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

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M. Gatto, G. Hareau, W. Pradel, V. Suárez, J. Qin
International Potato Center (CIP)

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Comments are invited.

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International Potato Center
P.O.Box 1558, Lima 12, Peru
cip@cgiar.org • www.cipotato.org

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LIST OF ABBREVIATIONS

BARI	Bangladesh Agricultural Research Institute
CCCs	crop-country-combinations
CIAT	Centro Internacional de Agricultura 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
HHs	households
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
RCRDC	Root Crop Research and Development Center
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 potato. 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 potato 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, as well as other environmental traits such as earliness, 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 potato varieties in seven major potato 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 15 experts working in the potato value chain participated in a one-day event to elicit *perceived* adoption rates and to update release databases. In total, 347 experts attended 23 workshops which were 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.

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), activities 2.1 with the following objective: 'Institutionalize the collection of diffusion data needed to conduct critical CGIAR impact evaluations'. An important component 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 seven countries in Southeast Asia which are considered major potato producing areas. Since CIP's impact is an important aspect of the study, discussion with CIP colleagues influenced the final selection of countries, which are: Bangladesh, China, India, Indonesia, Nepal, Pakistan, and Vietnam. Due to the relatively large sizes of China and India, we sampled 12 Provinces in China which represents 88% of the total potato area and 6 States in India, respectively. Combined we sampled a total of 23 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 potato 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, a total of 347 experts participated in 23 EE workshops which is an average of 15.09 per workshop. In spite of our efforts to identify and invite female experts, overall not many female experts could be identified and thus participated in the workshop (Table 1).

Generally, CIP staff facilitated the workshops or exceptionally also well-trained partners. This was the case in four States in India (i.e. Bihar, Gujarat, Karnataka, and West Bengal) and Pakistan.

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.

Table 1. Summary statistics of EE workshops

Country	No. of CCCs	No. of participants	No. female	Share female
Bangladesh	1	16	0	0%
China				
Chongqing	1	10	N/A	
Gansu	1	16	N/A	
Guangxi	1	11	N/A	
Guizhou	1	8	N/A	
Hebei	1	8	N/A	
Heilongjiang	1	9	N/A	
Inner Mongolia	1	9	N/A	
Ningxia	1	11	N/A	
Shaanxi	1	9	N/A	
Shanxi	1	12	N/A	
Sichuan	1	10	N/A	
Yunnan	1	13	N/A	
India				
Bihar	1	25	0	0%
Gujarat	1	19	0	0%
Karnataka	1	24	0	0%
Punjab	1	19	1	5%
Uttar Pradesh	1	19	0	0%
West Bengal	1	24	0	0%
Indonesia	1	14	2	14%
Nepal	1	17	3	18%
Pakistan	1	23	4	17%
Vietnam	1	21	4	19%
Total	**23**	**347**		
Average		**15.09**		

Note: Data for China on no. of female participants is N/A because of anonymized identities.

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 (see Appendix). We ensured, to the extent possible, that communication among participants was kept minimal 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.

Overall, this study created publicly available databases on release (Gatto et al., 2016a) and adoption (Gatto et al., 2016b).

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)

Regarding the NARS-CIP category, Thiele et al. (2008) 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 491 IVs in our study region. In 2015, a total of 210 IVs are currently adopted and cultivated (Table 2) which represents 43% of total releases.

Table 2. Improved varietal release and adoption by country

Country	Released		Adopted			Adopted no release
	(No)	(%)	(No)	(%)	(% of released)	(No)
Bangladesh	73	15%	10	5%	14%	0
China*	254	52%	100	48%	39%	9
India	70	14%	37	18%	53%	8
Indonesia	35	7%	16	8%	46%	0
Nepal	12	2%	14	7%	117%	2
Pakistan	29	6%	18	9%	62%	7
Vietnam	18	4%	15	7%	83%	7
Total	**491**	**100%**	**210**	**100%**	**43%**	**35**

Notes: *for 12 Provinces only. Category 'Adopted' includes total adopted varieties. Also varieties which have never been released.

China is by far the country with the most releases (254).[1] Bangladesh has released 73 IVs and thus released more than India (70). The remaining countries have relatively small national breeding programs which have released between 12 and 35 varieties.

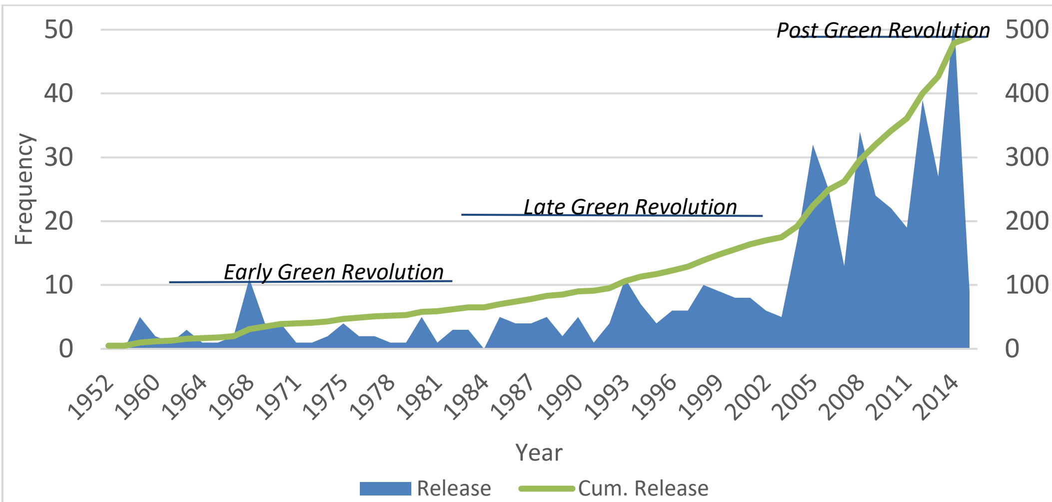
In terms of adoption, in absolute terms in China the highest number can be found (100), followed by India (37). The remaining countries all have adopted less than 20 varieties. However, high release rates are no guarantee for adoption. In China, only 39% of releases have been adopted. Only in Bangladesh even fewer releases are adopted (14%). In stark contrast are Nepal and Vietnam, where 100% and 83% of releases have been adopted, respectively. It is also noteworthy that 35 varieties have been adopted without a preceding formal release process. These could be 'imported' varieties or varieties/landraces which were popular and dissemination has been effective without any formal involvement.

Sporadic release of IVs occurred in the beginning of the 20th century. Only decades later, since 1950s releases have started to be more systematic yet little, as Figure 1 depicts[2]. In the 1960s and 1970s, a period often referred to as the first wave of the Green Revolution (GR) no considerable increase in varietal release can be observed (apart from a peak in 1968 where 25 varieties were released). Only later, during the 1990s, varietal release has picked up. On the one hand, our results confirm earlier findings by Everson and Gollin (2003) stressing that the

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

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 1952-2015.



Notes: Cumulative trend lines refer to right axis.

As mentioned, cumulative varietal releases appears to follow an exponential trend. Broken down by GR period, in the Early, Late, and Post GR period a total of 58, 98, and 332 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 69 and 239%, respectively (Table 3).

Table 3. Total cumulative varietal releases and changes by Green Revolution period

Cumulative			Changes	
Early GR	**Late GR**	**Post GR**	**Early-Late**	**Late-Post**
58	98	332	69%	239%

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 these related biotic and abiotic stresses. In our database, we distinguish a total of ten traits; three provide resistance against abiotic stresses (i.e. drought, heat, and frost) and seven provide resistance against biotic stresses (i.e. late blight, bacterial wilt, x-virus, y-virus, s-virus, leaf curl, and nematode). A total of 457 varieties are released with high resistant traits[3] (Table 4).

Table 4. Release and adoption of high resistant varieties

Trait	Released	Adopted	Ratio (adopted/released)
Resistances against abiotic stresses			
Drought	49	27	(0.55)
Heat	22	17	(0.77)
Frost	24	10	(0.42)
Total abiotic	95	54	(0.57)
Resistances against biotic stresses			
Late blight	87	39	(0.45)
Bacterial wilt	34	16	(0.47)
X-virus	72	33	(0.46)
Y-virus	66	30	(0.45)
S-virus	18	11	(0.61)
Leaf curl	59	24	(0.41)
Nematode	26	18	(0.69)
Total biotic	362	171	(0.47)
Total traits	**457**	**225**	**(0.49)**

Notes: Traits shown are for category 'high' only; Trait categories 'medium', 'low', and 'susceptible' are not shown. Data refers to one trait per variety, multiple traits in same variety are not accounted for; adopted category only for released varieties.

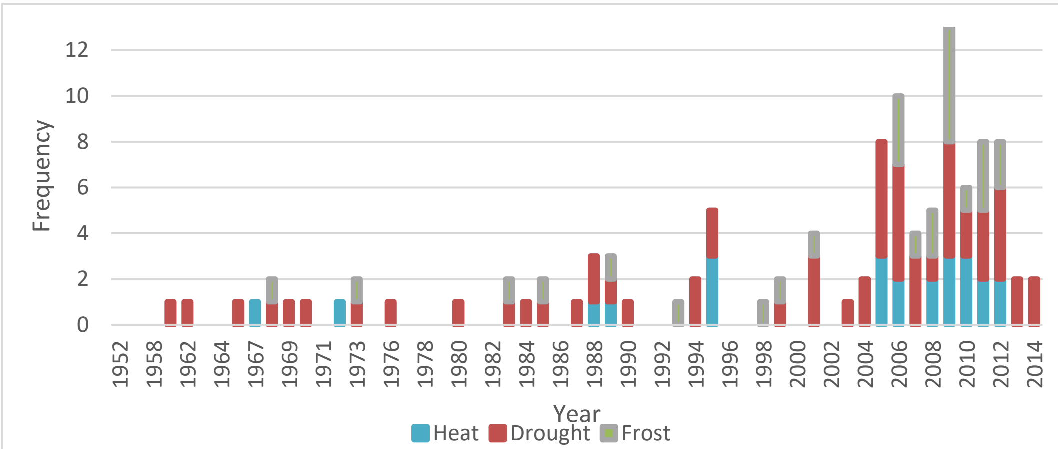
More efforts have been placed into breeding against biotic stresses (362 traits) than abiotic stresses (95 traits). Regarding the first, the main traits have been late blight (87 traits), X-virus (72 traits), and Y-virus (66 traits). In comparison, abiotic resistances have received lesser importance: drought (49 traits), frost (24 traits), and heat (22 traits). Also, in terms of adoption the mentioned biotic resistances are more often found in adopted varieties than their abiotic counterparts. In terms of adoption, importance of traits does not change. It is striking that on average less than 50% of all released high resistant varieties have been adopted. Varieties with abiotic traits (57%) have more often been adopted than biotic traits (47%).

Looking at the year of release of varieties with traits against abiotic and biotic stresses reveals that breeding intensity has increased drastically since 2000 (Figure 2 and 3). With respect to abiotic resistances, this may be a result of increased adaptation efforts to climate change. Before 2000, especially varieties with frost and heat

[3] In the survey, we specified four categories: 'high', 'medium', 'low', and 'susceptible'. These are based on the perceptions, knowledge, and assessments of national experts in the different countries.

resistances have only been sporadically released. Drought resistant varieties have been released most throughout the entire period 1952-2014 (Figure 2).

Figure 2. Amount of varieties released by abiotic resistances between 1952-2014



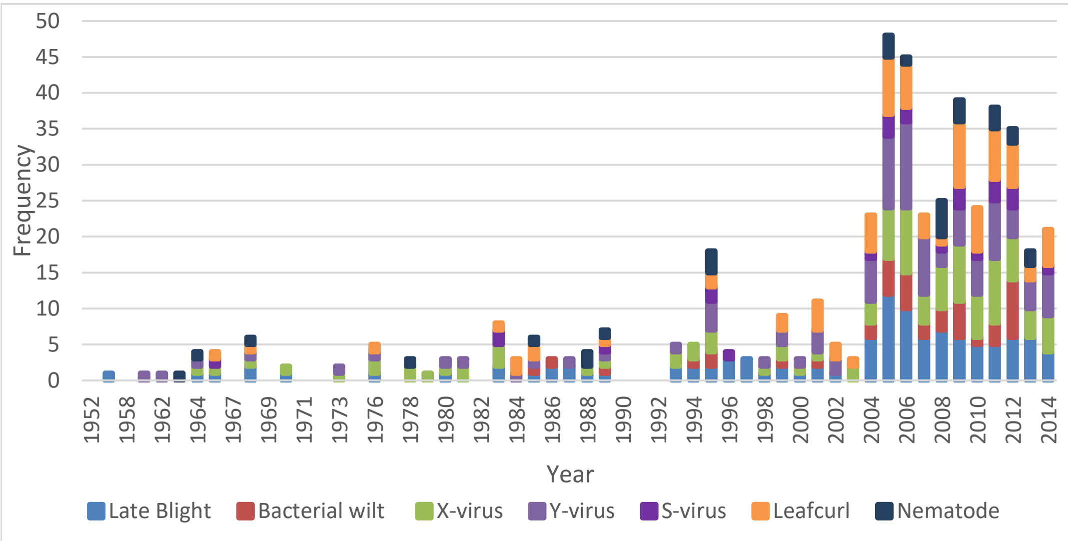
Notes: Resistances shown are for category 'high' only. Categories 'medium', 'low', and 'susceptible' are not shown. Data refers to one traits per variety, multiple traits in same variety are not accounted for.

Regarding biotic resistances, until the 1980s breeding efforts concentrated on late blight, X-virus, and Y-virus. Intensification of breeding for the remaining biotic resistances has started later during the late 70s/early 80s. In particular, bacterial wilt and S-virus traits started to receive more attention by breeders since the early 2000. As of 2004, all 7 traits included in our study have been bred into released varieties almost in every year (Figure 3).

It is worth mentioning that these breeding efforts have mainly taken place in China and India which developed strong national breeding programs. This is reflected in Table 5 which reveals the year of first varietal release by trait. In other countries only a few high resistant varieties were released: in Indonesia one, in Pakistan two, in Vietnam three, and in Nepal four. In all countries usually varieties with certain traits are adopted which are also released.[4] For instance in Bangladesh, a high resistant heat variety has not been released and accordingly, has not been adopted, not even through another channel, such as from a different NARS or private company. Likely, in these countries most of the released and adopted varieties have medium or low resistance to abiotic and biotic stresses.

[4] There are two exceptions. In Bangladesh, a high resistant X-virus variety has been released but no variety of this type has been adopted. Similarly, in Vietnam no high resistant Y-virus variety has been released but there is a variety adopted since 2005.

Figure 3. Amount of varieties released by biotic resistances between 1952-2014



Notes: Resistances shown are for category 'high' only. Categories 'medium', 'low', and 'susceptible' are not shown. Data refers to one traits per variety, multiple traits in same variety are not accounted for.

Table 5. Year of first release of high resistant variety by country

Trait	Bangladesh	China	India	Indonesia	Nepal	Pakistan	Vietnam
Heat		1989	1967				1995
Drought	1960	1966	1910				
Frost		1983	1968				2008
Late blight	1970	1956	1964	1980	1999		
Bacterial wilt		1985					2007
X-virus	1970	1966	1964		2014	2013	
Y-virus	1960	1968	1962		2014		
S-virus		1966					
Leaf curl		1966			1999		
Nematode		1989	1910			2013	

Notes: blank boxes refer to no variety of high resistant category has been released.

Release of CIP-related varieties

Until 2015, a total of 168 varieties have been released with a relationship to CIP. This is 34% of the total releases in our study region. Regarding adoption, 63 CIP-related released varieties are currently cultivated. This is 30% of the total adopted varieties. In different words, the ratio of NARS-related to CIP-related adopted varieties is 2/3 NARS – 1/3 CIP (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	16	10%	2	3%	4	2%			53	46%	8	13%
China*	105	63%	35	56%	142	69%	60	72%	6	5%	5	8%
India	12	7%	7	11%	42	20%	16	19%	16	14%	14	22%
Indonesia	16	10%	5	8%	9	4%	5	6%	10	9%	6	10%
Nepal	9	5%	8	13%	2	1%	2	2%	1	1%	4	6%
Pakistan	1	1%			7	3%			21	18%	18	29%
Vietnam	9	5%	6	10%					9	8%	8	13%
Total	**168**	**100%**	**63**	**100%**	**206**	**100%**	**83**	**100%**	**116**	**100%**	**63**	**100%**

Notes: *for 12 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 206 varieties based on own NARS material were released and 83 were adopted. These represent 42% and 40%, respectively, of total releases and adoptions.

In every country of this study, CIP-related varieties have been released and adopted. China, however, stands out. Here, 105 CIP-related varieties have been released and 35 have been adopted. This represents both 63% and 56%, respectively, of total CIP-related releases and adoptions and thus translates into a considerable contribution of CIP to the Chinese potato sector.

In contrast, in India release and adoption of CIP-related varieties appears to be meagre. Only 12 and 7 CIP-related varieties have been released and adopted, respectively. Of total CIP-related varietal release and adoption this represents only 7 and 11%.[5]

In Nepal, though relatively small in terms of total contribution, 90% of the releases (9 varieties) were adopted (8 varieties). In contrast, in Pakistan no CIP-related variety has been adopted and only one released variety is related to CIP.

See Table 2A in the Appendix for CIP-related varieties broken down for China by province.

[5] Overall, these figures should be read with caution. Discussions with other than Indian experts resulted in higher CIP impact. At this point, we are unable to estimate to what extent we underestimate the true release and adoption figures.

The first CIP-related varieties were released in 1982 in Vietnam. In the years to come, CIP's contribution to NARS' breeding programs has been sporadic. In the early 1990s, CIP-related material has been used in breeding efforts in a more systematic way (Figure 4). After two years of reduced releases in 2002 and 2003, CIP-related releases skyrocketed to reach its peak in 2005/06: CIP contributed to 15 and 11 of released and 7 and 8 of adopted varieties. All of which were released and adopted in China and India.

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. Whereas in Late GR period 27 CIP-related varieties were released, in the following Post GR period releases rose to 140. These are striking increases of 419% (Table 7).

Figure 4. Amount of varieties released by biotic resistances between 1952-2014

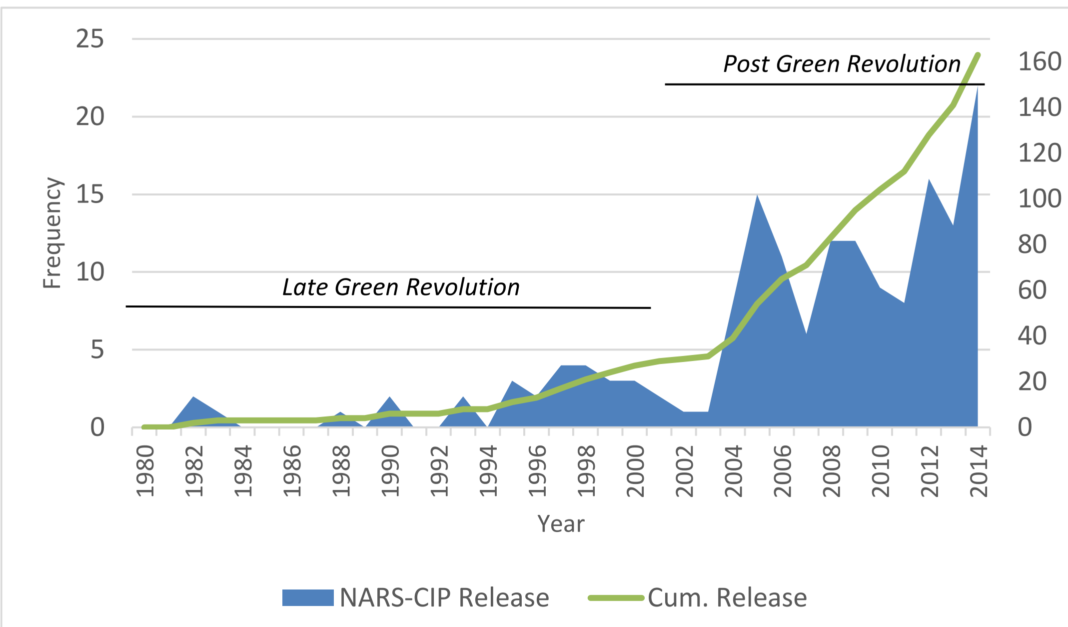


Table 7. Total cumulative NARS-CIP releases by GR period

Cumulative		Changes
Late GR	**Post GR**	**Late-Post**
27	140	419%

Both variations of CIP-related material (i.e. selected from crosses, selected from progenitors) have been similarly successful (Table 8). Releases of varieties selected from CIP crosses (85) were only slightly more compared with varieties selected from progenitors (77). Also in terms of adoption, NARS have selected slightly more from CIP crosses (37) than progenitors (25).

Table 8. CIP-related release and adoption until 2015 by country

Variety	CIP-related				CIP-crosses				CIP-progenitors			
	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)	Release	(%)	Adopt.	(%)
Bangladesh	16	10%	2	3%	16	19%	2	5%				
China*	105	63%	35	56%	37	44%	17	46%	63	82%	18	72%
India	12	7%	7	11%	1	1%	1	3%	11	14%	6	24%
Indonesia	16	10%	5	8%	13	15%	4	11%	3	4%	1	4%
Nepal	9	5%	8	13%	8	9%	7	19%				
Pakistan	1	1%			1	1%						
Vietnam	9	5%	6	10%	9	11%	6	16%				
Total	**168**	**100%**	**63**	**100%**	**85**	**100%**	**37**	**100%**	**77**	**100%**	**25**	**100%**

Notes: *for 12 Provinces only; CIP-related is a vector of variables including NARS selection from CIP crosses, NARS selection from CIP progenitors, NARS-bred variety distributed by CIP; not shown is category CIP-distributed but included in CIP-related.

In all countries studied, varieties based on CIP-crosses were released whereas varieties based on CIP-progenitors were released in China, India, and Indonesia. Chinese NARS have requested relatively most CIP-material, irrespective of the type of material. India, in contrast, has mainly used CIP-progenitors in breeding new varieties.

Varieties which are adopted by 2015 have been cultivated for an average of 14.6 years. Since the first IVs were released in the first period of the GR for all studied countries, giving all countries a similar reference year, we can assess varietal turnover by looking at average years of adoption. As Table 9 further depicts, varietal turnover is rather low in India (29.5 years) and high in Pakistan (5.9 years). The remaining countries all lie within this range. The oldest adopted varieties have been bred by NARS with own material (20.5 years). Varieties re-released by NARS but bred by developed countries are also rather old (18.9 years). Finally, NARS released and adopted varieties which are based on CIP material are the youngest (11.4 years).

Table 9. Average years of adoption by release classification

Country	Mean	NARS-developing	NARS-developed	NARS-CIP	Years since first release NARS-CIP
Bangladesh	10.3		12.5	1.5	25
China	15.6	17.9	22.1	9.5	32
India	29.5	28.8	44	18.4	27
Indonesia	10.1	12.4	11	6.7	10
Nepal	17.9	23	29.4	12.3	14
Pakistan	5.9		5.9		15
Vietnam	13.2		7.4	20	33
Total	**14.6**	**20.5**	**18.9**	**11.4**	**22.3**

Note: base year is 2015.

CIPs engagement with NARS dates back to more than 30 years ago. In China, the first CIP-related variety was released in 1983 ago; in Indonesia the first CIP-related variety was only released in 2005. Strikingly, though the first CIP-related variety was released in Bangladesh in 1990, average years of adoption since release is only 1.5. Compared with other countries, in Bangladesh CIP-related varieties have gained importance in more recent years. In contrast, in India and Vietnam relatively older CIP-related varieties are still cultivated.

Varietal adoption

The total area under potato amounts to 7.6Mha in selected countries in our study region in 2015. Although the total area was considerably smaller in 1997, about 5.4Mha, the pace of increase is slowing down. Between 1997-2007 total area has increased by 27%; in comparison, between 2007-2015 total area has increased by 11% (Table 10). Competition over land is likely slowing down potato extension which calls for increasing efforts to sustainably intensify existing cropping patterns.

A stunning 97% 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, 2003). Strong collaboration between NARS and IARC has contributed significantly to this development.

Table 10. Total potato area and adoption of improved varieties in study region

	1997	2007	2015	Changes ’97-‘07	Changes ’07-‘15
Total area (ha)	5,415,900	6,860,400	7,648,570	27%	11%
IV (ha)	5,021,800	6,284,200	7,408,644	25%	18%
IV share (%)	93%	92%	97%	-1%	5%

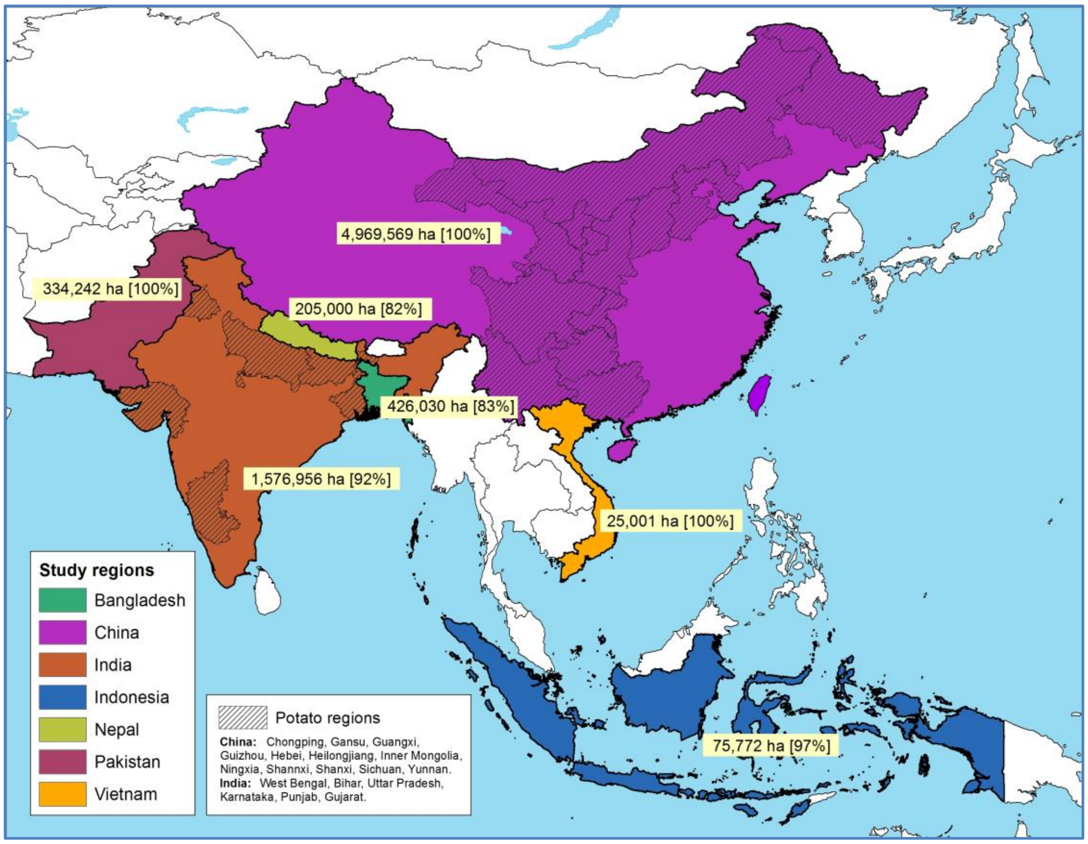
Source: own calculations and adapted from Thiele et al. (2008). IV = improved variety

Our data allows us to have a more disaggregated look at adoption rates. We collected perceived adoption rates for the major potato growing countries in our study region. Adoption rates by country and the area share planted to improved varieties is presented in Map 1.

China is the potato powerhouse of Asia. Total potato area in 12 Provinces selected amounts to 4.97Mha in 2015. This represents 88% of total potato area in China (FAO, 2015). Having about 1.58Mha planted to potato, India is the second most important in terms of area. In contrast, Indonesia (75,772ha) and Vietnam (25,000ha) only have small potato areas. According to experts, the potato area in Indonesia has always hovered at this level and is not further increasing because of the cheaper imports which makes domestic production unprofitable. In Vietnam, potatoes have been very popular as it was prioritized by the government after the war ended. Losing prioritization to rice and other crops, and a stigma of being ‘the poor men’s crop’, along with immense imports from China, have reduced the total potato area to its current level. Total potato area disaggregated by Chinese province and Indian region can be found in Table 3A in the Appendix.

It is striking that the area planted to IVs is 100% in three countries (i.e. China, Pakistan, and Vietnam), or close to (i.e. India and Indonesia). Only in Bangladesh (83%) and Nepal (82%) share of IVs is relatively smaller.

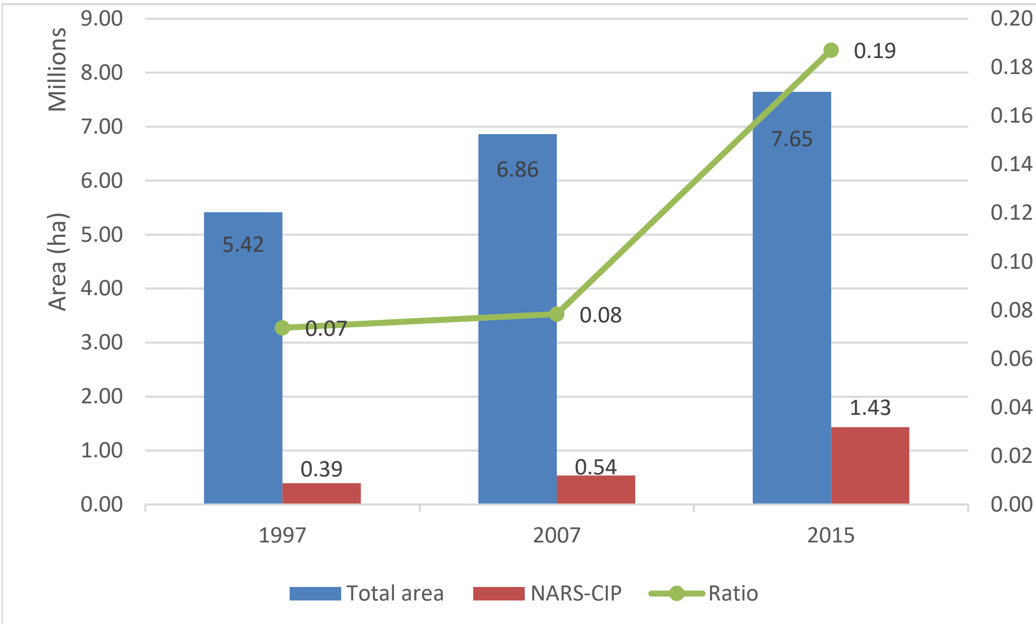
Map 1. Adoption estimations and share of IVs in study countries



Adoption by institutional source

International agricultural research centers (IARCs) have played critical roles in supporting national agricultural research systems (NARS) in breeding for improved varieties. In 2015, total area planted to varieties which are based on CIP material amounts to 1.43Mha. These are increases of 166% and 263% since 2007 and 1997, respectively (Figure 5). However, total potato area is increasing and thus it is worthwhile to look at the share of CIP's share of total potato area to find out about CIP's impact. Whereas in 1997 and 2007 the NARS-CIP share was between 7-8%, it more than doubled to reach 19% in 2015.

Figure 5. Total and NARS-CIP area in 1997, 2007, and 2015



Source: own calculation and adapted from Thiele et al. (2008): ratio (green line) refers to right axis.

Most of the total NARS-CIP area is planted in China (87%); only 8% in India[6] and 5% in Nepal. In the other countries total NARS-CIP area is negligible (Table 11). However, an individual country China stands out again: 25% of the total potato area in China is planted to NARS-CIP varieties. Interestingly, in Nepal the NARS-CIP share amounts to 34%. In India, Indonesia, Vietnam, and Bangladesh only little area is planted to NARS-CIP varieties. In Pakistan, no land is planted to NARS-CIP varieties. This should not come as a surprise, in Pakistan there is only one NARS-CIP variety which was released in 2000. More intriguing is the low NARS-CIP share of total area in Bangladesh where 16 NARS-CIP varieties have been released during 1990-2014.

In spite of the increasing usage of CIP material, in our study region 48% of the total potato area is planted to varieties based on NARS material only (NARS-developing). In this respect, India stands out where 87% of the area is planted to NARS varieties. Chinese varieties without material from CIP or developed countries accounts for 46% of total area. In Nepal and Indonesia, the NARS-developing share is relatively small and in Bangladesh, Pakistan, and Vietnam not existing.

Furthermore, 26% of the total area is planted to NARS varieties which are partly based on material from developed countries. Though this percentage appears low and mainly driven by China, 5 out of 7 countries have a higher percentage than this average: Pakistan (95%), Indonesia (92%), Bangladesh (83%), Vietnam (60%), and Nepal (30%).

[6] The total area planted to NARS-CIP bred varieties may be underestimated due to unclear documentation and local recognition of institutional origin.

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	702	0.00	0.00				381,371	0.19	0.83
China*	1,247,022	0.87	0.25	2,282,338	0.62	0.46	1,058,215	0.54	0.21
India**	109,263	0.08	0.07	1,367,267	0.37	0.87	59,642	0.03	0.04
Indonesia	2,304	0.00	0.03	3,884	0.00	0.05	69,583	0.04	0.92
Nepal	69,726	0.05	0.34	27,609	0.01	0.13	60,968	0.03	0.30
Pakistan	0						318,947	0.16	0.95
Vietnam	1,965	0.00	0.08				15,103	0.01	0.60
Total	**1,430,982**	**1.00**	**0.19**	**3,681,098**	**1.00**	**0.48**	**1,963,829**	**1.00**	**0.26**

Notes: **for 12 Provinces; **for 6 States. If share of total area does not equal 100%, the remaining share may be planted to landraces or 'others' which is a category including varieties covering smaller areas and/or varieties clustered in series of varieties.

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	702	702	0.00	1.00			
China*	1,247,022	596,601	0.88	0.48		650,422	0.86
India**	109,263	4,040	0.01	0.04		105,221	0.14
Indonesia	2,304	1,899	0.00	0.82		405	0.00
Nepal	69,726	69,301	0.10	0.99			
Pakistan	0						
Vietnam	1,965	1,965	0.00	1.00			
Total	**1,430,982**	**674,508**	**1.00**	**0.47**		**756,048**	**1.00**

Notes: *for 12 Provinces; **for 6 States. CIP-distributed not shown but included in total NARS-CIP area.

We can further distinguish CIP contribution by material type. In particular, NARS selection from CIP crosses and progenitors. The findings are summarized in Table 12.[7] A total of 674,508ha is planted to varieties partly selected from CIP-crosses which represents 47% of the total NARS-CIP area. Slightly more important, varieties partly based on CIP-progenitors are planted to 756,048ha (or 53% of total NARS-CIP area). In both cases, China contributes the largest share, 88% to CIP-crosses and 86% to CIP-progenitors. Nepal contributes about 10% to overall CIP-crosses which equals 99% of the total NARS-CIP area. In the remaining countries, potato area is only little planted to varieties partially based on CIP-crosses and no area is planted to varieties partially based on CIP-progenitors (i.e. Bangladesh, Nepal, Pakistan, and Vietnam). In India, most of the CIP related varieties planted

[7] We distinguished another category in which CIP facilitated the distribution of material to NARS. The total area covered with such varieties is, however, rather small. Only in Nepal, about 400ha are planted to these varieties.

are selected from CIP progenitors (105,221ha or 96%). However, this only contributes to 14% of the total area planted to varieties partially based on CIP progenitors.

Adoption and resistances

Knowledge about the released varieties and the respective area under cultivation allows us to infer the total area under varieties with resistances against abiotic and biotic stresses. We summarize our results for area under high resistance and susceptible varieties in Table 13.

Regarding abiotic traits, drought is most important in terms of area. About 13% is cultivated with high resistant drought varieties, 7% with high heat resistant, 3% with high frost resistant varieties. These results are mainly the aggregate for China and India results. In Bangladesh, the area under high heat resistant varieties is less than one percent. Even worse, the area under varieties susceptible to drought is 83% (or 381,723ha). This is troublesome because effects of climate change prolong drought periods, especially in Bangladesh's main potato growing areas (Shahid and Behrawan, 2008). Also in China drought is becoming a serious issue (Yu et al., 2014) and yet 8% (or 395,267ha) of the total potato area is still under varieties susceptible to drought. Likewise, in Nepal 13% (or 26,166ha) of the potato area is susceptible to drought.

Regarding heat resistance, 83% (or 381,723ha) in Bangladesh and 85% (or 1.3Mha) of the total potato area in India, respectively, are cultivated with a variety susceptible to heat. Interestingly, in China only 2% (or 119,322ha) of the total potato area is under a heat susceptible variety.

Adoption data for biotic stresses is more readily available, in particular for late blight and bacterial wilt. The total potato area which is under susceptible varieties amounts to 33% (or 2.5Mha) for bacterial wilt and 30% (or 2.3Mha) for late blight. In China and India, in particular, substantial areas are under susceptible late blight varieties, 24% (or 1.18Mha) and 31% (or 484,351ha), respectively. But also in Bangladesh (82% or 380,969ha) and Pakistan (70% or 233,836ha) late blight susceptible varieties are prevalent. In terms of total high resistance area, 10% (or 756,803ha) is cultivated with late blight varieties.

Bacterial wilt susceptibility of varieties is equally wide-spread in comparison. Though in China (13% or 631,272ha) fewer susceptible varieties are cultivated compared with late blight, in India a stunning 95% (or 1.5Mha) of the total area is cultivated with susceptible bacterial wilt varieties. In terms of total high resistance area, 8% (or 624,489ha) is cultivated with bacterial wilt varieties.

Area under varieties with other resistances, such as X-virus, Y-virus, S-virus, Leafcurl, and Nematodes, are relatively small in terms of high resistance as well as susceptibility. However, China stands out in terms of adoption of high resistant varieties. Leafcurl (28% or 1.38Mha), Y-virus (23% or 1.12Mha), and X-virus (18% or 872,261ha) are the most dominant traits.

The share of high resistant NARS-CIP varieties of total area and at country level can be found in Table 4A in the Appendix.

Table 13. Area under varieties with high resistance and susceptible by stress and country

Country	Drought		Frost		Heat		Late blight		Bacterial wilt	
	% high res.	% suscept.	% high res.	% suscept.	% high res.	% suscept.	% high res.	% suscept.	% high res.	% suscept.
Bangladesh	<1%	83%				83%	<1%	82%		83%
China	20%	8%	5%	9%	10%	2%	15%	24%	13	13%
India	3%	<1%	<1%	95%	3%	85%	1%	31%		95%
Indonesia							1%	1%		
Nepal		13%					6%	13%		
Pakistan				2%				70%		
Vietnam				5%	1%		2%	6%		37%
Total	**13%**	**11%**	**3%**	**25%**	**7%**	**24%**	**10%**	**30%**	**8%**	**33%**
	X-virus		**Y-virus**		**S-virus**		**Leafcurl**		**Nematode**	
Bangladesh	<1%	1%		17%				1%		
China	18%	9%	23%	10%	9%	9%	28%	7%	9%	2%
India	1%	<1%	1%	<1%					2%	49%
Indonesia										2%
Nepal	<1%		<1%				5%	13%		
Pakistan	28%	15%		21%				8%	5%	
Vietnam			<1%							
Total	**13%**	**6%**	**15%**	**9%**	**6%**	**6%**	**18%**	**6%**	**6%**	**11%**

Notes: Blank boxes refer to data not reported rather than missing; medium and low resistance not shown.

Earliness

An important trait potato varieties are increasingly equipped with is earliness or early-maturity. This allows the potato variety to mature within 75-90days without to comprise on yield. There is in particular potential in terms of intensification of cereal-based systems. For instance, between two rice cycles, these have a fallow period which allows for the cultivation of an early-maturing potato variety. Since rice is dominating as a crop in our study region, intensification with potato holds huge potentials.

In our study region, about 0.9Mha are planted to early-maturing potato varieties which is about 12% of the total area (Table 14). Most of the potato area (2.46Mha) is planted to medium-maturing varieties which accounts for 32% of the total area. Finally, 25% of the total area is planted to late-maturing potato varieties.

In China and Nepal, at the country level the highest percentages of early-maturing varieties can be found; these are 15% and 13%, respectively. Similarly, in India and Pakistan 6% is planted to early-bulkers. Strikingly, in Indonesia there are no varieties adopted with earliness.

Much of the area is planted to medium-maturing varieties. In Indonesia this is 97%, and Bangladesh 79%. In India, 50% of the total area is planted to medium-bulkers. Regarding medium-late-maturing varieties, most of the area in China (37%) and Nepal (31%) is planted to these varieties. Interestingly, late-maturing varieties are relatively less popular. Only 11% in China and 8% in India. In contrast, Nepal has most of its potato area (24%) planted to late-maturing varieties.

The share of early/medium/late-maturing NARS-CIP varieties of total area and at country level can be found in Table 4A in the Appendix.

Table 14. Area planted to varieties by earliness

Country	Total	Early		Medium Early		Medium		Medium Late		Late	
	(ha)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Bangladesh	462,030	17,403	4%			363,671	79%				
China	4,969,569	756,622	15%	261,087	5%	1,174,929	24%	1,860,682	37%	531,490	11%
India	1,576,956	92,125	6%			740,971	47%	22,420	1%	133,043	8%
Indonesia	75,772					73,742	97%	2,030	3%		
Nepal	205,000	26,166	13%			19,084	9%	63,403	31%	49,649	24%
Pakistan	334,242	19,413	6%			92,491	28%				
Vietnam	25,001	606	2%			222	1%				
Total	**7,648,570**	**912,335**	**12%**	**261,087**	**3%**	**2,465,111**	**32%**	**1,948,535**	**25%**	**714,182**	**9%**

Notes: early = 75-90 days; medium = 90-120 days; late = 120 days; medium early and medium late do not have clear cut-off points but lie between early-medium and medium-late, respectively. By country, the total area does not always add up to 100% which means that data is partly unavailable. However, it is safe to assume that most the area planted to varieties of unknown earliness traits is in the category medium or late. This is because early-maturing is a trait which need to be bred for and thus should be identifiable in currently adopted varieties.

Most dominating varieties

The 15 dominating varieties in our study region cover 58% of the total potato area in 2015. We summarize these in Table 15. Ranking first, the Chinese variety Kexin No.1 covers alone almost 10% (0.7Mha) of the total area. Compared with 2007, Kexin No.1 remains the most adopted potato varieties in the region (Thiele, et al., 2008). The Indian early-maturing variety, Kufri Pukhraj, made a large jump from rank 17 in 2007 to rank 2 in 2015. Now it covers about 7% (0.51Mha) of the total area. Other varieties, such as Favorita, Hui-2, Cardinal, and Zhuangshu No.2 have also gained in importance. Whereas Kufri Jyoti and Kufri Bahar lose in importance.

The ten most important NARS-CIP varieties all together cover 74% of the total NARS-CIP area and 14% of the total potato area (Table 16). Cooperation 88 is the most important NARS-CIP late blight resistant variety covering 164,328ha. E-potato No.5 and Longshu No.3 closely follow with 155,200ha and 149,280ha, respectively. In the overall picture, these rank 11, 12, and 13. Nine out of ten NARS-CIP varieties were bred in China. Only Kufri Chipsona 1, an Indian variety used for processing is in the top ten ranking seventh from being 37 in 2007. Interestingly, apart from Longshu No.3, all NARS-CIP varieties have in increasing trend.

Table 15. Fifteen most cultivated varieties

Rank 2015	Country	Variety Name	Source	Estimated area	Share of total (%)	Rank 2007	Trend
1	China	Kexin No. 1	NARS-developing	716,297	9.4%	1	=
2	India	Kufri Pukhraj	NARS-developing	521,376	6.8%	17	↑
3	China	Favorita	NARS-developed	489,879	6.4%	12	↑
4	China	Mira	NARS-developed	430,502	5.6%	4	=
5	India, Nepal	Kufri Jyoti	NARS-developing	343,810	4.5%	3	↓
6	India	Kufri Bahar	NARS-developing	272,642	3.6%	2	↓
7	China	Weiyu No.3	NARS-developing	271,111	3.5%	11	↓
8	China	Hui-2	NARS-developing	262,107	3.4%	9	↑
9	Bangladesh, India, Nepal, Pakistan	Cardinal	NARS-developed	184,698	2.4%	25	↑
10	China	Zhuangshu No.3	NARS-developing	167,880	2.2%	..	↑
11	China	Cooperation 88	NARS-CIP	164,328	2.2%	13	↑
12	China	E-potato No.5	NARS-CIP	155,200	2.1%	..	↑
13	China	Longshu No.3	NARS-CIP	149,280	2.0%	7	↓
14	Bangladesh, Pakistan	Asterix	NARS-developed	147,871	2.0%	..	↑
15	Bangladesh, India, Pakistan, Vietnam	Diamant	NARS-developed	138,231	1.9%	5	↓

Table 16. Ten most cultivated NARS-CIP varieties

Rank 2015	Country	Variety name	Type	Estimated area	Share of NARS-CIP total	Rank 2007	Trend
1	China	Cooperation 88	Crosses	164,328	11%	13	↑
2	China	E-potato No.5	Crosses	155,200	11%	..	↑
3	China	Longshu No.3	Progenitor	149,280	10%	7	↓
4	China	Xuanshu No.2	Progenitor	137,417	10%	..	↑
5	China	Tacna	Crosses	133,215	9%	..	↑
6	China	Unica	Crosses	121,936	9%	..	↑
7	India	Kufri Chipsona 1	Progenitor	60,840	4%	37	↑
8	China	Zhongshu No.3	Progenitor	52,627	4%	..	↑
9	China	Chuanyu 117	Crosses	50,863	4%	..	↑
10	China	Lishu No.6	Crosses	40,196	3%	..	↑

Source: SIAC survey and Thiele et al. (2008)

Direct and indirect CIP beneficiaries

Rather than measuring CIP's impact in terms of area, the number of beneficiaries reached is most important. In this section, we provide a crude measure for direct and indirect beneficiaries reached by CIP/with CIP material. Direct beneficiaries estimates are based on total NARS-CIP area (in ha) elicited through expert elicitation workshops and secondary data on average area planted to potato by country. Indirect beneficiaries are estimates further considering average HHs sizes by country. Table 17 summarizes our findings.

In our study region, a total of 15.3M farming households (direct beneficiaries) are cultivating 7.65Mha of potatoes in 2015, of which 14.5M households make use of improved varieties. Regarding CIP's impact, 2.93M beneficiaries have been reached with CIP-related varieties. Most of the direct beneficiaries have been reached in China (2.5M), India (0.2M), and Nepal (0.14M). In other countries, like Vietnam, Bangladesh, Indonesia, and Pakistan only a few people have been reached. The number of indirect beneficiaries reached by CIP is 10.3M individuals.

Table 17. Estimation number of direct and indirect beneficiaries

Country	Direct Beneficiaries (HHs)			Indirect Beneficiaries (HH members)		
	Total	**of IVs**	**of CIP-related varieties**	**Total**	**of IVs**	**of CIP-related varieties**
Bangladesh	1,704,120	1,414,420	2,808	7,668,540	6,364,890	12,636
China*	9,616,703	9,616,703	2,572,873	31,735,121	31,735,121	8,490,481
India**	3,113,847	2,712,355	201,758	14,946,466	13,019,306	968,439
Indonesia	75,772	73,499	2,304	295,511	286,646	8,986
Nepal	410,000	336,200	139,452	2,000,800	1,640,656	680,526
Pakistan	257,109	257,109		1,799,765	1,799,765	
Vietnam	125,005	125,005	9,825	487,520	487,520	38,318
Total	**15.30M**	**14.54M**	**2.93M**	**58.93M**	**55.33M**	**10.20M**

Notes: *for 12 Provinces; **for 6 States.
Source: own calculation based on SIAC area estimates and various experts. Average farm and household size based on Lowder et al. (2016). Detailed information available upon request.

Discussion and conclusions

General

In close collaboration with NARS, international agricultural research centers 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 239% to reach 491 in the Post GR. Most of the contribution, however, stems from Chinese NARS considerable breeding efforts. Of those total releases about 40% have found their way onto the farmers' fields. In Nepal and Vietnam, adoption rates are close to 100%, in China it is 62% and, strikingly, in Bangladesh it is only 7%. It seems that in Bangladesh many resources are allocated to the development of new varieties but that the delivery systems are rather ineffective.

In the wake of an increasing prevalence of abiotic and biotic stresses, we find that changing breeding objectives resulted in substantial releases of high-resistant varieties since 2000. On average, more emphasis has been placed on biotic than abiotic traits. We further find that all combinations of 10 abiotic and biotic traits (2 traits per variety), and 3 different traits per variety are available. However, there are regional differences. In China and India, for instance, high resistances against almost all major stresses can be found. In the other countries in our study region, less than half of the 10 major traits are bred into a high resistant variety, making these vulnerable to the immediate effects of climate change. In particular, Indonesia, Nepal, and Pakistan have not released a single high resistant variety with an abiotic trait.

In 2015, the potato area in our study region was 7.65Mha. An incredible 97% of the area is planted to improved varieties. The area increased by 11% compared to 2007. Between 1997 and 2007, the area increased by 27% which means that expansion has slowed down. Nevertheless, between 1997 and 2015, share of area planted to IVs increased by 4%. Whereas IVs are generally widely adopted, in Bangladesh and Nepal adoption of IVs are about 80% each. For Bangladesh, this again points at the (1) importance of landraces and (2) the relative weakness in disseminating IVs.

In terms of traits, leafcurl, Y-virus, and drought are the most important resistances to be found in adopted varieties. However, in total none of these exceed adoption rates of more than 20%. This may not pose a problem because the prevalence of abiotic and biotic stresses is context-specific. It is troublesome that in Nepal, Pakistan, and Vietnam, almost no area is planted to varieties with abiotic high resistances, which is in line with the release data. Secondly, in total, about 30% of adopted varieties are susceptible to late blight and bacterial wilt.

To facilitate the process towards more sustainable intensification, earliness is a required trait which allows the variety to bulk within 75-90 days. Especially in rice-dominating countries, intensification with potato could diversify diets and create additional incomes. In 2015, only 12% of the total area is cultivated with early-bulkers. In China, the highest share of early-maturing varieties can be found covering about 15% of the area. In other countries, such as Bangladesh, India, and Vietnam, where sustainable intensification has huge potential, only 2-6% of the area is planted to early-bulkers.

The 15 most important varieties cover about 58% of the total area. Kexin No.1, released in China in 1967, ranks number 1 with about 10% of the total area. Kufri Pukhraj, released in India in 1998, is the second most important variety covering about 7% of the total area. All of 10 varieties are older than 10 years, most of them are released 20-30 years ago. Compared with more recent releases, these varieties have weaker resistances to abiotic and biotic stresses. To analyze the determinants of adoption in spite of availability of better varieties, could be an interesting avenue for future research.

Impact of CIP

As part of international agricultural research centers, by 2015 CIP has contributed to the development of 168 IVs which is 34% of the total releases. 30% (63 IVs) of the released varieties have resulted in adoptions. In general, CIP-related releases and adoptions follow a similar increasing trend compared to the overall trend. In China, 105 released varieties are CIP-related. In Bangladesh, 16 CIP-related varieties have been released and only 2 have been adopted. In Pakistan, CIP has not had much impact in terms of varietal release and adoption. Only one released variety which was not adopted.

About 51% of the total CIP-material used was selected from CIP-crosses and 46% was selected from CIP-progenitors. Only in 1% of the cases, CIP played a role in facilitating the release of varieties of third parties. Compared with CIP-progenitors, all countries utilize CIP-crosses making these overall more popular. CIP-progenitors are only used by China, Indonesia, and India.

In terms of area, CIP-related varieties are planted to about 1.43Mha which is about 19% of the total area. In China, 25% of the total potato area is planted to CIP-related varieties (1.24Mha). In Nepal, CIP has made much impact as well. Here, 34% 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 Pakistan.

Regarding the ten most important CIP-related varieties, nine out of ten varieties are cultivated in China. Cooperation 88, released in China in 2001, covers about 165,000ha and is the most important CIP-related variety. Kufri Chipsona, released in India in 1998, covers 61,000ha. Compared to 2007, almost all CIP-related varieties are increasing in trend, especially Chipsona 1, which jumped from rank 37 to 7. Further research could analyze the adoption determinants of this varieties to better understand why certain varieties are successful and others not.

In terms of beneficiaries, overall CIP directly reached 2.93M farming HHs with CIP-related material. Indirectly, CIP was able to reach about 10.3M individuals.

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	Release		Adoption	
	(No)	(%)	(No)	(%)
Chongqing	6	2%	4	4%
Gansu	36	14%	17	17%
Guangxi	21	8%	10	10%
Guizhou	26	10%	7	7%
Hebei	4	2%	4	4%
Heilongjiang	30	12%	9	9%
Inner Mongolia	9	4%	5	5%
Ningxia	7	3%	1	1%
Shaanxi	6	2%	6	6%
Shanxi	22	9%	8	8%
Sichuan	35	14%	17	17%
Yunnan	52	20%	12	12%
Total	**254**	**100%**	**100**	**100%**

Appendix Table 2. Varietal release and adoption until 2015 by Chinese Provinces and release classification

Province	NARS-CIP				NARS-developing				NARS-developed			
	Release	(%)	Adopt.	(%)	Release	(%)%	Adopt.	(%)	Release	(%)	Adopt.	(%)
Chongqing	4	4%	2	6%	1	1%	1	2%	1		1	
Gansu	5	5%	3	9%	31	22%	14	23%				
Guangxi	9	9%	4	11%	10	7%	4	7%	2	40%	2	50%
Guizhou	5	5%	2	6%	21	15%	5	8%				
Hebei	1	1%	1	3%	3	2%	3	5%				
Heilongjiang	5	5%	2	6%	25	18%	7	11%				
Inner Mongolia	3	3%	2	6%	3	2%	1	2%	3	60%	2	50%
Ningxia	3	3%			3	2%	1	2%				
Shaanxi	1	1%	1	3%	5	4%	5	8%				
Shanxi	6	6%	2	6%	16	11%	6	10%				
Sichuan	22	21%	9	26%	13	9%	8	13%				
Yunnan	41	39%	7	20%	11	8%	5	8%				
Total	**105**	**100%**	**35**	**100%**	**141**	**100%**	**61**	**100%**	**5**	**100%**	**4**	**100%**

Notes: *for 12 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.

Appendix Table 3. Area and share of improved area by region in China and India

Country	Area (ha)	Improved (ha)	Improved (%)	NARS-CIP (%)
China				
Chongqing	346,653	346,653	100%	40%
Gansu	708,324	708,324	100%	25%
Guangxi	54,667	54,667	100%	32%
Guizhou	700,000	700,000	100%	22%
Hebei	200,000	200,000	100%	45%
Heilongjiang	253,333	253,333	100%	16%
Inner Mongolia	566,667	566,667	100%	7%
Ningxia	177,333	177,333	100%	33%
Shaanxi	386,631	386,631	100%	10%
Shanxi	200,000	200,000	100%	42%
Sichuan	789,334	789,334	100%	23%
Yunnan	586,627	586,627	100%	39%
Total	**4,969,569**	**4,969,569**	100%	
India				
Bihar	314,837	194,526	62%	10%
Gujarat	112,400	112,400	100%	0%
Karnataka	41,500	41,500	100%	1%
Punjab	90,000	90,000	100%	1%
Uttar Pradesh	607,000	607,000	100%	13%
West Bengal	411,219	411,037	100%	2%
Total	**1,576,956**	**1,456,463**	**92%**	

Appendix Table 4. Share of improved varieties planted to NARS-CIP area by trait and earliness

Country	Bangladesh	China	India	Indonesia	Nepal	Pakistan	Vietnam	Total
NARS-CIP area (ha)	702	1.2M	109,263	2,304	69,726		1,965	1.43M
High resistant traits								
Drought	50%	24%						21%
Frost		4%						3%
Heat		18%	1%				10%	16%
Late Blight	50%	19%	17%	18%	17%		26%	18%
Bacterial wilt		26%						23%
X-virus		44%			1%			38%
Y-virus		43%			1%		1%	38%
S-virus		15%						13%
Leafcurl		36%			14%			32%
Nematode		15%						13%
Earliness								
Early		10%	1%				31%	9%
Medium	100%	13%	78%	100%	1%		11%	17%
Late		22%			58%			22%

Appendix Table 5. List of most important and NARS-CIP varieties

Rank 2015	Country	Variety Name	Source	Estimated area	Rank 2007	Trend*
1	China	Kexin No. 1	NARS-developing	716,297	1	=
2	India	Kufri Pukhraj	NARS-developing	521,376	17	↑
3	China	Favorita	NARS-developed	489,879	12	↑
4	China	Mira	NARS-developed	430,502	4	=
5	India, Nepal	Kufri Jyoti	NARS-developing	343,810	3	↓
6	India	Kufri Bahar	NARS-developing	272,642	2	↓
7	China	Weiyu No.3	NARS-developing	271,111	11	↓
8	China	Hui-2	NARS-developing	262,107	9	↑
9	Bangladesh, India, Nepal, Pakistan	Cardinal	NARS-developed	184,698	25	↑
10	China	Zhuangshu No.3	NARS-developing	167,880	..	↑
11	China	Cooperation 88	NARS-CIP	164,328	13	↑
12	China	E-potato No.5	NARS-CIP	155,200	..	↑
13	China	Longshu No.3	NARS-CIP	149,280	7	↓
14	Bangladesh, Pakistan	Asterix	NARS-developed	147,871	..	↑
15	Bangladesh, India, Pakistan, Vietnam	Diamant	NARS-developed	138,231	5	↓
16	China	Xuanshu No.2	NARS-CIP	137,417	..	↑
17	China	Tacna	NARS-CIP	133,215	..	↑
18	China	Unica	NARS-CIP	121,936	..	↑
19	China	Zaodabai	NARS-developing	89,300	..	↑
20	China, India, Indonesia, Vietnam	Atlantic	NARS-developed	78,350	..	↑
21	Pakistan	Sante (white)	NARS-developed	75,539	..	↑
22	India	Bhura Aloo	NARS-developing	70,539	..	↑
23	China	Chuanyu 56	NARS-developing	66,833	20	↓
24	Indonesia	Granola L.	NARS-developed	62,708	24	=
25	China, India	Shepody	NARS-developed	62,432	..	↑
26	India	Kufri Chipsona 1	NARS-CIP	60,840	37	↑
27	China	Kexin No.13	NARS-developing	58,267	..	↑
28	China	Zhongshu No.3	NARS-CIP	52,627	..	↑
29	India, Pakistan	Kuroda	NARS-developed	50,965	..	↑
30	China	Chuanyu 117	NARS-CIP	50,863	..	↑
38	China	Lishu No.6	NARS-CIP	40,196	..	↑
39	China	Zhongshu No.5	NARS-CIP	38,707	..	↑
41	Nepal	Janakdev	NARS-CIP	37,914	..	↑
48	China	Chuanyu No.5	NARS-CIP	31,227	22	↓
53	India	Kufri Chipsona 3	NARS-CIP	24,758	..	↑
56	China	Xingjia No.2	NARS-CIP	23,800	..	↑

Rank 2015	Country	Variety Name	Source	Estimated area	Rank 2007	Trend*
58	China	Jinshu No.16	NARS-CIP	22,833	..	↑
60	China	Tongshu No.23	NARS-CIP	22,000	..	↑
62	India	P2	NARS-CIP	18,340	..	↑
67	China	Kangqing 9-1	NARS-CIP	15,400	202	↑
68	China	Youjin	NARS-CIP	15,200	..	↑
71	China	Zhongshu No.2	NARS-CIP	12,987	70	↓
74	China	Khumal Rato-2	NARS-CIP	11,643	120	↑
76	China	E-potato No.3	NARS-CIP	11,017	..	↑
81	China	Khumal Seto 1	NARS-CIP	9,703	96	↑
92	China	Chuanyu 39	NARS-CIP	6,837	195	↑
92	China	Chuanyu No.6	NARS-CIP	6,837	97	↑
94	China	Chuanyu No.10	NARS-CIP	6,737	194	↑
97	China	Dianshu No.6	NARS-CIP	6,611	159	↑
103	Nepal	TPS	NARS-CIP	6,015	..	↑
109	China	Qianyu No.6	NARS-CIP	5,000	..	↑
112	India	Yusikap	NARS-CIP	4,040	237	↑
113	China	Kunshu No.2	NARS-CIP	3,989	..	↑
128	China	Yunshu 401	NARS-CIP	2,644	..	↑
129	China	Dongnong 311	NARS-CIP	2,533	..	↑
132	Nepal	Khumal Laxmi	NARS-CIP	2,273	..	↑
135	China	Cooperation 23	NARS-CIP	1,983	..	↑
138	China	Mengshu 13	NARS-CIP	1,640	..	↑
140	China	Jingshu No.1	NARS-CIP	1,328	..	↑
142	India	Kufri Surya	NARS-CIP	1,235	..	↑
146	China	Tongshu No.20	NARS-CIP	1,000	..	↑
148	China	Minshu No.4	NARS-CIP	950	..	↑
149	Nepal	MS-42-3	NARS-CIP	938	..	↑
150	Nepal	Khumal Upahar	NARS-CIP	815	..	↑
152	China	Zhongshu No.18	NARS-CIP	702	..	↑
153	Indonesia	Tenggo	NARS-CIP	684	..	↑
157	Vietnam	O7	NARS-CIP	625	..	↑
158	Vietnam	KT3	NARS-CIP	606	190	↑
163	Vietnam	PO3	NARS-CIP	513	..	↑
165	Nepal	Khumal Ujjwal	NARS-CIP	426	..	↑
166	Indonesia	Dea	NARS-CIP	405	..	↑
167	Indonesia	Andina	NARS-CIP	405	..	↑
168	Indonesia	Medians	NARS-CIP	405	..	↑

Rank 2015	Country	Variety Name	Source	Estimated area	Rank 2007	Trend*
169	Indonesia	Repita	NARS-CIP	405	..	↑
173	Bangladesh	LB 7	NARS-CIP	351	..	↑
174	Bangladesh	LB 6	NARS-CIP	351	..	↑
177	Vietnam	KT2	NARS-CIP	202	226	↑
182	India	Kufri Himalini	NARS-CIP	50	..	↑
183	Vietnam	KT1	NARS-CIP	20	..	↑

Note: *trend in comparison to 2007.

Appendix 2. Expert-level Data Collection Instrument

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%	