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Release and Adoption of Improved Sweetpotato Varieties in Southeast and South Asia

M. Gatto, G. Hareau, W. Pradel, V. Suárez, J. Qin
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Comments are invited.

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List of Abbreviations

BARI	Bangladesh Agricultural Research Institute
CCCs	Crop-country-combinations
CIAT	Centro Internacional de Agricultural Tropical
CIP	International Potato Center
CPRI	Central Potato Research Institute
DIIVA	Diffusion and Impact of Improved Varieties in Africa
EE	Expert elicitation
GR	Green revolution
IARCs	International Agricultural Research Centers
IV	Improved variety
MSU	Michigan State University
NARC	Nepal Agricultural Research Council
NARS	National Research Programs
NGO	Non-governmental organization
RTB	Research Program on Roots, Tubers, and Bananas
SIAC	Strengthening Impact Assessment in the CGIAR
SPIA	Standing Panel of Impact Assessment
TRIVSA	Tracking Improved Varieties in South Asia

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INTRODUCTION

A key objective of international agricultural research is to improve the livelihoods of resource-poor farmers. Through crop genetic improvement research, international agricultural research centers (IARCs) and national research programs (NARS) jointly contributed to the development of improved varieties (IVs) for various crops.

During the early-Green Revolution (GR) of the 50s/60s the foundation was laid, with the focus on breeding high-yielding crop varieties. Only later, from mid-90s, breeding objectives have become more divers to provide farmers with crop technologies which enhance their resilience to climate change and (related) issues of pest and diseases. Since the start of the GR an increasing number of studies have revealed that crop-genetic improvements have considerably contributed to improving livelihoods in many developing countries, much of which related to research conducted by CGIAR (Evenson and Gollin, 2003a, 2003b; Renkow and Byerlee, 2010).

At the same time, there are large gaps in existing national statistics on release and adoption data of IVs for all major crops, including sweetpotato. This reality for many developing countries not only hampers a continuous and effective analysis of livelihood impacts, it also prevents scaling-up research findings, and thus obscures the magnitude of the effect of agricultural research. Also, policy-makers are likely to make uninformed decisions on targeting areas and agricultural interventions, resulting in ineffective and inefficient spending of public funds.

To fill the gaps in existing databases, a couple of large-scale projects have been launched. In 2000, a global project documented release and adoption data. The main objective was to analyze IARCs contribution to high-yielding varieties and, related, to productivity increases (Evenson and Gollin, 2003a, 2003b). Ten years later, in 2010, another study was conducted which mainly focused on Sub-Saharan Africa. In comparison, a major improvement was the analysis at the varietal level which allowed for detailed analysis of varietal change (Walker and Alwang, 2015).

Against this backdrop, it becomes clear that in the case of sweetpotato the last release and documentation efforts in Southeast and South Asia date back 15 years. In addition, the studies' objectives were mainly to assess productivity increases. Today's challenges of climate change and micronutrient deficiencies, however, require technologies and knowledge thereof for various other varietal traits. A release dataset, at the varietal level, including information on resistances against biotic and abiotic stresses, does not yet exist.

In this study we close the identified gaps in the existing literature and databases by documenting release and adoption of improved sweetpotato varieties in eight major sweetpotato producing countries in Southeast, South, and East Asia.

Methodologically, this study adopts a refined expert elicitation (EE) approach applied in previous projects. EE workshops were used as an inexpensive alternative to the collection of national representative adoption data. An average of 12.67 experts working in the sweetpotato value chain participated in a one-day event to elicit *perceived* adoption rates and to update release databases. In total, 228 experts attended in 18 workshops held during 2014-2016.

In this paper we summarize the main results of the study with a special emphasis on the contribution of the International Potato Center (CIP) to NARS breeding efforts and resulting releases and adoption.

The paper is structured as follows. In the next section we provide background information on the preceding projects which aimed to document release and adoption of IVs and we will render the context of this study. In section 3 we will describe materials and methods used. Section 4 provides the results and section 5 concludes.

BACKGROUND

The first study at a global scale was conducted by the Standing Panel of Impact Assessment (SPIA) in 2000. Involving many CGIAR centers, the study documents the release and adoption of more than 8000 IVs in 11 crops in over 100 countries (Evenson and Gollin, 2003b). In DIIVA (CGIAR's Diffusion and Impact of Improved Varieties in Africa, 2009-2013) the project documented release and adoption for 20 crops in 30 countries in Africa. In contrast to the earlier study, DIIVA focused on the varietal level with data collection from 2010 to 2012. Also, it applied a standardized methodology to collect the data. At the same time, Tracking Improved Varieties in South Asia (TRIVSA, 2010-2013) was conducted. In comparison, TRIVSA's scope was smaller concentrating efforts on 6 crops and 4 countries (Walker and Alwang, 2015).

The study at hand is part of the project 'Strengthening Impact Assessment in the CGIAR' (SIAC). In more detail, it is part of the activities 2.1 and has the following objective: 'Institutionalize the collection of diffusion data needed to conduct critical CGIAR impact evaluations'. An important component of this is the application of a standardized methodology to document release and adoption data. Overall, SIAC is under the auspices of SPIA and Michigan State University (MSU) and a joint effort revolving around 12 important smallholder crops (e.g. rice, cassava, potato, lentils) in 15 Southeast, East, and South Asian countries.

MATERIALS AND METHODS

Sampling and methodology

For this study we selected eight countries in Southeast Asia which are considered major sweetpotato producing areas. Since CIP's impact is an important aspect of the study, discussions with CIP colleagues influenced the final selection of countries, which are: Bangladesh, China, India, Indonesia, Nepal, Papua New Guinea, Philippines, and Vietnam. Due to the relatively large sizes of China and India, we sampled 9 Provinces in China and 3 States in India. Combined we sampled a total of 18 crop-country-combinations (CCCs).

We collected two databases for each CCC, one on release and one on adoption. The release database is comprised of data, such as year of release, release institution, genetic pedigree, level of biotic and abiotic resistances, and nutritional values. We usually collaborated with a partner institute in a country to collect these data prior to the workshop. The adoption database which includes detailed estimations for each released variety was established during a one-day workshop. During this workshop the release database was also validated. Following a standardized methodology, in collaboration with our local partners we first established a list of experts and potential participants. Experts were retired or still working in the sweetpotato value chain as breeders, extension agents, crop management specialists, seed traders. In doing so, we aimed at inviting experts from the private sector and from NGOs. Special attention was also placed on inviting female experts to create a great diversity of participants.

During 2014-2016, in total, 228 experts participated in 18 EE workshops which is an average of 12.67 experts per workshop.

Generally, CIP staff facilitated the workshops or exceptionally also well-trained partners. This was the case in 2 States in India (i.e. Uttar Pradesh and West Bengal).

At the beginning of the EE workshops, discussions on total area, major production areas, seasons, and agro-ecological zones, established the basis for adoption estimates. In a next step, we validated parts of the release database by checking the list of varieties against the expert opinion. To do so, we invited experts to individually write down on sticky notes according to their knowledge the names of varieties currently cultivated. We then presented the results on a wall and discussed these in the entire group.

After that, the entire group was split into smaller groups based on prior discussion on major production areas which resulted in disaggregated areas by sub-region or agro-ecology. We generally split the group on a random basis unless experts were knowledgeable only in specific areas. Then we purposively divided the group. Usually, not more than 2 groups were created. In case the amount of identified sub-regions and created groups was not equal, groups worked on more than one sub-regions, depending on the group knowledge. The next step involved individual expert adoption estimations in which we invited experts to give estimations for the allocated sub-region(s) or agro-ecological zone(s) by season. For this purpose, we handed out a standardized form – we call instrument (see Appendix). We ensured, to the extent possible, that communication among participants was kept at a minimum during this individual exercise. These individual opinions formed the basis for the group discussions and estimations. These were generally established through two different approaches. First, the appointed group leader listed individual estimates and calculated averages. The second approach entailed discussion on individual estimates, usually starting from the most important variety. Here, it was important to ensure the participation of all group members. A final overall validation in the entire group took place by projecting the results by region/agro-ecology and season.

At the end of the workshop, we had general discussions on opportunities and challenges for the respective CCC which greatly helped to better explain results.

Table 1. Summary statistics of EE workshops

Country	No. of CCCs	No. of participants
Bangladesh	1	15
China	9	
Anhui	1	8
Chongqing	1	8
Guangxi	1	11
Guizhou	1	5
Henan	1	11
Hubei	1	11
Hunan	1	11
Shandong	1	8
Sichuan	1	10
India	3	
Uttar Pradesh	1	27
West Bengal	1	16
Odisha	1	16
Indonesia	1	18
Nepal	1	18
Papua New Guinea	1	16
Philippines	1	10
Vietnam	1	9
Total	**18**	**228**
Average		**12.67**

Release classification

Release classifications are required to identify the origin of varieties and to specify the relationship with CIP material. This is in particular important to assess CIP's contribution to breeding and developing varieties in NARS. We adapt release classifications from Thiele et al. (2008):

1. Developing country NARS (NARS-developing):
    - NARS-bred varieties with no CIP role
    - NARS-selected varieties from crosses unrelated to CIP
    - NARS-released native variety
    - NARS borrowing non CIP-related varieties from other developing countries NARS
2. Developed country NARS (NARS-developed):
    - Varieties introduced from developed country NARS and private sector
3. NARS-CIP
    - NARS-bred varieties distributed/facilitated by CIP
    - NARS selection from CIP crosses
    - NARS crosses from CIP progenitors
4. Other:
    - Native varieties (i.e. landraces)

Thiele et al. (2008) further write: "The [third] category includes the three principal ways in which attribution to CIP can be documented. In the first, CIP has played a role in maintaining and making available selected advanced clones and varieties developed by NARS breeding programs in developing countries. CIP makes these materials available to other users as pathogen-free clones for testing and varietal release (…). In the second situation, CIP has used native and improved gene bank materials to make crosses and supplied them to NARS who have made selections leading to variety release. In the third situation CIP provided breeding materials for use by NARS with the capacity to make their own crosses for selection and variety release."

RESULTS

Varietal release

Since the start of documenting varietal release, NARS have released a total of 434 IVs in our study region. By 2015, a total of 195 IVs are currently adopted and cultivated (Table 2). China is by far the country with the most releases (236)[1]. In other countries, such as Philippines (32), India (31), Vietnam (19), Bangladesh (13), and Nepal (0), relatively few/no IVs have been released. Nepal does not have a sweetpotato breeding program and Papua New Guinea is also a special case. Here, the total number of releases (78) refer to number of promising farmer landraces which have been selected, cleaned, and re-introduced, rather than a result of breeding efforts. It worth noting that in Papua New Guinea more than 1,500 different landraces are cultivated presenting a great diversity to farmers.

Table 2. . Improved varietal release and adoption by country

Country	Release		Adoption			Adopted no release
	(No)	(%)	(No)	(%)	(% of released)	(No)
Bangladesh	13	3%	9	5%	69%	0
China*	236	55%	106	55%	45%	8
India	31	7%	20	10%	65%	4
Indonesia	25	6%	13	7%	52%	0
Nepal	0	0%	7	4%		7
Papua New Guinea	78**	18%	14	7%	18%	0
Philippines	32	7%	9	5%	28%	0
Vietnam	19	4%	17	9%	89%	0
Total	**434**	**100%**	**195**	**100%**	**45%**	**19**

Notes: *for 9 Provinces only. Category 'Adopted' includes total adopted varieties. Also, varieties which have never been released, **not official releases as a result of breeding efforts but re-introduced selection of cleaned farmer seed.

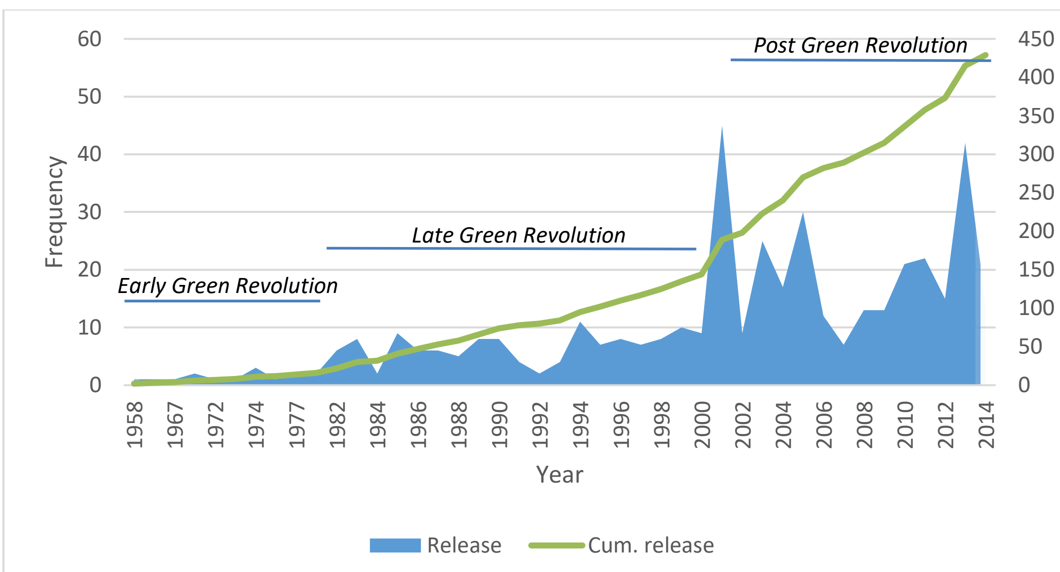
Regarding adoption, in absolute numbers China has adopted most varieties (106). In the other countries adoption rates are all below 20 varieties. In Nepal, all adopted varieties are directly from CIP and/or other sources. However, high release rates are no guarantee for adoption. In China, only 45% of releases have been adopted. Only the Philippines (disregarding Papua New Guinea for a moment) even fewer releases are adopted (28%). In stark contrast are Bangladesh and Vietnam, where 69 and 89% releases have been adopted, respectively. It is also noteworthy that 19 varieties have been adopted without a preceding formal release process. These could be 'imported' varieties

[1] For a release and adoption figures by district, see Table 1A in the Appendix.

or varieties/landraces which were popular and dissemination has been effective without any formal involvement.

Sporadic release and adoption of IVs occurred in the beginning of the 20th century. Only decades later, since mid-1980s release and adoption rates have started to be more systematic, yet small, as Figure 1 depicts[2]. During the 1980s and 1990s annual releases hovered around the 10 varieties point, a period often referred to as the first wave of the Green Revolution. Only later, in the early 2000s releases skyrocketed, a period referred to Post GR (2001-). In 2001 number of released peaked reaching 60 that year. On the one hand, our results confirm earlier findings by Everson and Gollin (2003a) stressing that the Late GR period (1981-2000) contributed significantly more to the GR than the Early GR period (1961-1980). On the other hand, our results point at another distinct phase following the Late GR. In the Post GR period (2001-), releases continue to increase considerably.

Figure 1. Amount of varieties released between 1958-2014



As mentioned, cumulative varietal releases appear to follow an exponential trend. Broken down by GR period, in the Early, Late, and Post GR period a total of 16, 128, and 290 varieties have been released, respectively. The Post GR has seen by far most releases. Compared with the Early and Late GR periods, in the Post GR period total releases have increased by 700 and 127%, respectively (Table 3).

2 The cut-off point is the year 2014. With some CCCs completed in 2014, in 2015 data collection was still ongoing. Thus, we do not have a complete dataset for all CCCs for 2015.

Oftentimes, China is driving the results due to its sheer size. Interestingly, China seems to level the amount of releases. The remaining countries contribute to the observed volatility and peaks (see Table 1A in Appendix).

Table 3. Total cumulative release and changes by Green Revolution period

umulative			Changes	
Early GR	Late GR	Post GR	Early-Late	Late-Post
16	128	290	700%	127%

Note: GR = Green Revolution

Abiotic and biotic stresses

One of the major breeding objectives in the Early GR was to breed for high-yielding varieties to boost farm productivity. Climate change and a rising emergence of pests and diseases has led to a change in breeding objectives to cope with climate related stresses. In our database, we distinguish a total of seven of such stresses (i.e. nematode, weevil, root rot, fusarium wilt, black spot, bacterial wilt, virus). In addition, for every stress we collected the degree of resistance, which can be high, medium, low, or sensitive.[3] In our study region, in total 164 high, 317 medium, and 75 low resistant sweet potato varieties have been released. And about 359 varieties are susceptible to one or more of the seven mentioned stresses. Through the sheer amount of susceptible and relatively high availability of medium resistant varieties it may be argued that farmers are only moderately equipped to adapt to climate change (see Table 4 for more detailed information).

Table 4. Release and adoption of varieties by degree of resistance

Trait	High		Medium		Low		Sensitive	
	Rel.	Adopt.	Rel.	Adopt.	Rel.	Adopt.	Rel.	Adopt.
Nematode	21	8	54	20	44	9	39	14
Weevil	8	3	58	33	14	7	87	40
Root rot	58	25	59	21	2	2	63	21
Fusarium wilt	24	10	10	5			50	14
Black spot	36	17	90	37	1	0	86	27
Bacterial wilt	12	6	22	18			7	2
Virus	5	0	24	23	14	10	27	9
Total	**164**	**69**	**317**	**157**	**75**	**28**	**359**	**127**

Note: Data refers to one trait per variety, multiple traits in same variety are not accounted for.

It is worth mentioning that these breeding efforts have mainly taken place in China and India which have developed strong national breeding programs. This is reflected in the year of first varietal release by trait (see Table 5). High resistant varieties were only released in Philippines (one in 1997) and Vietnam (one in 2011).

[3] These are based on the perceptions, knowledge, and assessments of national experts in the different countries.

Table 5. Year of first release of variety by country and resistance degree

Trait	Bangladesh	China	India	Indonesia
Nematode		1989 (H)		
Weevil	1988 (L)	1974 (H)	N/A (H)	1977 (M)
Root rot		1976 (H)	2008 (H)	
Fusarium wilt		1974 (H)		
Black spot		1958 (H)	1990 (M)	
Bacterial wilt		1973 (H)		
Virus	1985 (L)	2005 (H)	2008 (S)	
Trait	**Nepal**	**Papua New Guinea**	**Philippines**	**Vietnam**
Nematode		2001 (L)		
Weevil	N/A (L)	2001 (S)	1997 (H)	2011 (H)
Root rot	N/A (L)	2001 (S)		
Fusarium wilt		N/A (S)		
Black spot		2001 (S)		
Bacterial wilt				
Virus		2001 (S)		1980 (M)

Notes: Letters in brackets refer to degree of resistance (H=high, M=medium, L=low, S=sensitive). If no high resistant variety released then medium resistance is shown; if this is not applicable then low resistant variety, etc.; N/A not available (i.e. year is unknown).

Release of CIP-related varieties

Until 2015, a total of 45 varieties have been released with a relationship to CIP. This is 10% of the total releases in our study region. Regarding adoption, 27 CIP-related released varieties are currently cultivated which is about 14% of the total adopted varieties (Table 6).

Table 6. Varietal release and adoption until 2015 by country and release classification

Country	NARS-CIP				NARS-developing				NARS-developed			
	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)
Bangladesh	8	18%	4	15%	4	1%	4	3%	0		0	
China*	19	42%	8	30%	213	63%	93	63%	4	57%	4	67%
India	4	9%	0		28	8%	20	14%	0		0	
Indonesia	8	18%	6	22%	14	4%	6	4%	1	14%	0	
Nepal	0		4	15%	2	1%	2	1%	1	14%	1	17%
Papua New Guinea	1	2%	0		34	10%	3	2%	0		0	
Philippines	0		0		30	9%	9	6%	0		0	
Vietnam	5	11%	5	19%	13	4%	11	7%	1	14%	1	17%
Total	**45**	**100%**	**27**	**100%**	**338**	**100%**	**148**	**100%**	**7**	**100%**	**6**	**100%**

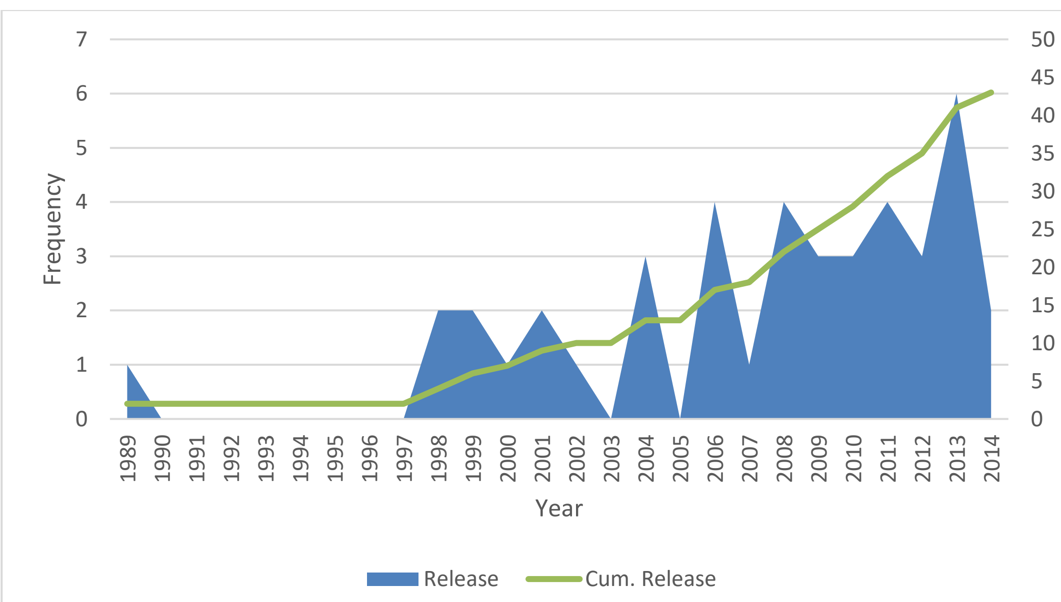
Notes: *for 9 Provinces only; NARS-CIP is a vector of CIP-related variables including NARS selection from CIP crosses, NARS selection from CIP progenitors, NARS-bred variety distributed by CIP.

Following Thiele et al. (2008), we further distinguished NARS-related varieties into 'NARS-developing' and 'NARS-developed'. In doing so, breeding efforts by NARS without any confounding of CIP and/or developed country material – at least in the first generation of parents– can be examined. A total of 338 varieties based on NARS material were released and 148 were adopted. These represent 80% and 77%, respectively, of total releases and adoptions.

Most of the CIP-related varieties have been released in China (19), followed by Bangladesh (8) and Indonesia (8). In the Philippines and Nepal, no CIP-related variety has been released. In the absence of a breeding program, however, Nepal received much CIP material of which 4 are cultivated in 2015. Papua New Guinea only released 1 CIP-related variety. Regarding the latter country, the abundance and diversity of landraces has likely inhibited uptake of structural breeding efforts. Overall, adoption of sweetpotato varieties in our study countries has been weak; in India, Papua New Guinea and the Philippines no CIP-related varieties have been adopted. See Table 1A in the Appendix for CIP-related varieties broken down for China by province.

The first CIP-related variety was released in India in 1971. Only later, in 1989, in Vietnam another CIP-related variety was released. In the years to come, CIP's contribution to NARS' breeding programs has stagnated to pick up more structurally since 1997 (Figure 2). Despite of two years in 2003 and 2005 of no releases, CIP's contribution has been increasing. In 2013, it has reached its peak of 6 released varieties.

Figure 2. Amount and changes of CIP-related varieties released between 1989-2014



Comparing Late with Post GR period, results suggest that Post GR period has been relatively more important in terms of amount of CIP-related releases and adoptions. Whereas in Late GR period 7 CIP-related varieties were released, in the following Post GR period release figures rose to 38. These are striking increases of 443% (Table 7).

Table 7. Cumulative NARS-CIP release, and changes

Cumulative		Changes
Late GR	Post GR	Late-Post
7	38	443%

Note: GR = Green Revolution

The data also allows us to distinguish between CIP-crosses and -progenitors (Table 8). Releases of varieties selected from CIP crosses amounted to 16 whereas from CIP progenitors amounted to 27, making CIP progenitors almost twice as successful. Likewise, CIP progenitors are more important in terms of absolute adoption. However, only 52% (14) of released CIP-progenitors are adopted and 69% (11) of CIP-crosses.

Table 8. Varietal release and adoption until 2015 by country and material type

Country	NARS-CIP				CIP-crosses				CIP-progenitors			
	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)
Bangladesh	8	18%	4	15%	2	13%	2	18%	2	7%	0	
China*	19	42%	8	30%	1	6%	0		18	67%	8	50%
India	4	9%	0		3	19%	0		0		0	
Indonesia	8	18%	6	22%	4	25%	3	27%	4	15%	3	25%
Nepal	0		4	15%	4	25%	4	36%	0		0	
Papua New Guinea	1	2%	0		0		0		0		0	
Philippines	0		0		0		0		0		0	
Vietnam	5	11%	5	19%	2	13%	2	18%	3	11%	3	25%
Total	**45**	**100%**	**27**	**100%**	**16**	**100%**	**11**	**100%**	**27**	**100%**	**14**	**100%**

Notes: *for 9 Provinces only; NARS-CIP is a vector of CIP-related variables including NARS selection from CIP crosses, NARS selection from CIP progenitors, NARS-bred variety distributed by CIP.

Varietal age may be used to assess varietal turnover across countries. In 2015, adopted varieties have been cultivated for an average of 13.7 years. As Table 9 further depicts, varietal turnover is lowest in India (20 years), followed by Philippines (19 years), and Bangladesh (18 years). The highest turnover is observed in Papua New Guinea (2 years) and Indonesia (8 years). For the former case, as discussed earlier, rather than formal releases, varieties are cleaned and reintroduced to farmers which may result in more effective dissemination and thus quicker turnover.

Table 9. Average varietal age by release classification

Country	Mean	NARS-developing	NARS-developed	NARS-CIP
Bangladesh	18	25.5		9
China*	14	13	50	
India	20	20		
Indonesia	8	5		11.5
Nepal				
Papua New Guinea	2	2		
Philippines	19	18.3		
Vietnam	15	15.3	18	13
Total	**13.7**	**13.7**	**43**	**9.4**

Notes: base year is 2015; *for 9 Provinces only.

Varietal adoption

The total area under sweetpotato amounts to 3.6Mha in selected countries in our study region in 2015. China accounts for 79% (2.8Mha) of the total making it the largest sweetpotato producer (Table 10). In Nepal, in contrast, the area is very little amounting to only 1,700ha making it the smallest sweetpotato producer. Second ranks Papua New Guinea with about 250,000ha (or 7% of total area) where sweetpotato is an important staple crop.[4]

A stunning 88% of the total area is planted to improved varieties in 2015. During the past 20 years, the share of improved varieties has grown by 4-5%. These are major developments considering that the share of improved varieties was very small (about 10%) in the Early GR period in the 1960s (Evenson and Gollin, 2003a). Strong collaboration between NARS and IARC has contributed significantly to this development. However, there are considerable regional differences. For instance, China where 100% of the area is planted to IVs evidently drives the total share of IVs. On the other hand, countries such as Bangladesh (6%), Papua New Guinea (13%), or Nepal (14%) share of improved varieties is relatively small. In India and Indonesia, the share of IVs is higher than 60%. Thus, the overall picture should be looked at with caution, and continued/increased support to develop new IVs and to effectively disseminate those is required. Total potato area disaggregated by Chinese province and Indian region can be found in Table 2A in the Appendix.

Table 10. Total area and area planted to improved varieties in 2015

[4] Official statistics on total area at national level is unavailable and, according to local experts, FAO (2015) statistics considerably underestimate the total area. At the workshop in Papua New Guinea we inferred the total area by using total production estimates in 2000 and the production trend information from FAOSTAT between 2000-2014. To arrive at the total area we also acknowledge regional mean yield differences.

Country	Total area (in ha)	Total area (in %)	Area planted to IV (in ha)	Area planted to IV (in %)
Bangladesh	42,999	1%	2,602	6%
China*	2,837,512	79%	2,837,512	100%
India**	81,033	2%	53,184	66%
Indonesia	140,774	4%	87,653	62%
Nepal	1,699	<1%	240	14%
Papua New Guinea	253,914	7%	33,838	13%
Philippines	110,107	3%	25,919	24%
Vietnam	129,900	4%	107,827	83%
Total	**3,597,938**	**100%**	**3,148,775**	**88%**

Notes: *For 9 Provinces only; **for 3 States only. IV = improved variety.

Adoption by institutional source

IARCs have been supporting NARS in breeding for improved varieties for many years. However, in the case of sweetpotatoes, CIP's little contribution in terms of released and adopted varieties, has translated into a small area planted to CIP-related varieties (163,706ha or 5% of total area). Table 11 further depicts that CIP has contributed most in Indonesia where 14,619ha (or 10% of area in Indonesia) is planted to CIP-related varieties. In China, this area is only 4% which translates into an area of about 115,952ha, most of it is located in Shandong province. The largest share (2.3Mha or 64%) of the total area is planted to varieties based on NARS material.

Table 11. Total area by release classification

Country	NARS-CIP			NARS-developing			NARS-developed		
	(ha)	(%)	Share of total area (%)	(ha)	(%)	Share of total area (%)	(ha)	(%)	Share of total area (%)
Bangladesh	943	1%	2%	1,098	<1%	3%			
China*	115,952	71%	4%	2,315,685	92%	82%	80,200	98%	3%
India**				52,875	2%	65%			
Indonesia	14,619	9%	10%	28,934	1%	21%			
Nepal	48	<1%	3%	92	<1%	5%	100	<1%	6%
Papua New Guinea				66,729	3%	26%			
Philippines				22,706	1%	21%			
Vietnam	32,144	20%	25%	39,641	2%	31%	1,235	2%	1%
Total	**163,706**	**100%**	**5%**	**2,527,760**	**100%**	**70%**	**81,535**	**100%**	**2%**

Notes: *For 9 Provinces only; **for 3 States only.

Table 12. Total NARS-CIP area by material type

Country	NARS-CIP	CIP-crosses			CIP-progenitors		
	(ha)	(ha)	(%)	Share of NARS-CIP area (%)	(ha)	(%)	Share of NARS-CIP area (%)
Bangladesh	943	116	0.01	0.00			
China*	115,952				115,952	0.81	0.71
India**							
Indonesia	14,619	6,325	0.33	0.04	8,294	0.06	0.05
Nepal	48	48	0.00	0.00			
Papua New Guinea							
Philippines							
Vietnam	32,144	12,852	0.66	0.09	19,292	0.13	0.12
Total	**163,706**	**19,341**	**1.00**	**0.12**	**143,538**	**1.00**	**0.88**

Notes: *for 9 Provinces; **for 3 States. CIP-distributed not shown but included in total NARS-CIP.

We further break down the CIP-related area by CIP-crosses and -progenitors (Table 12). In terms of area, CIP-progenitors have been more successful (143,538ha or 88% of CIP-related area) than CIP-crosses (19,341ha or 12% of CIP-related area).

Adoption and resistances

Knowledge about the characteristics of released varieties and the respective area under cultivation allows us to infer the total area under varieties with specific resistances (Table 13).

The reported data reveals that root rot, nematodes, and black spot are the three major diseases in our study countries. Root rot appears to be dealt with best: currently 24.2% of the total area is under varieties with high root rot resistance (in China 30.6% or 0.87Mha). Varieties with medium resistance to nematodes are cultivated on 18% of the total area which translates into 22.9% (0.65Mha) in China. In contrast, high resistant varieties against nematodes are cultivated on 5.2% (0.15Mha) in China and 16.9% (0.48Mha) of the area is still planted to nematode susceptible varieties. In China, a substantial area (28.6% or 0.81Mha) is cultivated to varieties which are susceptible to black spot. This suggests that black spot is a major disease in that region. At the same time, 21.2% (0.6Mha) is planted to medium-resistant black spot varieties.

For weevil disease, most data is available suggesting that weevil is an important disease in our study region. In particular in India, 12.4% (0.01Mha) of the area is under weevil susceptible varieties. But here 24.5% (0.02Mha) and 21.1% (17,200ha) of the area is planted to high- and medium resistant varieties, respectively. In Indonesia, weevil seems to be a big problem: 21.4% (0.03Mha) of the area is under weevil susceptible varieties.

For Vietnam, much data is not reported but varieties cultivated are characterized by medium weevil (about 40% of area or 0.05Mha) and virus resistance (about 50% of area or 0.06Mha).

Table 13. Area (in %) under varieties with high resistance and susceptible by stress and country

(in %)	Nematode				Weevil				Root rot				Fusarium wilt			
Country	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**
Bangladesh							3.5	2.6								
China	5.2	22.9		16.9		0.8	0.3	0.4	30.6	10.7		5.4	4.1	0.8		0.3
India					24.5	21.2		12.4	0.7							
Indonesia						23.9		21.2								
Nepal							4.8	9.4			6.1	8.1				
Papua New Guinea			8.7					8.7				8.7				8.7
Philippines						10.7		15.5								
Vietnam						39.7										
Total	**4.1**	**18**	**0.6**	**13.3**	**0.7**	**3.8**	**0.3**	**2.5**	**24.2**	**8.4**	**0**	**4.9**	**3.3**	**0.6**		**0.9**
	Black spot				**Bacterial wilt**				**Virus**							
Country	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**				
Bangladesh											6					
China	8.8	21.2		28.6	3.5	9.4		0.7	1.2	1.1		1.5				
India		0.1										0.7				
Indonesia																
Nepal																
Papua New Guinea				8.7								7				
Philippines																
Vietnam										49.8	6.4					
Total	**6.9**	**16.8**		**23.2**	**2.8**	**7.4**		**0.6**	**0.9**	**2.7**	**0.3**	**1.7**				

Notes: H= high resistance, M=medium resistance, L=low resistance, S=sensitive; blank boxes refer data not reported rather than missing; The many blank boxes refer to data not reported rather than missing. This is important because in same countries varieties with high/medium resistances could be released and adopted but have not been structurally documented.

Most dominating varieties

The 15 dominating varieties in our study region cover 50% of the total sweetpotato area in 2015. We summarize these in Table 14. Ranking first, the Chinese variety Shangshu 19 covers alone almost 12% (0.44Mha) of the total area. With a difference of almost 200,000ha, Xushu 18 ranks second, covering 7% (0.25Mha) of the total area. This variety is closely followed by Chaoshu No.1 (7% or 0.24Mha) and Nanshu 88 (6% or 0.23Mha) which rank third and fourth. The top 5 varieties jointly account for 35% of the total area.

All the top 15 varieties can be found in China. In addition, 13 out of 15 varieties are based on developing country material (category: NARS-developing). Only Jishu No. 21 is selected from CIP-progenitors and Nancy Hall is based on developed material. The former variety ranks 8 and covers 2% of the total area which is about 65,000ha. Jishu No 21. is only cultivated in Shandong province and the most successful CIP-related variety.

Other CIP-related varieties are not as successful. For instance, the second most important variety, Xichengshu 007, ranks 47 in the overall ranking covering about 14,000ha (see Table 15). Table 3A in the appendix depicts a complete picture of the importance of CIP-related varieties in terms of area of adoption in Southeast Asia.

Table 14. Fifteen most cultivated varieties in 2015

Rank 2015	Country	Variety name	Year of release	Source	Estimated area	Share of total (%)	Cum. share of total (%)
1	China	Shangshu 19	2003	NARS-developing	444,769	12%	12%
2	China	Xushu 18	1976	NARS-developing	247,090	7%	19%
3	China	Chaoshu No.1	1990	NARS-developing	236,145	7%	26%
4	China	Nanshu 88	1988	NARS-developing	228,841	6%	32%
5	China	Xushu 22	2005	NARS-developing	101,733	3%	35%
6	China	Guishu No.2	1994	NARS-developing	80,000	2%	37%
7	China	Suyu No.1	1978	NARS-developing	77,333	2%	39%
8	China	Jishu No.21	2007	CIP-progenitors	64,533	2%	41%
9	China	Sushu No.8	1996	NARS-developing	56,633	2%	43%
10	China	E-sweetpotato No.6	2008	NARS-developing	56,000	2%	44%
11	China	Chuanshu 34	1999	NARS-developing	47,393	1%	46%
12	China	Nanshu 99	1999	NARS-developing	47,393	1%	47%
13	China	Nancy Hall	1940	NARS-developed	46,667	1%	48%
14	China	Yushu No.8	1993	NARS-developing	32,067	1%	49%
15	China	Jishu No.5	1982	NARS-developing	29,333	1%	50%

Table 15. Ten most cultivated NARS-CIP varieties in 2015

Rank 2015	Overall rank 2015	Country	Variety name	Source	Estimated area	Share of NARS-CIP total (%)
1	8	China	Jishu No. 21	CIP-progenitors	64,533	0.0179
2	47	China	Xichengshu 007	CIP-progenitors	14,218	0.0040
3	67	Vietnam	K51	CIP-progenitors	9,075	0.0025
4	77	Vietnam	KLC266	CIP-cross	8,272	0.0023
5	94	China	Jizishu No. 1	CIP-progenitors	5,867	0.0016
6	95	China	Shangshu No.9	CIP-progenitors	5,633	0.0016
7	96	Indonesia	Beta 2	CIP-progenitors	5,564	0.0015
8	96	Vietnam	KL5	CIP-progenitors	5,304	0.0015
9	110	Vietnam	SO8	CIP-cross	4,580	0.0013
10	121	Indonesia	Cangkuang	CIP-cross	3,473	0.0010

DISCUSSION AND CONCLUSIONS

General

In close collaboration with NARS, IARCs have greatly contributed to the development and release of improved varieties. During the GR (1960-2000), breeding objectives strongly focused on breeding for high-yielding varieties to combat undernourishment. Global challenges such as climate change, related biotic stresses, and the awareness of the important of micronutrients in rural diets induced changes in breeding objectives. The focus shifted from high-yielding varieties to breeding for other traits which allowed farmers to be more resilient and improve local diets.

In this study we find that these changes induced a tremendous increase in releases of improved potato varieties in Southeast, East, and South Asia in the Post GR (2000 – today). Compared to the Late GR (until 2000), releases of IVs increased by 127% to reach total adoption of 434 varieties in the Post GR. Most of the contribution, however, stems from Chinese NARS considerable breeding efforts. Of those total releases about 45% have found their way onto the farmers' fields. An interesting trend seems to be that number of releases and adoptions are increasingly diverging. More research is needed to better understand the underlying reasons.

In the wake of an increasing prevalence of pests and diseases, we find that changing breeding objectives resulted in substantial releases of high-resistant varieties since 2000. However, there are regional differences. In particular, NARS breeding program in China are very effective resulting in releases of high-resistant varieties against all major stresses included in the study. It is also striking that many released varieties are susceptible to diseases. Weevil and blackspot have been found (in China) to be the most widespread disease and pest in terms of area planted to weevil and blackspot susceptible varieties. Despite major breeding efforts, this points at the continuous need to strengthen national breeding programs.

In 2015, the sweetpotato area in our study region was 3.6Mha. About 88% of the area is planted to improved varieties. There are major regional differences. Whereas in China 100% of the area is under IVs, in Bangladesh this is only 6%. Bangladesh thus represents the extreme example of a country in which (1) landraces are very important and (2) where dissemination of new releases is relatively ineffective.

The 15 most important varieties cover about 50% of the total area. Shangshu 19, released in China in 2003, ranks number 1 with about 12% of the total area. Xushu 18 and Chaoshu No.1, both released in China in 1976 and 1990, respectively, are the second and third most important varieties covering each about 7% of the total area. Varietal turnover seems to be slow despite availability of improved varieties. In this context, analyzing determinants of adoption could be an interesting avenue for future research.

Impact of CIP

As part of IARCs, by 2015 CIP has contributed to the development of 45 IVs which is 10% of the total releases. Of those, 27 IVs have resulted in adoptions. In general, CIP-related releases and adoptions follow a similar increasing trend compared to the overall trend. In China most of the CIP-related releases (19) and adoptions (8) can be found.

About 36% of the total CIP-material used was selected from CIP-crosses and 60% was selected from CIP-progenitors. Only in 4% of the cases (2 varieties in Bangladesh), CIP played a role in facilitating the release of varieties of third parties. CIP-crosses are used in Bangladesh, Indonesia, and Nepal, whereas CIP-progenitors are selected in China and Indonesia.

In terms of area, CIP-related varieties are planted to about 164,000ha which is about 5% of the total area. China accounts for most (71%) of total area cultivated to CIP-related varieties. However, this only represents 4% of total area in China. In Vietnam, CIP has made much impact as well. Here, 20% of the total area is planted to CIP-related varieties. In other countries, CIP's impact in terms of area is marginal or not existing, which is the case in India, Philippines, and Papua New Guinea. The top 5 varieties cover 35% of total area in study countries, and top 15 varieties cover 50%, respectively.

Regarding the ten most important CIP-related varieties, these can be found in mainly 3 countries (i.e. China, Indonesia, and Vietnam). Jishu No.21, released in China in 2007, covers about 64,500ha and is the most important CIP-related variety. Xichengshu 007, released in China in 2008, covers 14,218ha. Except for Jishu No.21 most of the remaining varieties cover relatively small areas, most of them below 10,000ha. For future research, it will be worth investigating the determinants of adoption of Jishu No.21 which can only be found in Shandong province.

There are a couple of challenges this research has dealt with. For instance, expert opinions have been criticized to be less accurate compared with household surveys. Though we cannot fully refute this claim, the adoption estimates in this study should be considered as *perceived* adoption. Second, the categorization of level of resistances (i.e. high, medium, low) is also based on experts opinion. Unfortunately, objective experimental data is not widely available which is often related to NARS's financial capabilities to fund appropriate experiments. Third and finally, data on nutritional values is very limited, mostly because of the same reasons as before, the lack of adequate financial resources. However, in times where we attempt to combat micronutrient deficiency, data on nutritional values is critical.

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APPENDIX

Appendix Table 1. Total release and adoption in China by Province

Province	Total				CIP-related	
	Release		Adoption		Rele.	Adop.
	(No)	(%)	(No)	(%)	(No)	(No)
Anhui	33	14%	22	21%		
Chongqing	15	6%	13	12%		
Guangxi	31	13%	13	12%		
Guizhou	9	4%	7	7%		
Henan	33	14%	9	8%	9	4
Hubei	20	8%	8	8%		
Hunan	19	8%	11	10%	1	1
Shandong	37	16%	9	8%	4	2
Sichuan	39	16%	14	13%	5	1
Total	**236**	**100%**	**106**	**100%**	**19**	**8**

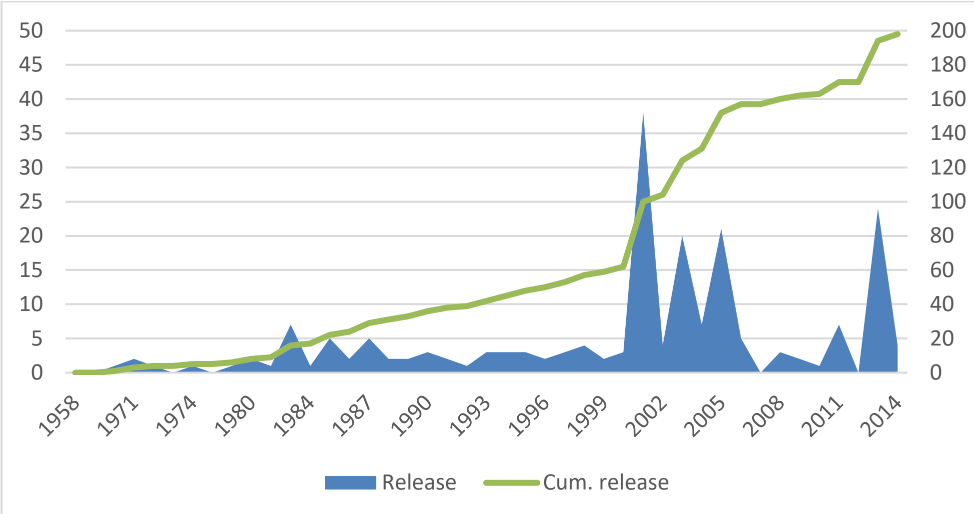
Appendix Table 2. Area and share of improved area by region in China and India

Country	Area (ha)	Improved (ha)	Improved (%)	NARS-CIP (%)
China				
Anhui	266,666	266,666	100%	
Chongqing	386,840	386,840	100%	
Guangxi	200,000	200,000	100%	
Guizhou	243,407	243,407	100%	
Henan	433,333	433,333	100%	6%
Hubei	266,666	266,666	100%	
Hunan	273,333	273,333	100%	1%
Shandong	293,334	293,334	100%	24%
Sichuan	473,933	473,933	100%	3%
Total	**2,837,512**	**2,837,512**	**100%**	**4%**
India				
Odisha	42,033	31,364	75%	
Uttar Pradesh	17,000	5,100	3%	
West Bengal	22,000	16,720	76%	
Total	**81,033**	**53,184**	**66%**	

Appendix Table 3. List of NARS-CIP varieties

Rank 2015	Overall rank 2015	Country	Variety Name	Source	Estimated area
1	8	China	Jishu No. 21	CIP-progenitors	64,533
2	47	China	Xichengshu 007	CIP-progenitors	14,218
3	67	Vietnam	K51	CIP-progenitors	9,075
4	77	Vietnam	KLC266	CIP-cross	8,272
5	94	China	Jizishu No. 1	CIP-progenitors	5,867
6	95	China	Shangshu No.9	CIP-progenitors	5,633
7	96	Indonesia	Beta 2	CIP-progenitors	5,564
8	96	Vietnam	KL5	CIP-progenitors	5,304
9	110	Vietnam	SO8	CIP-cross	4,580
10	121	Indonesia	Cangkuang	CIP-cross	3,473
11	122	China	Luoshu No.11	CIP-progenitors	3,467
12	123	China	Zhengthong 22	CIP-progenitors	3,467
13	132	China	Xiangshu No.14	CIP-progenitors	2,733
14	144	Indonesia	Papua Pattipi	CIP-progenitors	2,047
15	160	Indonesia	Jago	CIP-cross	1,426
16	159	Indonesia	Sukuh	CIP-cross	1,426
17	174	Bangladesh	CIP 440025	CIP-distributed	824
18	178	Indonesia	Sawentar	CIP-progenitors	682
19	203	Bangladesh	Lalkuthi	CIP-cross	78
20	206	Bangladesh	Kalomegh	CIP-cross	39
21	209	Nepal	CIP 440021	CIP-cross	16
22	210	Nepal	CIP 440267	CIP-cross	16
23	211	Nepal	CIP 440012	CIP-cross	5
24	212	Nepal	CIP 440015	CIP-cross	5
25	213	Nepal	CIP 440328	CIP-cross	5
26	214	Bangladesh	CIP 440074	CIP-distributed	3

Appendix Figure 1. Amount of varieties released and adopted without China between 1958-2014



Appendix. Expert-level Data Collection Instrument

(To be completed by each Expert)

A1. Name:____ A2. Affiliation:

A3. Today's Date:________________

A4. Country: A5. Crop:

A6. Sub-Region/agro-ecological domain: A7a. Season:

A7b. Year:

Note: The frame of reference for all the following questions is the crop, sub-region and season/year noted above.

B. Please provide your estimate of the relative importance of improved varieties vs. local landraces as measured by percentage area harvested:

Varietal type	% Area	E. Please provide a brief explanation in support of the estimates in B1 and B2 (*use a separate sheet if more space is required*)
Traditional/Local/Landraces	B1.	
Modern/Improved	B2.	
Total	100%	
C. Please list all the improved crop varieties (in descending rank order) you believe farmers are currently growing in this sub-region by season combination	D. Please share your perception of percentage share of area harvested devoted to each variety identified (*if the list is significantly more than 12 varieties, restrict to varieties occupying the top 95% of IV adoption area. Use your own judgment on when it makes sense to aggregate 'all other improved varieties'*)	E. Please provide a justification for the basis of your estimates of perceived adoption or a brief explanation in support of this perception (*use a separate sheet if more space is required*)
C1.	D1.	
C2.	D2.	
C3.	D3.	
C4.	D4.	
C5.	D5.	
C6.	D6.	
C7.	D7.	
C8. Local/Traditional varieties	D8.	
Total	100%	

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