ppm DM‡	15.6	10.5	**28.6**	**2.7**	15.1	**3.2**	2.5
Zinc, ppm DM‡	9.3	6.2	**17.1**	**0.9**	9.4	**1.5**	1.1

† FM = fresh matter; ‡ DM = dry matter

Consistent results / similar reports: means and ranges (Woolfe ,1992); germplasm evaluation with East Africa clones (Tumwegamire et al. 2011) ; in North American breeding material for storage root iron and zinc contents (Courtney et al. 2008).

Variance Components – what can be said today to breeders?

Yield (storage root & upper biomass) has a large genetic variation and large G by E especially in diverse genetic material and across agro-geographic zones => go to improve this trait but breed with decentralized breeding – breeding platforms

Dry matter, Starch, Sugars, and b-carotene have large genetic variation and low G by E in diverse genetic material and across agro-geographic zones => Improve these traits as you need – use color charts for b-carotene; clearly visible trait in sweetpotato (this does not hold true for other crops) – evaluated about 2000 genotypes in early breeding stages otherwise you will not reach required selection intensities

Very high b-carotene maximum values indicate pro-vitamin A biofortification is possible wherever you want - even where sweetpotato intakes are low

Iron and zinc have medium high genotypic genetic values, low genetic variation and medium G by E => improvement these traits is debatable – requires perhaps separate genepools – are target of 40 ppm zinc and 60 ppm iron correct (bio-availability)? – stop to improve these traits where you do not reach evaluation of about 2000 genotypes in early breeding stages

Variance Components Yields – we have some information but need more studies independent in each country and across mega-environments

Information about variance components for yield traits in sweetpotato is still limited.

Table. Variance component ratios for storage root yield

Vg	Vgxe	Verror	Country	Method	Referance
1	: 1.27	: 1.93	Cameron	Anova	Ngeve and Boukamp (1993)
1	: 0.69	: 0.55	Peru	Anova	Manrique and Herman (2002)
1	: 0.78	: 0.21	Peru	Anova	Grüneberg et al. (2005)
1	: 6.12	: 10.62	Uganda	Anova	Tumwegamire et al. (unpublished)
1	: 5.85	: 2.44	Peru	REML	see var. comp. quality in this presentation

Vg	Vgxl	Vgxs	Vgxlxs	Verror	Country	Method	Referance
1	: 0.32	: 0.06	: 0.50	: 1.33	Cameron	Anova	Ngeve (1993)
1	: -0.38	: -0.21	: 1.97	: 3.34	Cameron	Anova	Ngeve (1993)
1	: 1.46	: 0.96	: 1.83	: 2.62	Uganda/Kenya	REML	Grüneberg et al. (2004)
1	: 2.21	: -0.87	: 4.39	: 10.05	Uganda	Anova	Tumwegamire et al. (unpublished)

Important is to note that storage root Vgxs is always or most often the smallest Vgxe this means that a breeder can replace temporal variation of test environments with variation of test environments **in other words this means a breeder can test in less years and compensate the loss of precision by using more locations**

Crossover interactions & Marginal Environments

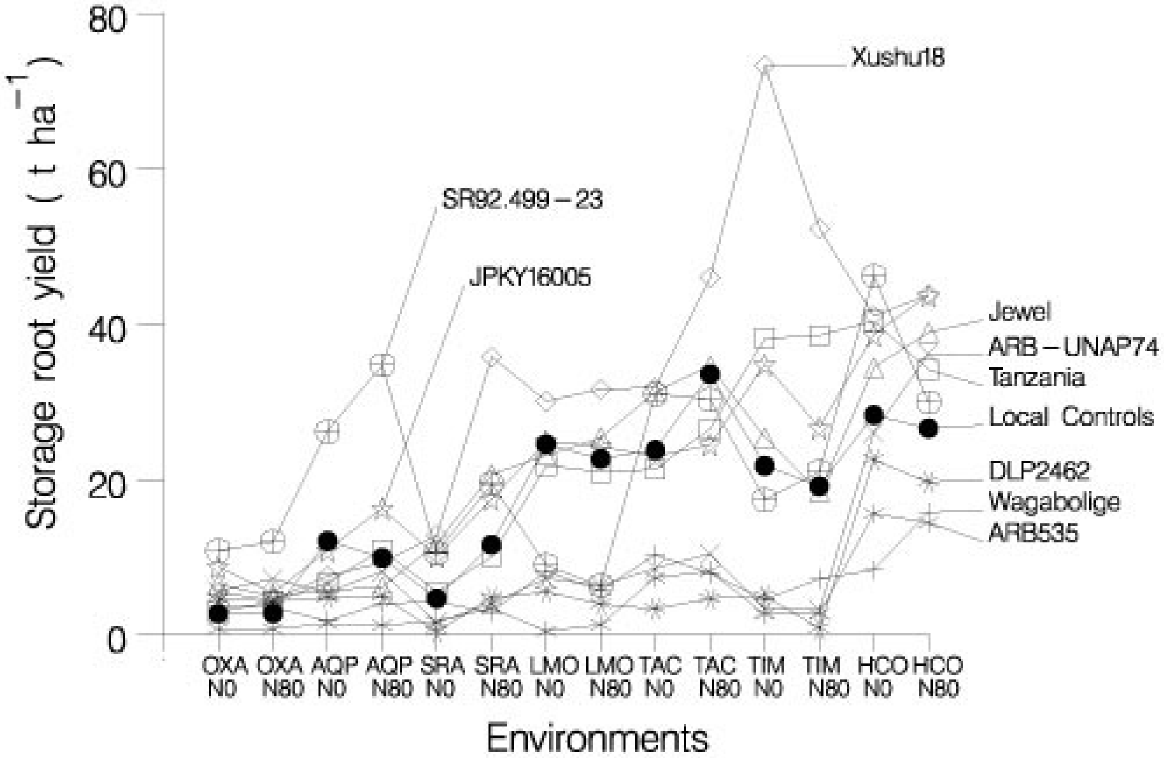


Fig. Storage root yield of local control (check) clones and another nine clones used for analysis of GE interactions across 14 environments (Grüneberg et al. 2005); OXA = Oxapampa, SRA = San Ramon, AQP = Arequipa, LMO = La Molina, TIM = Tingo Maria, TAC =Tacna, HCO =Huanuco; nitrogen fertilization: N0 = 0 kg ha^{-1} and N80 = 80 kg ha^{-1} .

It appears that specifically adapted clones likely to out-yield widely adapted clones in marginal environments (e.g. high altitude, environments with high SPVD or weevil pressure, drought and salt stress) – also named strong crossover interactions

– please note yield advantage in the figure above for SR92.499-23 is about 20 to 50% in the marginal environment

Breeding Methods - Recombination

True seed from field trails and farmer fields are still attractive were NARS do not have breeding nurseries (i.e. Malawi gained 4 varieties with this method)

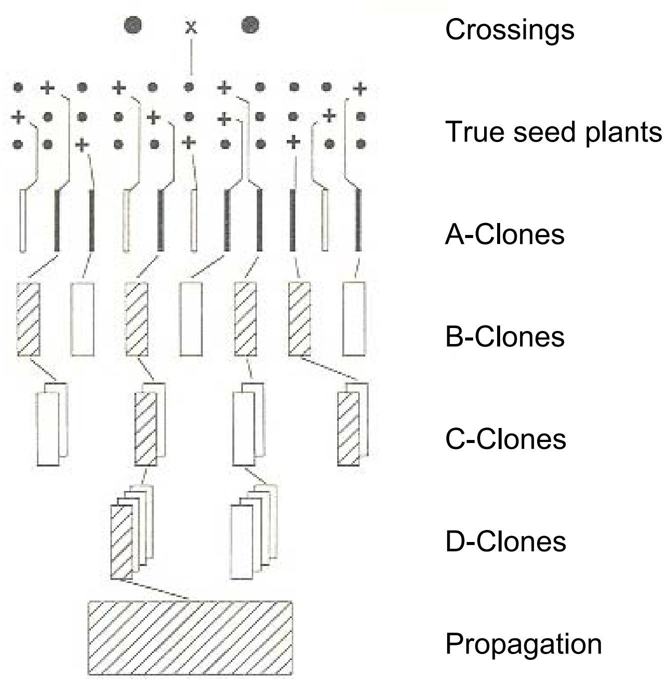
Polycross seed nurseries – most common recombination method in sweetpotato – produces huge amounts of seeds (40 to 100 thousand)

Controlled crosses – should be for theoretical reasons superior to polycrosses (currently under investigation); require skilled technicians – there are technicians which can produce large amounts of controlled cross seeds)

Controlled crosses are required for heterosis exploitation (what is this we will see later)

Figures: You need true seed to become a breeder - Rubona 2008 (A), Namulonge 2011 (B), Xuzhou 2008 (C), Lima 2008 (D)

Breeding Methods – traditional breeding methods are too slow to achieve "good" progress, to make breeder happy & attract young scientists, **and donors**



This figure "The general breeding scheme of clonally propagated crops" is from Becker (1992)

Similar scheme can found in many other textbooks – unfortunately !!!

Two approaches to make things faster

1. Accelerated breeding (ABS) by less years and more locations on basis of variance component estimations incl. early breeding stages
2. Genomic selection – heavy use of SNP markers and prediction models

Note approach 1 (ABS) resulted already in many accelerated variety releases for sweetpotato in SSA within the period 2009 to 2012 (see our last slide) – of course approach 2 promised to be better

Accelerated Breeding (ABS)

Planting the ABS at San Ramon in 2005 (one of 3 locations) – with 1 year in controlled crossings / with 2 years in polycrosses you select the material for later breeding stages

Plot size: 1 m row plot in early breeding stages not more not less and no plot replications !!!

Heterosis

Offspring is superior to the mid-parent performance (see figure)

F1 > (P1 + P2) /2 - where F1 is the family mean and P1 and P2 is the parental performance

What is the offspring in a clonally propagated crops such as sweetpotato? The family derived from a cross – note in a heterotic cross combinations / families you still can select for “the best” clone

In a experiment with so-called mega-clones (important clones across regions) **- we found positive heterosis in 14 out of 28 families with a heterotic yield advantage** – we think such a result with experimental material is was not sufficient to go and change breeding programs, but sufficient to convince a donor to invest in a study in applied breeding material

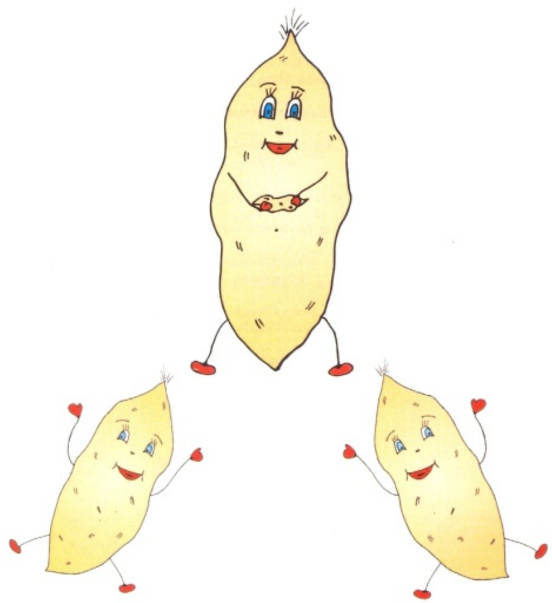
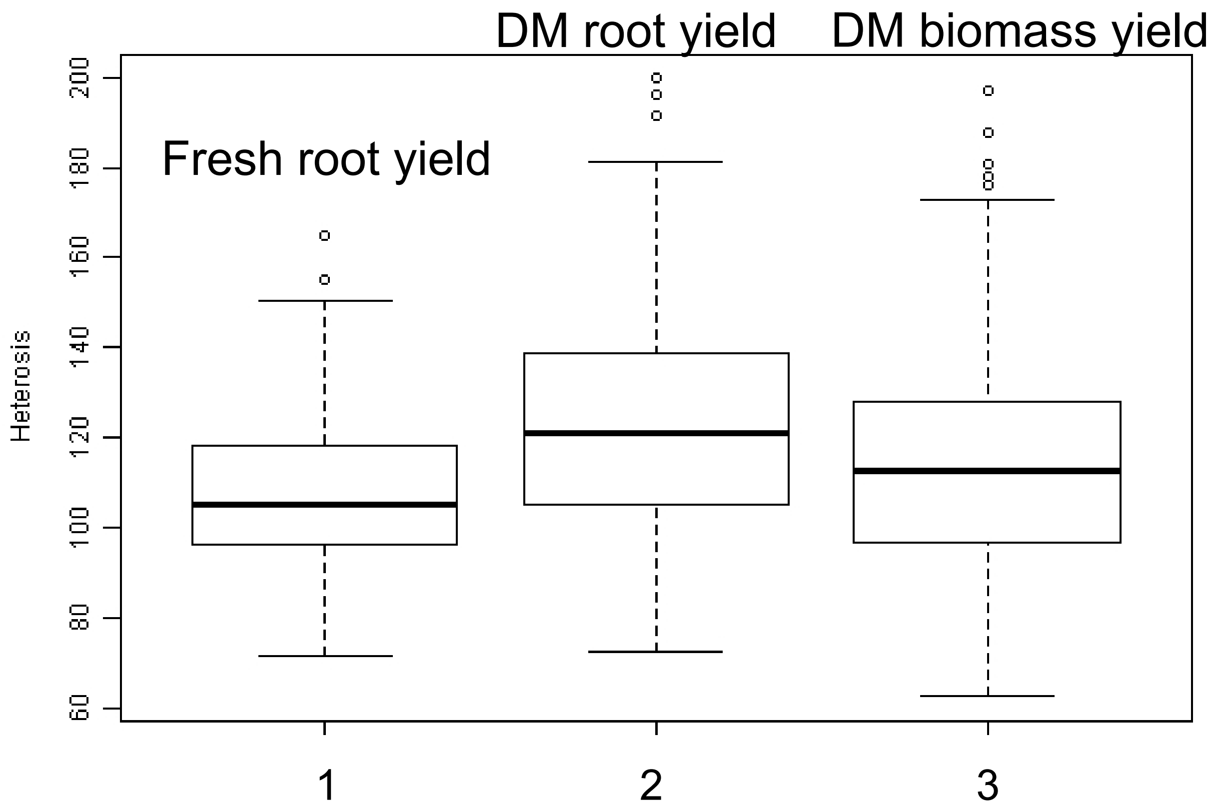


Illustration of Heterosis

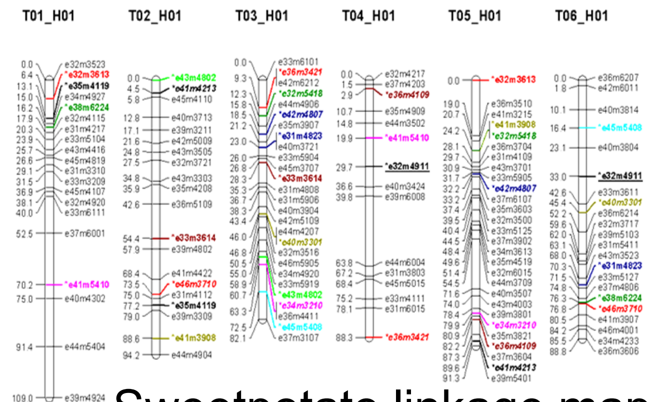
Heterosis observations in sweetpotato – HQ experiment in SASHA I funded by BMGF

Heterosis is exploitable / stabilized by establishing two genetic divergent genepools (Gallais 2003)



Mid parent – mid offspring heterosis. In total 6,898 offspring clones tracing back to 31 PZ and 49 PJ parents recombined in 231 cross combinations / families tested at two locations and two plot replications. Heterosis is by establishing two genepools so far without reciprocal recurrent selection (RRS) => there will be more heterosis with RRS

Breeding Methods – next generation tools (will they improve yields?)



Sweetpotato linkage map

- **Two mapping populations** (NCSU, Uganda/CIP, CIP) – linkage maps
  Tag genes for starch, dry matter, beta-carotene, virus resistance

- To accelerate sweetpotato breeding with superior genomic tools (might need **complete SP genome sequence**)

- The SP genome sequence is difficult to assemble from a hexaploid
  Asian Tripartite consortium (Chinese, Korean, Japanese) will continue

- Genome sequence of the **diploid ancestor of SP** but ancestry among the Batatas section would be needed by sequencing homologous loci

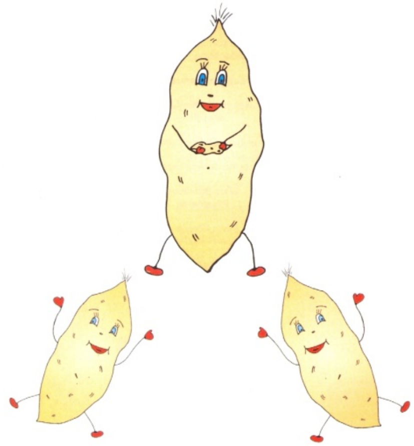
- **Training population** to assess breeding value of progenitors, about 300-500 varieties and advanced breeding lines for phenotypying important traits in different locations (e.g. 3 in Africa, 1 in Asia, and 1 in USA).

- Developing a **SNP (single nucleotide polymorphism) platform** and GbS (genotyping by sequencing).

Varieties released 1992 to 2012 – restricted to SSA more information across regions in the paper for this presentation

Country	No. of varieties released		
	1999 to 2008	2009 to 2012*	**Total**
Ethiopia	10	0	**10**
Ghana	0	4	**4**
Kenya	5	4	**9**
Malawi	6	10	**16**
Mozambique	12	20	**32**
Nigeria	3	5	**8**
Rwanda	8	11	**19**
S. Africa	12	18	**30**
Tanzania	6	7	**13**
Uganda	19	1	**20**
Zambia	7	0	**7**
Total	**88**	**80**	**168**

*2012 Application for variety release done



Thank-you for your Attention