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REVIEW ARTICLE

Potato Genetic Resources and their Utilization in India

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Abstract

In India, ICAR-Central Potato Research Institute, Shimla presently holds a modest collection of over 4,669 accessions, comprising cultivated species, parental lines, indigenous varieties, advanced clones and wild/semi-wild tuber-bearing *Solanum* species. This is the largest potato collection in South Asia. The exotic *tubersoum*, *andigena* and wild species germplasm accessions have been imported from 40 countries based on requirements of resistance or tolerance to various biotic and abiotic stresses. Potato germplasm has been evaluated against several diseases and insect pests and also for morphological and yield traits. Donors have been identified against all the major diseases; some are resistant to two to three diseases. The utilization of indigenous and exotic genetic resources has resulted in the development and release of 70 indigenous potato varieties suitable for different agro-ecologies and 46 elite genetic stocks have been registered with ICAR-National Bureau of Plant Genetic Resources (NBPGR). This paper reviews the status of potato genetic resources and their utilization in India.

Keywords: Genetic stocks, Genetic resources, Potato, Utilization, Varieties.

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Introduction

Potato (*Solanum tuberosum* L.) is the most important non-grain food crop globally and is the most important crop for ensuring food security for developing countries, and a highly nutritious food providing more calories, vitamins and nutrients than any other staple food. Wide genetic resources are a high priority for any crop improvement program. Genetic resources are a collection of the large number of genotypes representing the genetic diversity of a crop species and its wild relatives. Genetic diversity is essential for crop improvement and maintaining the agro-ecosystem functioning. In the present climate change scenario, potato is an important crop for food and nutritional security. The long historical period of varietal development from its ancestors' native cultivars to modern, present-day potato varieties has become the treasure of potatoes. The centers of origin of crop species are the richest source of genetic diversity. Prof. S. M. Bukasov and his co-workers were the first to explore the centres of diversity of tuber-bearing *Solanum* species during 1925-26 and in subsequent years to collect from remote and non-accessible areas the old land races, and primitive and wild species. In later years, explorations were carried out by scientists from other countries as well and valuable genetic material was collected. The International Potato Centre (CIP), Lima, Peru, a CGIAR institute, holds the largest potato germplasm collection. Other important collections are available with N.I. Vavilov Institute of Plant Industry, St. Petersburg, Russia; United States Potato Introduction Project (NRSP-6), Sturgeon-Bay, Wisconsin, USA; Dutch German Potato Collection (CGN), Wageningen, the Netherlands; Leibniz Institute of Plant Genetics and Crop Plant Research (IPK),

Table 1: Indigenous and exotic potato varieties in India (Pushkarnath, 1969)

Indigenous varieties	*Exotic varieties*
Chamba Red, Coonoor White, Coonoor Red, Darjeeling Red Round, Desi, Dhantauri, Gola Type A, Gola Type B, Gola Type C, Phulwa, Phulwa Purple Splashed, Red Long Kidney, Sathoo, Shan and Silbilati	Ally, Arran Counsal, Ben Cruachan, Craig's Defiance, Dunbar Cavalier, Great Scot, Italian White Round, Late Carman, Magnum Bonum, Majestic, Northern Star, President, Raeburn's Gregor Cups, Red Rock, Royal Kidney and Upto-Date

Germany; Commonwealth Potato Collection (CPC) and Scottish Crop Research Institute (SCRI now the James Hutton Institute-JHI), Dundee, Scotland.

The total gene pool available for research and breeding purposes can be classified into five distinct classes, *viz*., i) present and past commercial varieties, ii) breeding lines and genetic stocks in breeding programs, iii) old land races, iv) primitive edible wild species and their hybrids, and v) wild species. The wild and primitive species are valuable for their resistance to a wide range of biotic and abiotic stresses. Landraces possess quality characteristics and varieties and hybrids are important because of their adaptation and agronomic characteristics. This paper reviews the status of potato genetic resources and their utilization in India.

Potatoes in India

The potato was believed to be introduced in India towards the beginning of the 17th century, most probably by Portuguese traders or British missionaries (Pushkarnath, 1976). The early history of the potato in India is obscure till the mid 18th century. From 1830 onwards, the potato has a history as a commercially grown crop in India. The earliest potato introduction in India resembled subsp. *andigena* were adapted to short days, had long dormancy and could withstand high temperatures in country stores. These were known by different names in local dialects depicting some character, *viz*., *Phulwa*-flowering in the plains, *Gola*-round potatoes, *Satha*-maturing in 60 days, etc. Between 1924 and the end of World War II, a large number of European varieties were introduced into India for adaptability. These, however, failed to make an impact as potato is grown in India in conditions very different from those in Europe.

Potato Germplasm Collections in India

In India, the first attempt to collect indigenous variability of potatoes was made in the 1940's. About 400 samples were collected from different parts of the country. Within this mass of variability, 16 varieties were identified as known exotic cultivars, while the rest were grouped into 16 distinct morphotypes whose original identity could not be established (Pal and Pushkarnath, 1951; Pushkarnath, 1969) (Table 1). These cultivars represented some of the earliest introductions and their clonal variants and were termed *desi* varieties. Morphologically, these varieties resembled subsp. *andigena*. Among indigenous varieties, Phulwa, Darjeeling Red Round and Gola were popular in the plains, whereas European varieties Craig's Defiance, Great Scot, Up-to-Date and Magnum Bonum were popular in the hills.

After the establishment of the Central Potato Research Institute (CPRI now ICAR-CPRI) in 1949, the collection, conservation, evaluation and documentation of potato germplasm and its utilization became a regular activity. Acquisition of exotic germplasm from different countries continued. This activity was accelerated after the establishment of the International Potato Centre (CIP) in Lima, Peru in 1972. Over a period of time, however, some of the old indigenous collections got riddled with viruses and were lost. Surveys were conducted from 1983 to 1992 in Uttar Pradesh, Bihar, West Bengal, Assam, Meghalaya, and Himachal Pradesh to retrieve these and any other variability not available in the collection. In all 621 samples were collected, studied for various morphological characters and grouped into 125 morphotypes. In India, the ICAR-CPRI presently holds a modest collection of over 4,669 accessions, comprising cultivated species (subsp. *tuberosum* and *andigena*), parental lines, indigenous varieties, advanced clones and wild/semi-wild tuber-bearing *Solanum* species (Table 2). This is the largest potato collection in South Asia. The exotic *tubersoum*, *andigena*, and wild species' germplasm accessions have been imported from 40 countries based on our requirements of resistance or tolerance to various biotic and abiotic stresses. The major source of this collection has been the International Potato Center (CIP), Lima, Peru and the USA Potato Gene bank, Sturgeon Bay, Wisconsin. Before the establishment of the CIP, potato germplasm was largely imported from the Commonwealth Potato Collection, Dundee, Scotland. Nearly 42% (1946 accessions) of genetic resources have been acquired from the International Potato centre Lima Peru (Figure 1). At present CIP holds nearly 7490 accessions comprising 4894 cultivated and 2596 wild relatives and it reflects the availability of nearly 26% CIP germplasm in India. The institute, at present, has in its collection about 540 accessions of 125 wild species consisting of diploids, triploids, tetraploids, pentaploids and hexaploids.

Conservation

At ICAR-CPRI, the available germplasm is maintained by *in-vivo* clonal propagation, *in-vitro* clonal propagation, and sexual propagation.

Field gene bank or in-vivo clonal propagation

The germplasm is maintained through clonal propagation in glasshouses at Shimla and as duplicate sets in fields at Kufri and Jalandhar. All *S. tuberosum* subsp. *tuberosum* and a part

Table 2: Potato germplasm holding at ICAR-CPRI, Shimla

Material	*No. of accessions*				*No. of donor countries*
	Tuber	*In-vitro*	*True seed*	*Total*	
a) Tuberosum (Cultivars / parental lines)					
Indian					
Cultivars bred at CPRI	56	60		63	
Advanced hybrids	86	50	-	96	
Indigenous varieties	51	107	-	107	
Indigenous samples	97	42		97	
Exotic	1837	2754	-	3004	30
b) Andigena	701	77	-	762	5
c) Wild/ semi-cultivated sps.	119 (40 species)	130 (29 species)	294 (70 species)	540 (125 species)	5
Total germplasm				4669	

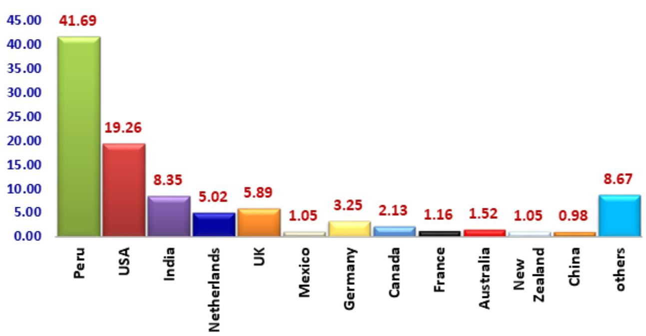

Figure 1: Country wise collection of potato germplasm at ICAR-CPRI, Shimlav

of subsp. *andigena* accessions are maintained and multiplied to facilitate their evaluation for adaptability to different agro-climatic regions as well as for resistance/tolerance to various biotic/abiotic stresses. This is the traditional method of conservation and germplasm are exposed to viral and mycoplasmal diseases, resulting in the degeneration of germplasm stocks. Loss of material due to natural calamities and loss of correct identity due to mechanical mixtures or wrong labeling are the other risks associated with this method. Labor and maintenance costs are also high.

True potato seed or sexual propagation

True potato seeds (botanical seeds) produced through sexual propagation are easy to produce and maintain in disease-free conditions. The wild and semi-cultivated potato species are presently maintained in true seed form. True seeds are produced by selfing and/or sib-mating. Sib-mating is often resorted to in diploid species most of which are self-incompatible. True seeds for short-term storage are maintained at 10 to 15°C at ICAR-CPRI and long-term storage at the National Genebank, ICAR-National Bureau of Plant Genetic Resources, New Delhi. Preservation of germplasm as true seed is less laborious and inexpensive as moisture content is low and can be kept at low temperatures for many years. In addition, it is easier to maintain the material free of pathogens as only a few viruses are known to be seed-transmitted.

In-vitro conservation

The ability of plants to grow under aseptic conditions has resulted in the development of *in-vitro* techniques for germplasm conservation. By this technique, nodal cuttings are micropropagated on MS media containing 40 g/litre sucrose and 20 g/litre mannitol. Plantlets are incubated under 16 hours photoperiod at 5 to 6°C. Under these conditions, potato plantlets can be preserved for up to 30 months without sub-culturing. This method has several advantages, *viz*., a) maintenance round the year in disease conditions, b) safety from natural calamities, c) the possibility of conserving the large number of genotypes in limited space, and d) easy exchange in *in-vitro* form. Presently, more than 3,200 accessions are conserved in this form. The disadvantage is that growth retardants may alter plant morphology and induce DNA methylation (Harding, 1994) and somaclonal variation (Kumar, 1994).

Cryo-preservation

This is the best method for long-term conservation of vegetatively propagated plants. By this method, plant material is frozen at an ultra-low temperature of around -196°C in liquid nitrogen. This technique was derived from the observations that plant species could survive below freezing temperatures in temperate areas. At ultra-low temperatures, cell division metabolic and biochemical processes are arrested; thus, the plant material can be stored without deterioration or modification for a long period. Tissues can be stored virtually indefinitely with low labor costs and little space. Work input is needed mainly at the beginning when samples are prepared and cooled. Once in storage, only refilling of liquid nitrogen is needed. Other advantages are the prevention of infections and genetic changes. Further, the cleanliness degree is higher for cryopreserved explants than *in-vitro* and field cultures. Cryopreservation is only useful for long-term storage

Table 3: Wild species as sources of resistance to various diseases

Diseases	*Sources*
Viruses - PVX	*S. acaule, S. berthaultii, S. brevicaule, S. chacoense, S. commersonii, S. curtilobum, S. phureja, S. sparsipilum, S. sucrense, S. tarijense and S. tuberosum* ssp. *andigena*
PVY	*S. acaule, S. chacoense, S. demissum, S. gourlayi, S. phureja, S. rybinii, S. stoloniferum, S. tuberosum* ssp. *andigena*
PLRV	*S. acaule, S. brevidens, S. chacoense, S. demissum, S. etuberosum, S. raphanifolium, S. stolonifrum and S. tuberosum* ssp. *andigena*
Late blight- Vertical	*S. cardiophyllum, S.demissum, S. ediense, S. stoloniferum* and *S. verrucosum*
Horizontal	*S. berthaultii, S. bulbocastanum, S. chacoense, S. circaeifolium, S. demissum, S. microdontum, S. phureja, S. pinnatisectum, S. polyadenium, S. stoloniferum, S. tarijense, S. tuberosum* ssp. *andigena, S. vernei* and *S. verrucosum*
Wart	*S. acaule, S. berthaultii*
Common scab	*S. chacoense, S. tuberosum* ssp. *andigena*
Bacterial wilt	*S. chacoense,S. microdontum, S. phureja, S. sparsipilum and S. stenotomum*
Cyst nematodes	*S. acaule, S. berthaulti , S. boliviense, S. bulbocastanum, S. capsicibaccatum, S. cardiophyllum, S. demissum, S. gourlayi, S. kurtzianum, S. leptophyes, S. multidissectum, S. oplocense, S. sparsipilum, S. spegazzinii, S. sucrense, S. tuberosum* ssp. *andigena* and *S. vernei*
Root knot nematode	*S. bulbocastanum, S. cardiophyllum, S. chacoense, S. curtilobum, S. hjertingii, S. kurtzianum, S. microdontum, S. phureja, S. sparsipilum* and *S. tuberosum* ssp. *andigena*
Aphids	*S. berthaultii, S. bukasovii. S. bulbocastanum, S. chomatophilum, S. infundibuliforme, S. lignicaule, S. marinasense, S. medians, S. multidissectum, S. neocardenasii,and S. stoloniferum*
Frost	*S. acaule, S. ajanhuiri*
Heat and drought	*S. acaule, S. bulbocastanum, S. chacoense, S. commersonii, S. gourlayi, S. megistacrolobum, S .microdontum, S. ochoae, S. papita, S. pinnatisectum, S. spegazzinii* and *S. tarijense*
High protein content	*S. phureja* and *S. vernei*

because the material is normally not ready for immediate utilization and re-warming and growth of plant material takes some time.

Evaluation

To make the best use of genetic resources in breeding programmes, it is necessary to have sufficient description and evaluation data on desirable as well as undesirable traits in a gene pool. Where such information is unavailable, passport data on characteristics of species' natural habitats are of great importance. For example, late blight-resistant species are found in the Mexican gene pool, where late blight fungus (*Phytophthora infestans*) has been found to reproduce sexually. Similarly, frost resistance is found in species capable of growing at altitudes above 3,500 meters. Some important sources of resistance to major potato diseases, pests, and abiotic stresses are listed in Table 3.

In the early stages of potato research in India, large numbers of European varieties were evaluated to identify cultivars adapted to temperate long-day conditions (hills) and sub-tropical short-day conditions (plains). Simultaneously, attention was paid to identifying suitable parental lines for Indian potato breeding program (Table 4). The germplasm accessions were thus evaluated for economic characters like adaptability (Luthra *et al*. 2008a, 2009a), resistance to late blight (Singh *et al.* 2001b; Kumar *et al*. 2005a, 2005b; Srivastava *et al*. 2012; Lal *et al*. 2013, 2018; Gujar *et al*. 2016; Luthra *et al*. 2018b), bacterial wilt (Upadhya *et al*. 1976; Chakrabarti *et al*. 1992; Nagesh *et al*. 1993; Gadewar *et al*. 2003), wart (Singh and Gopal, 1990, 1994; CPRI 2003-04), nematodes (CPRI 1983, CPRI 2003-04), potato tuber moth (CPRI 1992-93; CPRI 2003-04; Chandla *et al*. 2007), powdery scab (Dutt and Pushkarnath, 1960), charcoal rot (Paharia *et al*. 1962; Upadhya *et al*. 1977; Somani, 2008), hopper burn (Chaudhary *et al*. 1983; Malik and Luthra, 2007, Luthra *et al*. 2013), viruses (Garg and Gopal, 1994; Singh *et al.* 2001a), stem necrosis (Khurana 1997, Singh *et al.* 1998; Garg *et.al.* 1999; Singh and Khurana, 2005; Somani, 2009), tuber dormancy (Joseph and Gopal, 1994; Luthra and Gopal, 1999; Luthra *et al*. 2003b), tuber dry matter and protein content (Gaur and Gupta, 1981; Gaur and Rana, 1982), nutrition (Luthra *et al*. 2018b), keeping quality (Gupta *et al.* 2015, Luthra *et al*. 2018c), early planting (Luthra *et al*. 2003a, Malik and Luthra, 2007, Luthra *et al*. 2013), foliage maturity (Kumar *et al.* 2005c), processing attributes (Marwaha *et al.* 2002; Gupta *et al*. 2014; Luthra *et al*. 2018b), cold sweetening (Pandey *et al.* 2005, Luthra *et al.* 2009b), frost tolerance (Luthra *et al*. 2007, 2008b) etc.

The germplasm accessions have been studied for flowering and fruiting behavior (Gopal, 1994; Kumar *et al.* 2005c) and true potato seed (TPS) attributes (Luthra *et al.* 2000, Kumar and Gopal, 2003b). These have also been characterized for morphological traits like tuber skin color,

Table 4: Some promising potato accessions having multiple-resistance

CP numbers	*Variety*	*Characters*
CP1363	AG-16 (X143) (USA)	Early maturity, resistance to late blight (tuber), good keeper, medium dry matter, good chipping quality, resistance to common scab.
CP1402	Bea (Netherlands)	Early maturity, adapted to plains, moderately resistant to late blight (foliage to tuber), immune to wart, resistance to PVX, resistance to stem necrosis, resistance to PVA, tolerance to heat.
CP1410	Gineke (Netherlands)	Immune to wart, highly resistant to stem necrosis, good chipping quality, medium dry matter, resistant to common scab, resistant to PVA, and tolerant to drought.
CP1447	Conchita (United Kingdom)	Highly resistant to late blight, resistance to PVX & PVY, resistance to *Globodera pallida*.
CP1461	Sieglinde (Germany)	Moderately resistant to PVX & PVY, resistance to *Globodera pallida*. Moderately resistant to late blight, highly resistant to stem necrosis, good keeper.
CP1474	Duquesa (Spain)	Medium maturity, resistance to late blight (foliage & tuber), resistance to PVX & PVY, immune to wart, good keeper.
CP1588	Cosima (Germany)	Adapted to normal & early planting to plains, resistance to late blight (foliage), moderately resistant to hopper burn & mites, good keeper.
CP1604	B5052-7 (USA)	Adapted to plains, resistance to late blight (foliage & tuber), immune to wart, moderately resistant to charcoal rot, resistance to PVX & PVY, resistance to ring rot, moderately resistant to common scab, resistance to stem necrosis.
CP1664	Royal Kidney (United Kingdom)	Adapted to plains, resistance to late blight (foliage & tuber), immune to wart, resistance to PVX & PVY, resistance to both spp of cyst nematodes
CP1673	Dr. McIntosh (Irelands)	Early maturity, adapted to hills and plains, resistance to late blight (foliage & tuber), moderately resistant to stem necrosis, immune to PVA, good keeper.
CP1690	Irish Cobbler (Canada)	Adapted to hills & plains, resistance to late blight (foliage & tubers), moderately resistant to stem necrosis, good keeper.
CP1729	La 1106-5 (USA)	Adapted to plains, resistant to late blight (foliage & tuber), resistant to cyst nematodes (both Spp.), good keeper.
CP1798	316.1 (USA)	Resistance to late blight (foliage to tuber), immune to wart, resistance to PVX, good chipping quality, medium dry matter.
CP1818	B 6039-1 (USA)	Immune to wart, tolerance to bacterial wilt, resistance to hopper burn, high dry matter, good keeper.
CP1927	B 6739-2 (USA)	Medium maturity, adapted to plains, resistance to late blight (foliage & tuber), resistance to stem necrosis, moderately resistant to hopper burn.
CP1971	Saturna (Netherlands)	Adapted to hills, immune to wart, resistance to scab, resistance to stem necrosis, resistance to hopper burn & mites, resistance to PVX & PVY, immune to PVA, resistance to common scab, high dry matter.
CP2011	CIP 676082 (Peru)	Adapted to hills & plains, resistant to late blight (foliage & tubers), moderately resistant to stem necrosis.
CP2018	CIP 750847 (Peru)	Adapted to hills & plains, resistant to late blight (foliage & tubers), immune to wart, and resistant to hopper burn.
CP2058	CIP 379386 (Peru)	Adapted to hills & plains, tolerant to heat, highly resistant to late blight (foliage), immune to wart, moderately resistant to charcoal rot, and resistant to hopper burn.
CP2118	Desiree (Netherlands)	Medium maturity, adapted to plains, resistance to PVX, tolerance to heat & drought, immune to wart, resistance to powdery scab.
CP2173	MS 82.80	Adapted to hills & plains, resistant to late blight (foliage & tubers), moderately resistant to termite, resistant to hopper burn.
CP2175	LT-5 (Peru)	Early maturity, adapted to hills & plains, resistance to late blight (foliage), immune to wart, resistance to stem necrosis, resistance to hopper burn, tolerance to heat.
CP2369	V-3 (Peru)	Medium maturity, adapted to plains, resistance to late blight (tuber), resistance to PVX, PVY & PLRV, moderately resistance to hopper burn & mites.
CP2371	LT-8 (Peru)	Early maturity, adapted to hills & plains, moderately resistant to late blight (tuber), immune to wart, resistant to PVX, high dry matter, and tolerant to heat.
CP2384	AGG 69.1 (Peru)	Medium maturity, adapted to hills and plains, resistance to late blight (foliage), resistance to cyst nematodes (both spp.), moderately resistant to PVA.

CP2385	AND 69.1 (Peru)	Medium maturity, adapted to hills & plains, resistance to late blight (foliage & tuber), resistance to PVY, high dry matter.
CP3088	Oblix (Netherlands)	Adapted to hills & plains, tolerance drought, resistance to PLRV, immune to wart, resistance to common scab and resistance to *Globodera rostochinesis*.
CP3091	Nicola (Netherlands)	Adapted to hills, resistance to late blight (tuber), immune to wart, tolerance to bacterial wilt, resistance to PVX & PVY, resistance to both spp of cyst nematodes, moderately resistance to common scab & drought.
CP3098	27/15 (Peru)	Early maturity, adapted to hills & plains, resistance to late blight (foliage & tuber), immune to wart.
CP3171	Bzura (Poland)	Early maturity, adapted to hills & plains, resistance to late blight (foliage & tuber), immune to wart, resistance to PLRV.
CP3187	BW-8 (Peru)	Adapted to hills & plains, resistance to late blight (tuber), resistance to PVX & PVY, resistance to cyst nematodes (both spp.)
CP3191	24/40 (Peru)	Early maturity, adapted to hills & plains, resistance to late blight (foliage & tuber).
CP3247	LB-2 (Peru)	Adapted to hills, resistance to late blight (foliage & tuber), resistance to PVX & PVY, resistance to cyst nematodes (*Globodera pallida*)
CP3251	LB-3 (Peru)	Adapted to hills, resistance to late blight (foliage & tuber) and resistance to PVX & PVY.
CP3290	Hope Hely (Hungary)	Adapted to hills & plains, resistance to late blight (foliage & tuber).

tuber shape, eye depth, flesh color and flower color as per descriptor of the International Board for Plant Genetic Resources (now IPGRI). The germplasm accessions found promising for various characters have also been studied for combining ability (Gaur *et al.*1983, 1985, 1993; Gopal 1996a, 1996b; Gopal and Gaur, 1997; Kaushik *et al.* 1996; Pandey and Gupta, 1997; Luthra, 2001; Luthra *et al.* 2003a; Kumar and Gopal, 2006; Kumar *et al.* 2005b, Luthra *et al.* 2006a).

Documentation

The information on passport data, morphological characters and reaction to various biotic and abiotic stresses of subsp. *tuberosum* and subsp. *andigena* collections, available at the CPRI, has been published from time to time in the form of germplasm catalogs (Pal and Pushkarnath, 1951; Pushkarnath, 1964; Gaur *et al.* 1984; Gopal *et al.* 1992; Birhman *et al.* 1998; Kumar *et al.* 2005d; Kumar *et al.* 2008; Dalamu *et al.* 2021).

Utilization

The choice of parents in crossing depends on the objectives of the program. Breeders prefer to work with parents who have good agronomic attributes, adaptation, and other desired traits. Characters with high heritability and monogenic dominant control are the easiest to transfer. The use of germplasm for the selection of parents, in order of preference, is a) *S. tuberosum* subsp. *tuberosum* collection involving commercial varieties, breeding lines, stocks in ongoing breeding programs and old landraces, b) subsp. *andigena*, c) primitive cultivated species, d) wild tuber-bearing species, and e) wild non-tuber-bearing species.

Use of S. tuberosum subsp. tuberosum

Due to superior agronomic attributes and good adaptability, commercial varieties, parental lines and old landraces have been extensively used in variety improvement programs all over the world. However, continuous breeding cycles and selection for similar economic attributes have resulted in fixing favorable alleles in the population, thereby reducing genetic variability in *S. tuberosum* subsp. *tuberosum* collections. This reduces the chances of recovering high heterosis for economic characters. Since distantly related lines are more complementary and produce heterotic effects, genetic distances are recommended for planning crosses in breeding programs (Gaur *et al.* 1978; Gopal and Minocha, 1997; Luthra *et al.* 2005, Luthra 2009). Luthra *et al.* (2005) and Luthra (2006, 2009) suggested the selection of parents based on genetic divergence followed by progeny tests for effective exploitation of heterosis in potatoes.

Use of S. tuberosum subsp. andigena

S. tuberosum subsp. *andigena* is a short-day adapted wild and weedy relative of cultivated subsp. *tuberosum*. Subsp. *tuberosum* is known to be evolved from subsp. *andigena*, through selection for good agronomic attributes and adaptability to long days. *S. tuberosum* subsp. *tuberosum* thus represents only a fraction of total genetic variability present in subsp. *andigena*. To augment the genetic variability of subsp. *tuberosum*, efforts have been made to further harness the genetic variability of subsp. *andigena*. In Europe, recurrent selection cycles for economic attributes and adaptation to long days were established in subsp. *andigena* populations. The final population developed in the process came to be known as 'Neo-tuberosum' population. Selections from this population resembling subsp. *tuberosum*, were subsequently involved in breeding programs. The *andigena* collection available in India possesses wide wealth of valuable traits such as resistance/tolerance to biotic and abiotic stresses, high starch and

Table 5: List of elite genetic stocks registered by ICAR-CPRI, Shimla with ICAR-NBPGR

S. No	*Donor identity*	*IC/EC No*	*INGR No*	*Year*	*Pedigree*	*Novel unique features*
1	EX/A680-16	IC296790	INGR01011	2001	Clone No 502-14 x Bulk Pollen)	Short days adapted with resistance to early and late blight.
2	QB/A 9-120	IC296650	INGR04057	2004	EX/A680-16 x Kufri Jyoti	High resistance to late bight and GCA for agronomic traits.
3	QB/B92-4	IC296651	INGR04058	2004	Kufri Red x CP 1755	High dry matter and low reducing sugars & good GCA.
4	PS/F-220	IC296661	INGR04059	2004	B-8695 x Kufri Jyoti	Resistant to potato stem necrosis.
5	MP/99-322	IC445068	INGR04109	2004	MCP-1x 48-1	High starch, dry matter, low amylose & resistance to late blight.
6	E/79-42	IC522200	INGR05022	2005	D42/9 x *S. vernei* clone vtn2 62-33-3	Combined resistance to cyst nematodes & late blight disease.
7	JW 96	IC524019	INGR05023	2005	Kufri Jyoti x CP1362	Early maturing (60 days).
8	JX 123	IC547013	INGR06021	2006	JE812 x CP2144	Resistance to early blight.
9	JN-189	IC553285	INGR07040	2007	Kufri Jawahar x S. andigena	Resistance to leaf hopper burn & potato stem necrosis tospi virus.
10	D4	IC567213	INGR09067	2009	Androgenic di-haploid of TPS parental line JTH/C-107	Flowering, male fertile androgenic dihaploid of tetraploid potato.
11	C-13	IC567214	INGR09068	2009	Androgenic di-haploid of Kufri Chipsona-2	Flowering, male fertile androgenic dihaploid of tetraploid potato, highly resistant to late blight.
12	JX 90	IC585711	INGR09069	2009	CP1346 (Krirrinee) X MS/78-62	Horizontal resistant to late blight &early blight, high yield under early (75 days) & medium (90 days) crop duration.
13	SS-2040	EC460686	INGR09120	2009	Clonal selection from segregating progeny of the accession SS 2040 of *S. tuberosum* ssp. *andigena*	Higher frost tolerance introduced through ssp. *andigena* a cultivated clone.
14	SS-1725-22	EC412923	INGR09121	2009	Clonal selection from segregating progeny of the accession SS 1725 of diploid wild species *S. spegazzinii*	Higher frost tolerance introduced through a wild species clone of *S. spegazzinii.*
15	YY 6/3 C11	IC0586781	INGR10143	2010	Clonal selection from the segregating progeny of YY-6 x YY-3 using marker assisted selection	An elite parental line possessing potato virus Y (PVY) extreme resistance gene Ryadg in triplex (YYYy) condition.
16	E 1-3	IC0590089	INGR11050	2011	*S. tuberosum* dihaploid 'C-13' (+) Wild species *S. etuberosum*	Tetraploid somatic male fertile hybrid carrying resistance to potato virus introgressed from *S. etuberosum.*
17	P-7	IC0590090	INGR11051	2011	*S. tuberosum* dihaploid 'C-13' (+) Wild species *S. pinnatisectum*	Tetraploid, somatic male fertile hybrid carrying resistance to potato late blight introgressed from *S. pinnatisectum.*
18	SS 1735-02	IC0594469	INGR13048	2013	Clonal selection From the TPS population GLKS-269 (*S. demissum*; 2n = 6x;4 EBN)	An elite wild potato clone possessing very high resistance against late blight and low cold induced sweetening even after 6 months of cold storage (2–4°C).

19	MP/97-921	IC0594470	INGR13049	2013	MP/92-154 x MP/91-65	High dry matter content (>24% in hills & >22% in plains); superior chip color (even after 6 months cold storage); low reducing sugar and sucrose content; highly resistant to late blight; ideal free amino acid and phenol content; extreme resistant to potato virus PVY.
20	JEX/A 785	IC0616582	INGR15059	2015	Clonal selection from segregating progeny of the acc. PI280868 of *S. tuberosum* spp. *andigena*	Suitable for cold chipping and resistance to cold induced sweetening.
21	JEX/A 911	IC0618556	INGR16010	2016	Clonal selection from segregating progeny of acc. CIPC700939 of *S. tuberosum* ssp. *andigena*	Suitable for making multicolor chips & tuber flesh attractive multicolored.
22	SM/00-120	IC0616580	INGR16022	2016	EB/A-304 x EX/A-680-16	A photo-insensitive high yielding hybrid with high resistance to late blight both in hills & subtropical plains.
23	SS 1652-09	IC0616581	INGR16023	2016	Selection from acc. PI No. GRA 338x381	SS/1652-09 is a clone of wild potato species *S. jamesti*; highly resistant to late blight; low cold induced sweeting after 6 months cold storage.
24	VMT 5-1	IC623450	INGR17061	2017	K Lalima x VDS-81	Meiotic tetraploid (MT) with 2x genome from semi-cultivated species, *S. verrucosum* and other 2x from cultivated potato cv. K. Lalima. Highly resistant to late blight. Performs well under short & long day conditions.
25	Crd-6	IC623449	INGR17062	2017	Protoplast fusion between dihaploid *S. tubersum*'C-13' (+) *S. cardiophyllum* (P1341233)	Tetraploid and male fertile somatic hybrid. Resistance to potato late blight disease.
26	MS/6-1947	IC623447	INGR17063	2017	MS/82-638 x JX 576	Drought tolerant advanced potato clone with good keeping quality & high tuber yield.
27	MS/8-1565	IC623448	INGR17064	2017	MS/89-1095 x CP 3290	Purple skin colored specialty advanced potato clone with very good keeping quality & high tuber yield.
28	MP/6-39	IC623446	INGR17065	2017	Kufri Himsona x Kufri Pukhraj	Processing advanced hybrid. Excellent keeping quality. High tuber yield.
29	MSH/14-113	IC630606	INGR19101	2019	Interspecific potato somatic hybrid P8 (*S. tuberosum* + *S. pinnatisectum*) × Kufri Jyoti (*S. tuberosum*)]	Diverse genetic base with very high resistance to late blight disease & High tuber dry matter content.
30	J.93-58	IC625993	INGR19103	2019	Kufri Pukhraj x MS/82-797	Better water use efficiency than popular cultivars and high yield.
31	BER57	IC635057	INGR20072	2020	Wild potato species: *S. berthaultii*; Acc. PI 265857	Highly resistant to late blight disease. Diploid wild potato species with a wider genetic base.
32	PLD47	IC635058	INGR20073	2020	Wild potato species: *S. polyadenium*; Acc. CGN17747	Highly resistant to late blight disease. Diploid wild potato species with a wider genetic base.
33	JAM07	IC635059	INGR20074	2020	Wild potato species: *S. jamesii*; Acc. PI 498407	Highly resistant to late blight disease. Diploid wild potato species with a wider genetic base.

34	SM/11-120	IC637593	INGR21073	2021	CP2379 x Kufri Himalini	Highly resistant to both the species of potato cyst nematode (*G. pallida* and *G. rostochiensis*). Highly resistant to late blight and non-preference to white flies.
35	MSH/14-129	IC637594	INGR21074	2021	Kufri Gaurav × P2 (P2=*S. tuberosum* dihaploid 'C-13' + *S. pinnatisectum*)	Interspecific somatic hybrid derived clone with wider genetic base. High yield combined with moderate late blight resistance.
36	MCD24	IC637595	INGR21075	2021	Clone 'MCD24' belongs to wild potato species *S. microdontum;* Acc. PI 218224	Highly resistant to late blight disease. Diploid wild potato species with diverse genetic base.
37	N/9-42	IC638884	INGR21111	2021	JN2207 x Kufri Pukhraj	Better nitrogen use efficiency than popular cultivars.
38	MSH/14-7	IC640713	INGR21169	2021	MSH/14-7 [Kufri Garima × Bulk pollen of somatic hybrids (*S. tuberosum* + *S. pinnatisectum*)]	Interspecific somatic hybrid-derived clone with a wider genetic base. High yield combined with moderate resistance to late blight under field conditions.
39	CPH62	IC640714	INGR21170	2021	*S. cardiophyllum*; Acc. PI283062	Highly resistant to late blight disease. Diploid species with diverse genetic base. Suitable for protoplast fusion & somatic hybrid development.
40	PNT43	IC640715	INGR21171	2021	*S. pinnatisectum*; Acc. CGN17443	Highly resistant to late blight disease. Diploid species with diverse genetic base. Suitable for protoplast fusion and somatic hybrid development.
41	STO61	IC640716	INGR21172	2021	*S. stoloniferum*; Acc. PI225661	Approved: Highly resistant to late blight disease. Diploid species with diverse genetic base.
42	MSH/17-16	IC640717	INGR21173	2021	Kufri Garima × Crd10 (interspecific potato somatic hybrid derived from *S. tuberosum* dihaploid' C-13' + wild S. cardiophyllum	Interspecific somatic hybrid-derived potato hybrid with a wider genetic base. Yellow tuber flesh color hybrid with high carotenoid content.
43	NUE/15-8	IC640718	INGR21174	2021	Kufri Jyoti × Kufri Gaurav	High nitrogen use efficiency traits such as NUE, Agronomic NUE (AgNUE), nitrogen uptake efficiency (NUpE), & nitrogen utilization efficiency (NUtE). High yield under low nitrogen (50 kg N/ha) supply under field conditions and suitable for low input agriculture.
44	MSP/15-26	IC644002	INGR22062	2022	Bareilly Red × CP3770	MSP/15-26 is an elite cultivated potato clone (*S. tuberosum*; 2n = 4x = 48). Possessing high carotenoids in flesh. Yellow flesh color with red vascular ring.
45	MSP/15-51	IC644003	INGR22063	2022	Bareilly Red × CP3770	MSP/15-51 is an elite cultivated potato clone (*S. tuberosum*; 2n = 4x; 48). High ascorbic acid in flesh. Distinct red purple flesh.
46	NUE/15-23	IC645767	INGR22188	2022	Kufri Jyoti × Kufri Gaurav	High nitrogen use efficiency traits such as NUE, Agronomic NUE (AgNUE), nitrogen uptake efficiency (NUpE), and nitrogen utilization efficiency (NUtE). High tuber yield under low nitrogen fertilizer input under field conditions.

protein content, good keeping quality and response to fertilizers (Nagaich, *et al.* 1978; Nagaich, 1983; Chaudhary *et al.* 1983; Birhman *et al.* 1988; Luthra and Gopal, 1999; Shekhawat *et al.* 2005, Kumar *et al.* 2008). *Andigena* is also a good source of resistance to many diseases and pests, including resistance to late blight, *Phoma* blight, charcoal rot, root-knot nematodes and cyst nematodes. It also provides resistance to physiological stresses like drought and frost. The crosses involving subsp. *tuberosum* and subsp. *andigena* are known to exhibit heterosis for tuber yield and its components, though late maturity is often observed in progenies. The *andigena* are particularly suitable for potato improvement in sub-tropical Indo-gangetic plains in India (Kang and Birhman, 1993; Gopal *et al.* 2000; Kumar and Gopal, 2003a, Kumar and Kang 2006). Use of subsp. *andigena* has resulted in the development of varieties like Kufri Pukhraj, Kufri Chipsona-1 and Kufri Giriraj, which appear to have more durable resistance to late blight.

Use of cultivated and wild species

Only a few cultivated/wild species have been used in breeding programs. Even in these cases, the number of clones used from each species has been extremely limited. Further, these species have served as donors of only the desired dominant genes controlling disease resistance. Other characteristics in such crosses have been largely lost due to continued back-crossing with the *tuberosum* parent and correlated response to selection for desirable traits. The non-tuberosum species like *S. etuberosum* has been used through somatic hybridization.

Somatic hybridization has been used in potatoes to overcome the sexual barriers between the cultivated (*Solanum tuberosum* L.) and wild species. Symmetric protoplast fusion approaches involving diploid *Solanum* species combined with di-haploid *S. tuberosum* have been essentially used to develop tetraploid somatic hybrid potatoes with desirable introgression from wild relatives. This technology has led to the production of multiple resistant somatic hybrids. ICAR-CPRI, Shimla have developed three interspecific potato somatic hybrids using androgenic dihaploid clone 'C-13' (regenerated from *Solanum tuberosum* cv. Kufri Chipsona-2) and wild species *S. pinnatisectum* (1EBN) for adaptability, tuber traits, late blight resistance and keeping quality (Sarkar *et al.* 2011; Tiwari *et al.* 2013; Luthra *et al.* 2016), *S. cardiophyllum* (1EBN) for late blight resistance (Chandel *et al.* 2015, Luthra *et al.* 2019) and *S. tuberosum* (1EBN) for potato virus Y resistance (Tiwari *et al.* 2014). Further, these somatic hybrids have been utilized for the development of advanced stage clones in breeding programs. Elite genetic stocks of somatic hybrid, namely P-7 (late blight), Crd-6 (late bight) and E-1-3 (Potato virus), and somatic hybrid derived advanced clones, namely MSH/14-113, MSH/14-129 and MSH/17-16 (late blight) has been registered with NBPGR (Table 5).

Genetic Stocks Registered

Genetic stocks, defined as plants or populations developed and/or selected for genetic studies, represent a unique type of extremely valuable germplasm which, represents genetic resources of either transient or long-lasting value. Genetic stocks can be divided into three general groups: cytological stocks, mutants and germplasm sets. Genetic stocks are important components of the total conserved genetic resources of potatoes. In potato breeding, genetic stocks are breeding lines that contain specific desirable traits but lack some economic traits required for commercial exploitation. Genetic stocks are an asset as a parental line in the breeding program for the introgression of specific traits in the progenies. Since the inception of ICAR-Central Potato Research Institute, Shimla, in 1949, concerted breeding efforts have resulted in the identification and registration of 46 genetic stocks with ICAR-NBPGR, New Delhi (Table 5). These elite genetic stocks are valuable sources of resistance to biotic/abiotic stresses and also carry valuable genes for many other traits.

Potato Varieties and their Parentage Background

Information on the parental origin of potato varieties that have been cultivated or themselves used as parental lines for further selection provides a wealth of information on historical breeding choices (Van Berloo and Hutten, 2005). Such historical records allow a better understanding of the current population structure and can, therefore provide relevant data for breeders to use when making the right decisions in their respective breeding programs (Machida, 2015).

Institute has led to the development of 69 improved potato varieties and one TPS population (92-PT-27) over last 72 years for cultivation in diverse agro-climatic zones of the country. Of these, two varieties, *viz*., Kufri Safed and Kufri Red are clonal selections from indigenous *'desi'* varieties Phulwa and Darjeeling Red Round, respectively, whereas the remaining 68 are hybrids as they were derived from the mating of the female and male parent.

The parentage of 68 varieties shows that 26 varieties have both parents of Indian origin (Table 6), 28 have one parent of Indian origin and one of exotic origin (Table 7) and the remaining 14 have both parents of exotic origin (Table 8). In total, 103 parents have been used in the breeding program involving 55 female and 53 male parents. The most frequently used indigenous varieties or advanced clones are Kufri Jyoti (6 varieties), Kufri Red, Phulwa, MS/82-638 and MP/92-35 (3 varieties), Kufri Pukhraj, Kufri Alankar, Kufri Bahar, Kufri Chipsona-2, Kufri Himsona, Kufri Khyati and Kufri Kundan (2 varieties). The exotic cultivars/ clones that have figured more frequently as parents of Indian varieties are Craigs Defiance and Katahdin (3 varieties), $(VTn)^2$ 62.33.3, 27/40, Adina, Ekishirazu, EX/A 680-16, Irish

Table 6: Potato varieties developed using both parents from indigenous germplasm

S. No.	*Variety*	*Original name*	*Year of release*	*Parentage*
1	Kufri Sindhuri	C 140	1967	Kufri Red x Kufri Kundan
2	Kufri Chandramukhi	A 2708	1968	Seedling 4485 x Kufri Kuber
3	Kufri Neelamani	A 7871	1968	Kufri Kundan x 134-D
4	Kufri Badshah	JF 4870	1979	Kufri Jyoti x Kufri Alankar
5	Kufri Megha	SS/C-562	1989	SLB/K-37 x SLB/Z-73
6	Kufri Jawahar	JH 222	1996	Kufri Neelamani x Kufri Jyoti
7	Kufri Sutlej	JI 5857	1996	Kufri Bahar x Kufri Alankar
8	Kufri Giriraj	SM/85-45	1998	SLB/J-132 x EX/A 680-16
9	Kufri Anand	MS/82-717	1999	Kufri Ashoka x PH/F-1430
10	Kufri Arun	MS/92-2105	2005	Kufri Lalima x MS/82-797
11	Kufri Shailja	SM/87-185	2005	Kufri Jyoti x EX/A 680-16
12	Kufri Chipsona 3	MP/97-583	2006	MP/91-86 x Kufri Chipsona 2
13	92-PT-27	TPS population	2007	83-P-47 x D150
14	Kufri Himsona	MP/97-644	2008	MP/92-35 x Kufri Chipsona-2
15	Kufri Sadabahar	MS/93-1344	2008	MS/81-145 x PH/F-1545
16	Kufri Khyati	J/93-86	2008	MS/82-638 x Kufri Pukhraj
17	Kufri Frysona	MP/98-71	2010	MP/92-30 x MP/90-94
18	Kufri Neelima	OS/93-D-204	2010	E/79-15 x E/79-42
19	Kufri Garima	MS/99-1871	2012	PH/F 1045 x MS/82-638
20	Kufri Gaurav	JX576	2012	JE 812 x Kufri Jyoti
21	Kufri Ganga	MS/6-1947	2018	MS/82-638 x Kufri Gaurav
22	Kufri FryoM	MP/04-578	2020	Kufri Chipsona 1 x MP/92-35
23	Kufri Sangam	MP/6-39	2020	Kufri Himsona x Kufri Pukhraj
24	Kufri Thar 3	WS/05-146	2020	JN2207 x Kufri Jyoti
25	Kufri Lohit	MS/11-664	2021	Kufri Kanchan x Kufri Khyati
26	Kufri Bhaskar	HT/11-3	2022	Kufri Khyati x Kufri Surya

Table 7: Potato varieties developed using one parent from indigenous germplasm and one from exotic germplasm

S. No.	*Variety*	*Original name*	*Year of release*	*Parentage*
1	Kufri Kumar	S 1758	1958	Lumbri x Katahdin
2	Kufri Alankar	A 3649	1968	Kennebec x ON2090
3	Kufri Chamatkar	ON 1202	1968	Ekishirazu x Phulwa
4	Kufri Jeevan	SLB/E 427	1968	M109-3 x Seedling 698-D
5	Kufri Khasigaro	SLB/A-67	1968	Taborky x Seedling 698-D
6	Kufri Naveen	SLB/E-402	1968	3070d (4) x Seedling 692-D
7	Kufri Sheetman	C 3745	1968	Craigs Defiance x Phulwa
8	Kufri Dewa	C 3804	1973	Craigs Defiance x Phulwa
9	Kufri Bahar	E 3797	1980	Kufri Red x Gineke
10	Kufri Lalima	BS/C-1753	1982	Kufri Red x AG 14 (Wis. X 37)
11	Kufri Swarna	PCN/76-110	1985	Kufri Jyoti x $(VTn)^2$ 62.33.3 (CP1974)
12	Kufri Ashoka	PJ 376	1996	EM/C-1020 x Allerfrüheste Gelbe
13	Kufri Pukhraj	JEX/C-166	1998	Craigs Defiance x JEX/B-687
14	Kufri Chipsona 1	MP/90-83	1998	MEX.750826 x MS/78-79
15	Kufri Chipsona 2	MP/91-G	1998	F-6 (CP2346) x QB/B 92-4

16	Kufri Kanchan	SE/I-1307	1999	SLB/Z-405 (a) x Pimpernel
17	Kufri Pushkar	JW 160	2005	QB/A 9-120 x Spatz
18	Kufri Surya	HT/92-621	2006	Kufri Lauvkar x LT1 (CP2066)
19	Kufri Girdhari	SM/93-237	2008	Kufri Megha x Bulk pollen of 10 genotypes
20	Kufri Mohan	MS/5-1543	2016	MS/92-1090 x Claudia (CP1704)
21	Kufri Sahyadri	OS/1-497	2018	D/79-56 x $(VTn)^2$ 62.33.3 (CP1974)
22	Kufri Neelkanth	MS/8-1565	2018	MS/89-1095 x Hope Helly (CP3290)
23	Kufri Lalit	2001-P-55	2018	85-P-670 x 27/40 (CP3192)
24	Kufri Chipsona 4	MP/01-916	2020	Atlantic x MP/92-35
25	Kufri Karan	SM/00-42	2020	Cruza-27 x HB/83-39
26	Kufri Manik	PS/08-88	2020	Kufri Arun x 27/40 (CP3192)
27	Kufri Thar 1	J/92-167	2020	Kufri Bahar x Deodara (CP1785)
28	Kufri Chipsona 5	MP/9-45	2022	Kufri Himsona x CP1371 (B3556-12)

Table 8: Potato varieties developed using both parents from exotic germplasm

S. No.	*Variety*	*Original name*	*Year of release*	*Parentage*
1	Kufri Kisan	PS 454	1958	Up-to-date x Sd. 16
2	Kufri Kuber	ON 2236	1958	(*S. curtilobum* x *S. tuberosum*) x *S. andigenum*
3	Kufri Kundan	Hybrid-9	1958	Ekishirazu x Katahdin
4	Kufri Neela	A 1528	1963	Katahdin x Shamrock
5	Kufri Jyoti	SLB/Z-389(b)	1968	3069d (4) x 2814a (1)
6	Kufri Muthu	SLB/Z-785	1971	3046 (1) x M109-3
7	Kufri Lauvkar	A 7416	1972	Serkov x Adina
8	Kufri Sherpa	F 5242	1983	Ultimus x Adina
9	Kufri Himalini	SM/91-1515	2006	I-1062 (CP2184) x Tollocan (CP2132)
10	Kufri Lima	CP4054	2018	C90.266 x C93.154
11	Kufri Thar 2	CP4175	2020	CIP92.119 x CIP88.052
12	Kufri Kiran	HT/7-1329	2021	LT9 (CP2372) x Irish Cobler (CP1748)
13	Kufri Uday	CP4409	2021	CIP387521.3 x Aphrodite
14	Kufri Daksh	WS/07-113	2022	Irish Cobler (CP1748) x LT1 (CP2066)

Cobler, LT1, seedling 698-D, M109-3 9 (2 varieties). Among the 32 unreleased indigenous selections used as parents include 83-P-47, 85-P-670, D/79-56, D150, E/79-15, E/79-42, EM/C-1020, EX/A 680-16, HB/83-39, JE 812, JEX/B-687, JN2207, MP/90-94, MP/91-86, MP/92-30, MP/92-35, MS/78-79, MS/81-145, MS/82-638, MS/82-797, MS/89-1095, MS/92-1090, ON2090, PH/F-1045, PH/F-1430, PH/F-1545, Phulwa, QB/A 9-120, QB/B 92-4, SLB/J-132, SLB/K-37, SLB/Z-405 (a) and SLB/Z-73 were advanced improved clones. Some of these had reached the stage of multi-locational trials but could not be released as varieties.

Use of CIP Germplasm in Varietal Improvement

The germplasm received from International Potato Center, Lima, Peru accounts for nearly 42% of germplasm available in ICAR-CPRI repository and has contributed to the release of 19 potato varieties, including 10 varieties having one immediate parent in their pedigree, 6 varieties having one or both parents in their pedigree and three varieties namely Kufri Lima, Kufri Thar-2 and Kufri Uday having both parents in their pedigree (Table 9). Kufri Lima, Kufri Thar-2 and Kufri Uday have been released in India following the evaluation of advanced clones received from CIP, Lima, Peru, under ICAR-CPRI and CIP collaborative program on potato improvement.

Limited Use of Genetic Resources

The limited use of genetic resources in potato variety improvement is due to several reasons. One of the reasons is that most of the collections have not been adequately evaluated and cataloged. Secondly, there have not been many efforts to develop parental lines from wild *Solanum* species as this is a long and difficult task owing to differences in ploidy, tight linkages with undesirable characteristics, and the non-crossability of some species. It is estimated that only 13 species have been used so far in variety of improvement programs all over the world. Wild species such as *S. demissum,*

Table 9: Use of germplasm derived from International Potato Center, Lima, Peru

Variety name	*Year of release*	*Parentage*	*CIP parent*	*Year of receipt*	*Remarks*
Kufri Swarna (PCN/76-110)	1985	Kufri Jyoti x $(VTN)^2$ 62.33.3	$(VTN)^2$ 62.33.3 (CIP800291)	1971/ 1973	Immediate parent
Kufri Chipsona-1 (MP/90-83)	1998	MEX.750826 x MS/78-79	MEX.750826 (CIP720124)	1987	Immediate parent
Kufri Chipsona-2 (MP/91-G)	1998	F-6 x QB/B 92-4	F-6 (CIP 377427.1)	1987	Immediate parent
Kufri Surya (HT/92-621)	2006	Kufri Lauvkar X LT-1	LT-1 (CIP 377257.1)	1980	Immediate parent
Kufri Chipsona-3 (MP/97-583)	2006	MP/91-86 x Kufri Chipsona-2 (F-6 x QB/B 92-4)	F-6 (CIP 377427.1) in pedigree of K. Chipsona-2	1987	In pedigree of one parent
Kufri Himalini (SM/91-1515)	2006	I-1062 x Tollocan	Tollocan (CIP 720054)	1984	Immediate parent
Kufri Himsona (MP/97-644)	2008	MP/92-35 x Kufri Chipsona-2	F-6 (CIP 377427.1) in pedigree of K. Chipsona-2	1987	In pedigree of one parent
Kufri Frysona (MP/98-71)	2009	MP/92-30 x MP/90-94; MP/92-30 (CIP378711.5 x AL575); MP/90-94 (CIP378711.5 MS/78-79)	Muziranaara (CIP378711.5) and AL575	1987	In pedigree of both parents
Kufri Chipsona-4 (MP/01-916)	2010	Atlantic x MP/92-35 (CIP378711.5 x CIP720125)	CIP378711.5 x CIP720125 in pedigree of MP/92-35	1987	In pedigree of one parent
Kufri Lalit (2001-P-55)	2013	85P670 x CP3192 (CIP380013.12)	CIP380013.12	1989	Immediate parent
Kufri Lima (CIP397065.28)	2018	(391 180.6 (C90.266) x 392820.1 (C93.154))	(391 180.6 (C90.266) x 392820.1 (C93.154))	2007	Both parents
Kufri Sahyadri (OS/1-497)	2018	D/79-56 x CP 1974 $(VTN)^2$ 62.33.3)	$(VTN)^2$ 62.33.3 (CIP800291)	1973	Immediate parent
Kufri Karn (SM/00-42))	2018	Cruza-27 (CP2376-575031) x HB/83-39	Cruza-27 (CIP575031)	1983	Immediate parent
Kufri Manik (PS/08-88)	2018	K. Arun x CP3192 (CIP380013.12)	CIP380013.12	1989	Immediate parent
Kufri Thar-2 (CIP397006.18)	2020	(389468.3 (92.1 19) x 88.052)	(389468.3 (92.1 19) x 88.052)	2008	Both parents
Kufri Uday (CIP392797.22)	2021	CIP387521.3 x APHRODITE	CIP387521.3	2012	Both parents
Kufri Chipsona-5 (MP/9-45)	2022	Kufri Himsona x CP1371 (B3556-12)	F-6 (CIP 377427.1) in pedigree of K. Himsona	1987	In pedigree of one parent
Kufri Bhaskar (HT/11-3)	2022	Kufri Khyati x Kufri Surya	LT-1 (CIP 377257.1) in pedigree of K. Surya	1980	In pedigree of one parent
Kufri Daksh (WS/07-113)	2022	Irish Cobler (CP1748) x LT1 (CP2066)	LT-1 (CIP 377257.1)	1980	Immediate parent

S. acaule, S. chacoense, S. spegazzinii, S. stoloniferum, S. vernei have been utilized for the development of several cultivars. Genes of *S. demissum* have been incorporated into more than 50% of the world's cultivars for resistance to late blight and PLRV. In most of these programs, dihaploids of subsp. *tuberosum* have been used as a bridge to transfer resistance from wild/cultivated species to cultivated potato. In pre-breeding programs involving hybridization and selection at diploid level followed by tetraploidization of desirable selections, attempts are made to develop parents with the desirable genes at quadruplex or triplex level to ensure high-frequency transfer of resistance to progenies. In India, wild species *S. verrucosum* and *S. microdontum* have been used as donors of durable resistance (horizontal) to late blight (Sharma *et al*. 1982). Varieties like Kufri Jeevan, Kufri Jyoti, Kufri Khasigaro, Kufri Naveen, Kufri Neelamani,

Figure 2: Colored potato varieties: Kufri Manik, Kufri Neelkanth and Kufri Lohit

Figure 3: Most popular potato varieties of India: Kufri Jyoti, Kufri Bahar and Kufri Pukhraj

Kufri Muthu, Kufri Badshah, Kufri Megha and Kufri Jawahar were developed by incorporating resistance genes in indigenously developed material, through exotic material from UK having *S. demissum* genes. Similarly, *S. chacoense* has been used to provide resistance to charcoal rot (Upadhaya *et al.* 1977). Resistance to cyst nematodes in the variety Kufri Swarna and Kufri Sahyadri has been derived from *S. vernei*.

Impact of Indigenous Potato Varieties

Among 70 varieties released so far, 10 are early, 46 are medium and 14 are late in maturity. Also, whereas 60 varieties possess white or yellow skin, nine varieties, *viz*., Kufri Red, Kufri Sindhuri, Kufri Lalima, Kufri Kanchan, Kufri Arun, Kufri Lalit, Kufri Manik (rich in iron & zinc), Kufri Lohit and Kufri Uday possess red tuber skin (Figure 2). The new potato variety Kufri Neelkanth (rich in antioxidants) produces attractive purple ovoid tubers with yellow flesh. Most of these varieties possess resistance/tolerance to major diseases and pests. About 90% of potatoes are grown in North Indian plains and commensurate with this area, the largest number (49) of varieties has been developed for this region. Varieties have also been developed for north Indian hills and other special problem areas, viz., Sikkim, north Bengal hills, and south Indian hills.

Three indigenous potato varieties, namely Kufri Pukhraj, Kufri Jyoti and Kufri Bahar (Figure 3) are the most popular among the farmers and occupy 33, 21 and 17% of areas in six major potato growing states (Pradel *et al.* 2019). Kufri Pukhraj, released two decades ago, has become the farmer's first choice in Bihar, Gujarat and Punjab, occupying 39, 85 and 64% of cultivated areas in these states. This variety is also popular in Uttar Pradesh and West Bengal, occupying about 28 and 19% of the total area under potato cultivation. The latest information on Kufri Pukhraj reveals that it is one of the most popular short-duration varieties in the North Indian plains and is grown in nearly 33% of the potato area of the country. The annual economic surplus during 2020-21 has been estimated to be 4729 crores (at 2018 prices, DARE, ICAR, Significant achievement, 2021-22). Kufri Jyoti is another widely adapted variety and is grown throughout India in hills, plains and plateaus. It is the most popular variety in West Bengal and Karnataka, occupying about 56 and 94% of the area under potato cultivation. Kufri Bahar is the farmer's preferred choice in Uttar Pradesh, occupying about 45% of the area. These three Indian potato varieties *viz*., Kufri Pukhraj, Kufri Jyoti and Kufri Bahar, occupy 2nd, 5th and 6th place, respectively in South East Asian potato growing countries too (Gatto *et al.* 2018).

Farmers' preferences for red-skinned potatoes keep the demand for Kufri Sindhuri in Bihar high. Kufri Kanchan, a wart-immune variety, is popular among the farmers of north Bengal and Sikkim hills, where the wart is an endemic problem and there is a distinct preference for red skin tubers. Similarly, Kufri Swarna and Kufri Neelima, having resistance to cyst nematodes, is popular in Nilgiri hills. The late blight-resistant varieties developed by the institute, Kufri Himalini, initially released for Northern hills, is also becoming popular in plains and plateau areas, where late blight is a production constraint. New potato varieties Kufri Girdhari and Kufri Karn have also been developed for late blight resistance. In the sub-tropical plains of India, potato is one of the crops in multiple cropping systems. The Institute has developed new and improved varieties for the farmers of sub-tropical plains, which include Kufri Khyati, Kufri Mohan, and Kufri Ganga (Figure 4), which are becoming popular in sub-tropical plains. For expanding the crop area in the plateau region and the early planted crops in north India, varieties that can respond favorably to high-temperature conditions

Figure 4: Table potato varieties: Kufri Khyati, Kufri Mohan and Kufri Ganga

Figure 5: Heat tolerant potato varieties: Kufri Surya, Kufri Lima and Kufri Kiran

and possess resistance to hopper burn and mite damage are required. Kufri Surya, Kufri Lima (with extreme resistance to PVX and PVY), Kufri Kiran (Figure 5) and Kufri Bhaskar have been developed for high-temperature stress areas. These varieties are likely to pick up and become popular among farmers.

In the recent past, potato processing got a boost with the release of varieties suitable for chipping and the development of technology for storing potatoes for processing. The breeding work led to the development of eight varieties exclusively for processing purposes (Figure 6), namely Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Frysona, Kufri Chipsona-4, Kufri FryoM, Kufri Sangam (Dual purpose) and Kufri Chipsona-5 for cultivation in plains and Kufri Himsona for cultivation in hills. Among these varieties, Kufri Frysona and Kufri FryoM are suitable for French fries, while all others are chipping varieties. Besides being suitable for processing, these varieties also have high yields and resistance to late blight. The availability of such varieties will help stabilize the potato price fluctuations in the market and help in increasing the area and production of potatoes in the country. Recently, water-use efficient varieties (Figure 7), namely, Kufri Thar-1, Kufri Thar-2, Kufri Thar-3 and Kufri Daksh, have been released for cultivation in drought-prone areas of north Indian plains.

Currently, 28 varieties are under the institute's breeder/quality seed production program. The statistics of breeder seed of 18 varieties supplied by ICAR-CPRI during 2021 to different state government agencies reveal the maximum share of the popular potato variety Kufri Chipsona-1.

(17.28%) followed by Kufri Bahar (16.42%), Kufri Jyoti (14.11%), Kufri Pukhraj (11.36%), Kufri Khyati (7.27%), Kufri Mohan (7.06), Kufri Chandramukhi (4.65%), Kufri Chipsona-3 (4.43%), Kufri Surya (4.10%), Kufri Himalini (3.97%), Kufri Garima (2.11%), Kufri Frysona (1.90%), Kufri Anand (1.88%), Kufri Sindhuri (1.81%), Kufri Lauvkar (0.66%), K Badshah (0.37%), Kufri Lalit (0.36%) and Kufri Gaurav (0.25%). The virus-free *in-vitro* culture tubes of basic seed material of the listed 18 varieties and Kufri Lima, Kufri Karan, Kufri Sangam, Kufri Sahyadri, Kufri Neelkanth, Kufri Kanchan, Kufri Neelkanth, Kufri Ganga, Kufri Thar-1 and Kufri Thar-2 were also supplied to 18 different seed producing agencies in India.

The ICAR-CPRI varieties are well-adopted by farmers in different parts of the country. In India, nearly 95% area under potatoes is grown with indigenous improved varieties developed by the ICAR-CPRI. The potato varieties are suitable for different agro-climatic regions. In addition to these, the State Agricultural Departments have also released some potato cultures. These are ON1645, PS-555, K-122, and G-24 in Uttar Pradesh; Co-Shimla in Tamilnadu, and Gulmarg Special, Gulmarg Queen, Shalimar potato 1 (clonal selection, tubers white, round, shallow eyes, white-yellow flesh-2012) and Shalimar Potato 2 (clonal selection, tubers pink, round, shallow-medium eyes, cream flesh-2012) in Jammu & Kashmir.

Many Indian potato varieties have found favour in foreign countries. Indian varieties are grown in Mexico, Sri Lanka, Philippines, Madagascar, Bolivia and Vietnam (Table 10). For example Kufri Chandramukhi in Afghanistan, Kufri Jyoti in Nepal and Bhutan and Kufri Sindhuri in Nepal and Bangladesh. Many Indian clones have also been released as varieties in other countries. For example, I-654 as CCM-69.1 in Mexico, I-822 as Krushi and I-1085 as Sita in Sri Lanka, I-1035 as Montanosa and I-1085 as BSUP-04 in Philippines, I-1035 as Mailaka in Madagascar, and I-1039 as India and Red skin in Bolivia and Vietnam, respectively. The CIP advanced clone, CIP392797.22 released in India as Kufri

Figure 6: Potato varieties for processing: Kufri Chipsona-1, Kufri Frysona and Kufri Sangam

Figure 7: Water use efficient potato varieties: Kufri Thar-1, Kufri Thar-2 and Kufri Thar-3

Uday, had been released in different countries as Unica (Peru, 1998), Qingshu 9 (China, 2011), Tajikiston (Tajikistan, 2014), Yusi Maap (Bhutan, 2017), Mkanano (Africa, 2018) and Unica (CIP392797.22) (Nigeria, 2023). In Afghanistan, Kufri Chipsona 4 and Kufri Himalini have been released as Sadaf-20 and Bamyan-20, respectively. As Indian potato enjoys a high degree of consumer preference in neighboring countries, there is enormous scope for the export of seed and table potatoes.

The availability of indigenous varieties, good quality seeds and the right package of agronomic practices triggered a revolution in potato productivity, causing very fast growth in the area, production and productivity. The potato production in India during 2020-21 was 54.23 million tonnes from 2.25 million ha area with a productivity of 24.12 t/ha as compared to 1949 when India used to produce 1.54 million tons potatoes from 0.23 million ha area at an average productivity level of 6.59 t/ha. It is the hard work of potato farmers, scientists and policymakers that potato production, area and productivity increased over more than seven decades by 35.21, 9.78 and 3.66 times, respectively. India is the second largest annual producer of potatoes after China. Considering all other factors involved in this quantum jump in potato productivity, we can safely assume that at least 50% of the contribution is due to the release of improved, high-yielding varieties possessing resistance/tolerance to various biotic and abiotic stresses. It is pertinent to mention that potato varieties developed at ICAR-CPRI contributed 57,512 crores annually to the gross value added (GVA) at the current price.

Future Thrusts

ICAR-Central Potato Research Institute, Shimla, is India's National potato germplasm collection repository. Efforts are being made to improve quarantine facilities to handle large import of germplasm to augment the available collection. Infra-structural facilities are also being strengthened to maintain the large collections of *in-vitro* plants. The present-day Indian potato varieties have a narrow genetic base for most of the economically important characters. The genetic base of 70 potato varieties developed over the past 70 years can be traced back to only 103 parents. Most of these parents represent tetraploid potato cultivars with a negligible representation of *S. tuberosum* subsp. *andigena* and wild/cultivated species. There is a need for better utilization of *S. tuberosum* subsp. *andigena*, adapted to short days and suitable for subtropical plains. Agronomically improved parental lines with acceptable tuber shape, color, depth of eyes and maturity needs to be developed from *andigena* source and assessed for combining ability for economic characters for better utilization in breeding programs.

Table 10: Indian potato varieties/hybrids being grown in other countries

Country	*Varieties/Hybrids*
Afghanistan	Kufri Chandramukhi, Kufri Chipsona – 4 as Sadaf-20 Kufri Himalini as Bamyan-20
Bangladesh	Kufri Sindhuri
Bhutan	Kufri Jyoti
Bolivia	I-1039 as cv. India
Madagascar	I-1035 as Mailaka
Mexico	I-654 as CCM-69.1
Nepal	Kufri Jyoti, Kufri Sundhuri
Philippines	I-1035 as cv. Montanosa, I-1085 as cv. BSUP-04
Sri Lanka	I-822 as cv. Khrushi, I-1085 as cv. Sita
Vietnam	I-1039 as cv. Red skin

Potato tuber moth and bacterial wilt are major problems of the crop in mid-hills and the plateau region. So far no reliable resistance sources have been reported for both of them. Hence, the available potato genetic resources need to be extensively evaluated for these traits. Other characteristics of interest are processing attributes, including cold chipping and nutritional components for which the collection needs to be exploited. The under-exploitation of wild and cultivated species in various improvement programs is primarily due to the long time required to develop desirable parental lines. Gene bank collections, therefore, need to be transformed into "working collections". In this context, biotechnology can offer opportunities for the horizontal introgression of genes into cultivated potatoes across trans-specific barriers. Characterization of accessions for specific genes in terms of their allelic constitution is also required. Work on DNA fingerprinting needs to be strengthened to have a catalog for monitoring the genetic integrity of germplasm collection from time to time to make the system WTO and TRIPS compatible. In a nutshell, a core collection and focused approach hold the key to utilizing potato genetic resources in the future.

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