Molecular analysis of cytoplasm type in Indian potato varieties

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Abstract Thirty-eight Indian potato varieties and fifty-two advanced hybrid lines were analyzed for cytoplasm types using both plastid and mitochondrial genome specific markers. Indian genotypes thus analysed could be broadly grouped into 4 cytoplasm types i.e. T/β (69), W/α (18), W/γ (1) and A/ε (2). The T/β type cytoplasm, typical of common cultivated potato (ssp. tuberosum) was absent in six released varieties (Kufri Chipsona-1/-2/-3 series, Kufri Jawahar, Kufri Megha and Kufri Himalini) and fifteen out of fifty two hybrids analyzed. This information was further used to predict cytoplasm type on the basis of common shared maternal pedigree in thirty-eight other advanced hybrids, which revealed majority (25) had T/ β type cytoplasm with W/ α and A/ ϵ cytoplasm observed in 12 and 1 genotype, respectively. T/β type cytoplasm was observed in all 28 early bulking hybrids studied along with all old genotypes. It was revealed that considerable broadening of maternal base was observed in recently developed genotypes. W/ α type cytoplasm was present in most of processing (all 3 chipping varieties and 9 of 12 MP hybrids) and late blight resistant (11of 23 hybrids) genotypes.

Keywords Cytoplasmic divergence · Introgression · Mitochondrial genome · Plastid genome · Potato

Abbreviations

cp-type Plastid genome type
T tuberosum type
A andigena type

GM Maternal grandmother

cpDNA Plastid DNA

mt-type Mitochondrial genome type

W Wild type

cpSSR Chloroplast simple sequence repeats
GGM Matrilineal great grandmother

mtDNA Mitochondrial DNA

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Introduction

Potatoes (Solanum tuberosum L. ssp. andigena) originated in the Andean mountains of South America and are adapted to tubering in short days. In



contrast, Chilean potatoes (S. tuberosum ssp. tuberosum) are adapted to tubering in long days. The potato is a highly heterozygous, autotetraploid crop that suffers inbreeding depression on selfing (Mendoza and Haynes 1974). There are no homozygous breeding lines in potato for exploiting heterotic vigour. The exploitation of a few South American clones, which were successfully introduced to Europe and USA during the 17th century, and their use in most of the potato breeding programmes worldwide resulted in a narrow genetic base of cultivated potatoes. This was further aggrevated by cytoplasmic-genetic male sterility, which restricts use of many genotypes as male parents in breeding. As a consequence, substantial gains in the yield potential of newly developed varieties have not been obtained. All these factors call for broadening of genetic base of cultivated potato.

S. tuberosum ssp. andigena has wide diversity and, therefore, has been extensively used in neo-tuberosum programmes (Glendinning 1983) and in effecting tuberosum × andigena crosses, which results in enhanced heterosis and vigour. In tuberosum × andigena crosses, yield gains are accompanied by reduced tuber size and increased male sterility (Maris 1989), while reciprocal cross is male fertile indicating that cytoplasm plays an important role in potato breeding (Grun 1990). Wild species have also been successfully used for introgression of many genes bearing desirable traits in potato. However, their use is limited due to lengthy prebreeding that often involves co-segregation of linked undesirable traits.

Considering the importance of organelle genomes (plastid and mitochondrial genomes) in potato breeding, their analysis is of immense use in studying introgression of agronomic traits. Typically, organelle genomes are haploid, non-recombinant and are usually maternally inherited. The very low mutation rates of organelle genomes as compared to the nuclear genome make them a powerful tool for such studies. Most cultivated Chilean potatoes (ssp. tuberosum) have T-type plastid DNA and β type mitochondrial genome, which is lacking in Andean potato ssp. andigena as well as wild Solanum species. Five basic cpDNA types (T/C/W/S/A) have been identified in cultivated landraces of potato (Hosaka and Hanneman 1988). These organelle genome types are not species specific but their frequencies vary in different species, with frequencies varying with latitude in the Andes within the same species. T cptype is linked to β mt-type (thereby defined as *tuberosum* mt genome), while mt-types α , γ and δ were found in combination with W cp-type in wild species; and mt-type ε was found in A- and S-type cultivated species (Lossl et al. 1999).

In a crop like potato, which is highly heterozygous and auto-tetraploid, organelle studies are expected to provide a better picture of available diversity. This study was therefore undertaken to analyse divergence revealed by plastid as well as mitochondrial genome type in thirty-eight Indian varieties and fifty-two advanced hybrids. The present study included three markers (H1, H2, H3) based on chloroplast genome deletion (Hosaka 2003) and four cpSSR markers (Provan et al. 1999), to investigate plastid genome type. Mitochondrial genome type was investigated using PCR analysis (ALM1 + 3, ALM4 + 5 and ALM6 + 7) specific for mitochondrial genome types (Lossl et al. 1999; 2000).

Materials and methods

Plant material and isolation of DNA

The present study included thirty-eight Indian varieties and fifty-two advanced hybrids (Table 1a, b). For DNA extraction, leaves were collected from 45 day old single plants grown in a glasshouse in the long summer days of Shimla (Latitude: 31.60 N, Longitude: 77.13 E, Altitude: 2202 msl). A modified CTAB method (Doyle and Doyle 1987) was used to isolate genomic DNA from 2 g of fresh leaves. The amount of DNA was quantified by spectrophotometer and quality was checked both by A260/280 ratio and by gel-electrophoresis.

Chloroplast and mitochondrial DNA markers

A total of ten PCR based markers consisting of three chloroplast deletions (H1, H2 and H3) (Hosaka 2003); four cpSSR (NTCP6, NTCP 8, NTCP 9 and NTCP 14) (Provan et al. 1999) and three mitochondrial PCR markers (ALM1 + ALM3; ALM4 + ALM5 and ALM6 + ALM7) (Lossl et al. 1999; 2000) were used in the present study (Table 2). H1 marker is known to amplify a 446 bp fragment in wild/andigena potato plastid genome region;



Table 1 (a) Details of Indian potato varieties used in present study

Wauseon T β Kennebec T β Kufri Lalima T β Ekishirazu T β SA 4485 T β SA 4485 T β A 53 MEX.750826 W α A 65 MEX.750826 W α A 5 MEX.750826 W α A 5 MEX.750826 W α A 60 Mex.750826 W α A 7 β β A 1 β β A 1 β β A 1 β β A 1 β β A 2 β β β A 3070 d(4) T β A 2 B	Variety	Female parent	Cp-type	Mt-type	Remarks including	Year of	Year of
A3649) Wauseon T β A3649) Kennebec T β Pl-376) Kufri Lalima T β Pl-376) EM/C-1020 T β (JF4870) Kufri Lalima T β nr (ON1202) Ekishirazu T β nr (ON1202) Ekishirazu T β a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-16) F-6 W α a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-16) F-6 W α a-2 (MP/91-16) F-6 W α SM85-45) SLB/1-132 T β SLB/1-132 T β T A(H222) Kutri Neelmani T β RSLB/E427) M109-3 T β RSLB/2 389) 3069 d(4) T β RSLA/2 389 1 T β RSLA/2 158) L		•			matrilineal pedigree	release	crossing
A3649) Kennebec T β A3649) Kufri Lalima T β P1-376) Kufri Lalima T β P1-376) Kufri Lalima T β IT β T β IT β T β IT β IT β IT β IT β IT β IT β SM85-45) SLB/J-132 W x SM85-45) SLB/J-132 W x SM85-45) SLB/J-132 W x SM85-45) SLB/J-132 W x SLB/J-132 W x x M109-3 T β SLB/Z-405(a) T β SLB/Z-405(a) T β SL1758) Lumbri T β GHybrid 9) Ekishirazu T β GHybrid 9) Ekishirazu T β <td>1. Atlantic</td> <td>Wauseon</td> <td>Т</td> <td>β</td> <td>Atlantic = Wauseon \times Lenape (with <i>S. chacoense</i> in pedigree)</td> <td></td> <td></td>	1. Atlantic	Wauseon	Т	β	Atlantic = Wauseon \times Lenape (with <i>S. chacoense</i> in pedigree)		
PJ-376) Kufri Lalima T β PJ-376) EMC-1020 T β PJ-376) EMKri Lalima T β r (JF4870) Kufri Jyoti T β r (MP00-83) Ekishirazu T β a-1 (MP90-83) MEX.750826 W α a-2 (MP91-63) F-6 W α a-1 (MP90-83) MEX.750826 W α s-1 (MP90-83) MEX.750826 W α crais S Defiance T β SWB5-45) SLB/1-132 T β SWB5-45) SLB/1-132 T β SLB/2-1515 Huffin Neelmani T β SLB/2-451 M109-3 T β 1 (SEA-1307) SLB/Z-405(a) T β 1 (SEA-1307) SLB/Z-405(a) T β 1 (Hybrid 9) Ekishirazu T β 1 (Hybrid 9) Ekishirazu T β 1 (A	2. Kufri Alankar (A3649)	Kennebec	Τ	β	GM = Seedling 96-56; GGM = Earlane	1968	1957
PJ-376) EM/C-1020 T β (JF4870) Kufri Jyoti T β nr (ON1202) Ekishirazu T β nukhi (A2708) Sd. 4485 T β a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-63) F-6 W α na-3 (MP/91-83) MP/91-86 W α na-3 (MP/91-53) F-6 W α craig's Defiance T β SM/85-45) SLB/J-132 T β SM/85-45) SLB/J-132 T β SLB/J-132 T β T SLB/J-132 T β SLB/Z-405(a) T β ro T aborky T β ro T aborky T β (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (A7416) Serkov T β	3. Kufri Arun (MS/92-2105)	Kufri Lalima	Τ	β	GM = Kufri Red	2004	1991
(JF4870) Kufri Jyoti T β ar (ON1202) Ekishirazu T β aukhi (A2708) Sd. 4485 T β a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-G) F-6 W α a-2 (MP/91-S83) MP/91-86 W α cha-3 (MP/91-583) MP/91-86 W α SM85-45) SLB/1-132 T β SM85-45) SLB/1-132 T β SM85-45) SLB/1-132 T β SLB/E427) M109-3 T β SLB/E427) M109-3 T β con Taborky T β stroked T β charmon T β charmon T β stroked T β stroked T β charmon T β charmon T β <th< td=""><td>4. Kufri Ashoka (PJ-376)</td><td>EM/C-1020</td><td>Т</td><td>β</td><td>I</td><td>1996</td><td>N.A.</td></th<>	4. Kufri Ashoka (PJ-376)	EM/C-1020	Т	β	I	1996	N.A.
uvkli (A2708) Ekishirazu T β uukli (A2708) Sd. 4485 T β a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-G3) F-6 W α na-3 (MP/91-583) MP/91-86 W α craig's Defiance T β SM/85-45) SLB/1-132 T β SM/85-45) SLB/1-132 T β SLB/222) Kufri Neelmani T β SLB/Z-405 M α α SLB/Z-389) 3069 d(4) T β stranding T β β r F β β r SER/C-1307) SUB/C-405(a) T β r SER/C-1307) Serkov T β r SER/C-1753) Kufri Red T β r SER/C-1753) Kufri Red T β r SER/C-1753) Katahdin T <td>5. Kufri Badshah (JF4870)</td> <td>Kufri Jyoti</td> <td>Т</td> <td>β</td> <td>GM = 3069 d(4)</td> <td>1979</td> <td>1963</td>	5. Kufri Badshah (JF4870)	Kufri Jyoti	Т	β	GM = 3069 d(4)	1979	1963
nukhi (A2708) Sd. 4485 T β a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-G) F-6 W α a-2 (MP/91-G) F-6 W α na-3 (MP/91-S83) MP/91-86 W α Craig's Defiance T β Craig's Defiance T β SM/85-45) SLB/132 T β SM/85-45) SLB/132 T β SUB/132 Kufri Neelmani T β SLB/2405 M109-3 T β SLB/2405 M109-3 T β SLB/Z-405(a) T β SI (Hybrid 9) Ekishirazu T β (BA/2153) Kufri Red T β (A7416) Serkov T β SLB/Z 785) Satabdin T β SLB/2 402) Grain's Dadace T β GESH/A 402 Grain's Dadace T β	6. Kufri Chamatkar (ON1202)	Ekishirazu	Т	β	I	1968	1943
a-1 (MP/90-83) MEX.750826 W α a-2 (MP/91-G) F-6 W α na-3 (MP/97-583) MP/91-86 W α α craig's Defiance T β α α α SM/85-45) SLB/J-132 T β α	7. Kufri Chandramukhi (A2708)	Sd. 4485	Τ	β	I	1968	1957
a-2 (MP/91-G) F-6 W α na-3 (MP/97-583) MP/91-86 W α craig's Defiance T β SM/85-45) SLB/J-132 T β SM/85-45) 11062 W α SM/85-45) 11062 W α SLB/J-132 T β (JH222) Kufri Neelmani T β SLB/Z-405 W α CB/Z-405 T β CB/Z-405 Caraixia T β CB/Z-405 Caraixia T β CB/Z-405 Caraixia <t< td=""><td>8. Kufri Chipsona-1 (MP/90-83)</td><td>MEX.750826</td><td>M</td><td>8</td><td>MEX.750826 (from Mexico)</td><td>1997</td><td>1989</td></t<>	8. Kufri Chipsona-1 (MP/90-83)	MEX.750826	M	8	MEX.750826 (from Mexico)	1997	1989
na-3 (MP/97-583) MP/91-86 W α SM/85-45) SLB/J-132 T β sm (SM/91-1515) I1062 W α in (SM/91-1515) I1062 W α sm (SM/91-1515) I1062 W α (JH222) Kufri Neelmani T β SLB/E427) M109-3 T β LB/Z 389) 3069 d(4) T β ro Taborky T β ro Taborky T β (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β (BS/C 1753) Sub/K-37 W α SLB/Z 785) 3046 (1) T β Craix's Dafeard T β T Craix's Dafeard T β Craix's Dafeard T <td< td=""><td>9. Kufri Chipsona-2 (MP/91-G)</td><td>F-6</td><td>M</td><td>8</td><td>F-6 (from Peru)</td><td>1997</td><td>1990</td></td<>	9. Kufri Chipsona-2 (MP/91-G)	F-6	M	8	F-6 (from Peru)	1997	1990
SM/85-45) Craig's Defiance T β ai (SM/91-1515) I1062 W α (JH222) Kufri Neelmani T β SLB/E427) M109-3 T β SLB/E427) M109-3 T β 1 (SE/1-1307) SLB/Z-405(a) T β 1 (SE/1-1307) SLB/Z-405(a) T β 1 (SE/1-1307) SLB/Z-405(a) T β S (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β SERk-37 W α SLB/Z-785) 3046 (1) T β SLB/Z-785) Katahdin T β Craix's Defiance T β Craix's Defiance T β Craix's Defiance T β R R R R R R R R R R R R R R R <	10. Kufri Chipsona-3 (MP/97-583)	MP/91-86	M	8	GM = F6 (from Peru)	2002	1996
SMM85-45) SLB/I-132 T β mi (SM/91-1515) Hu62 W α (JH222) Kufri Neelmani T β (SLB/E427) M109-3 T β SLB/E427) M109-3 T β LB/Z 389) 3069 d(4) T β ro Taborky T β ro Taborky T β (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/C 1753) Katahdin T β SLB/C 1753) Katahdin T β CHS/C 1753) Katahdin T	11. Kufri Dewa	Craig's Defiance	Т	β		1973	1959
in (SM/91-1515) I1062 W α (JH222) Kufri Neelmani T β SLB/E427) M109-3 T β LB/Z 389) 3069 d(4) T β 1 (SE/I-1307) SLB/Z-405(a) T β 1 (SE/I-1307) SLB/Z-405(a) T β 1 (SE/I-1307) Lumbri T β 1 (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/C 1753) Katahdin T β	12. Kufri Giriraj (SM/85-45)	SLB/J-132	Т	β	GM = 3345d(1)	1997	1985
(JH222) Kufri Neelmani T β SLB/E427) M109-3 T β LB/Z 389) 3069 d(4) T β 1 (SE/I-1307) SLB/Z-405(a) T β 1 (SE/I-1307) Taborky T β 1 (SE/I-1307) Taborky T β S1758) Lumbri T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β SLB/C 1753) Katahdin T β	13. Kufri Himalini (SM/91-1515)	11062	M	8	DM = 22%	2002	1999
SLB/E427) M109-3 T β LB/Z 389) 3069 d(4) T β n (SE/I-1307) SLB/Z-405(a) T β ro Taborky T β S1758) Lumbri T β (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/K-37 W α SLB/C 1753) Katahdin T β	14. Kufri Jawahar (JH222)	Kufri Neelmani	Т	β	GM = Kufri Kundan	1996	N.A.
LB/Z 389) 3069 d(4) T β 1 (SE/I-1307) SLB/Z-405(a) T β ro Taborky T β S1758) Lumbri T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β CRIS/S Katahdin T β CHEXCLOS Creig's Defences T β	15. Kufri Jeevan (SLB/E427)	M109-3	Н	β	M109-3 has complex pedigree (involving andigena var. Landiforme and <i>S. demissum</i> line S75)	1968	N.A.
r (SE/I-1307) SLB/Z-405(a) T β ro Taborky T β S1758) Lumbri T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β SLB/E 402) 3070 d(4) T β CHEXC166) Creitz's Defence T β CHEXC166) Creitz's Defence T β	16. Kufri Jyoti (SLB/Z 389)	3069 d(4)	Т	β	GM: 2182EF(7)	1968	N.A.
ro Taborky T β (Hybrid 9) Ekishirazu T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β (SLB/e 402) 3070 d(4) T β (HYM) T β	17. Kufri Kanchan (SE/I-1307)	SLB/Z-405(a)	L	β	SLB/Z-405 is a tuberosum \times andigena hybrid	2000	N.A.
S1758) Lumbri T β (Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β (A7416) SLB/K-37 W α SLB/Z 785) 3046 (1) T β (SLB/e 402) 3070 d(4) T β (HYX/166) Creig's Defences T β (HYX/166) Creig's Defences T β	18. Kufri Khasigaro	Taborky	Т	β	I	1968	1958
(Hybrid 9) Ekishirazu T β (BS/C 1753) Kufri Red T β (A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β (SLB/e 402) 3070 d(4) T β (HX/C166) Crein's Defence T β (HYM) T β	19. Kufri Kumar (S1758)	Lumbri	Т	β	I	1958	1943
(A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β SLB/Z 785) 3070 d(4) T β Chita's Defences T β Christ's Defences T β	20. Kufri Kundan (Hybrid 9)	Ekishirazu	Т	β	I	1958	1939
(A7416) Serkov T β SLB/K-37 W α SLB/Z 785) 3046 (1) T β (SLB/e 402) 3070 d(4) T β Al528) Katahdin T β Alfaxor, 166) Creig's Defences T β	21. Kufri Lalima (BS/C 1753)	Kufri Red	L	β	GM = Clonal selection of Darjeeling Red Round	1982	1964
SLB/K-37 W α SLB/Z 785) 3046 (1) T β (SLB/e 402) 3070 d(4) T β .1528) Katahdin T β .HEX/C166) Croin's Defence T β	22. Kufri Lauvkar (A7416)	Serkov	Т	β	I	1972	1957
3046 (1) T β 3070 d(4) T β Katahdin T β	23. Kufri Megha	SLB/K-37	W	8	GM = Z-443	1989	N.A.
$3070 \text{ d}(4)$ T β Katahdin T β	24. Kufri Muthu (SLB/Z 785)	3046 (1)	Т	β	I	1971	N.A.
Katahdin T β	25. Kufri Naveen (SLB/e 402)	3070 d(4)	T	β	GM = 2182EF	1968	1962
Crain's Defiance	26 Kufri Neela (A1528)	Katahdin	T	β	GM = USDA40568	1963	1957
Ctaig s Denance 1 p	27. Kufri Pukhraj (JEX/C166)	Craig's Defiance	Τ	β	Kufri Pukhraj = $tuberosum \times$ andigena hybrid	1997	1978



frii Pushkar (JW-160) QB/A 9-1. Ifri Red Darjeeling frii Shailaja (SM/87-185) Rufri Jyot frii Sheetman (C3745) Craig's Do Griffi Sherpa (F5242) Ultimus frii Sindhuri (C140) Kufri Red frii Bahar (E3797) Kufri Red frii Surya (HT/92-621) Kufri Bah frii Swama (O 5) Kufri Bah Kufri Jyot Kufri Jyot Kufri Jyot Kufri Jah Kufri Jah Kufri Jah Kufri Jah	ar T T T T T T T T T T T T T T T T T T T	pe Mt-type \(\beta \) \(\be	Remarks including matrilineal pedigree Clonal selection of Darjeeling Red Round GM = 3069 d(4) Kufri Shailaja: tuberosum × andigena hybrid - GM = Rhode Star, GGM = Prof. Wohltman GM = Clonal selection of Darjeeling Red Round GM = Clonal selection of Darjeeling Red Round GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S. vernei</i> in pedigree GM = EM/C 1020		Year of crossing 1994 - 1987 1963 1959 1961 N.A. 1972
28. Kufri Pushkar (JW-160) 29. Kufri Red 30. Kufri Shailaja (SM/87-185) 31. Kufri Sheetman (C3745) 32. Kufri Sherpa (F5242) 33. Kufri Sindhuri (C140) 34. Kufri Surya (HT/92-621) 35. Kufri Surya (HT/92-621) 36. Kufri Surya (HT/92-61) 37. Kufri Swarna (O 5) 38. Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri	ted Round ance ar	<u> </u>	Clonal selection of Darjeeling ReGM = 3069 d(4) Kufri Shailaja: tuberosum × andigena hybrid — GM = Rhode Star, GGM = Prof. Wohltman GM = Clonal selection of Darjeel Round GM = Clonal selection of Darjeel Round GM = Serkov GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has S in pedigree GM = EM/C 1020		1994 - 1987 1959 1961 1961 N.A. 1972
29. Kufri Red 30. Kufri Shailaja (SM/87-185) Kufri Jyoti 31. Kufri Sheetman (C3745) Craig's Def 32. Kufri Sherpa (F5242) Ultimus 33. Kufri Sindhuri (C140) Kufri Red 34. Kufri Surya (HT/92-621) Kufri Red 35. Kufri Surya (HT/92-621) Kufri Bahai 36. Kufri Swarna (O 5) Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri	ted Round ance ar ar	<i>~~ ~~ ~ ~ ~ ~ ~ ~</i>	Clonal selection of Darjeeling ReGM = 3069 d(4) Kufri Shailaja: tuberosum × andigena hybrid – GM = Rhode Star, GGM = Prof. Wohltman GM = Clonal selection of Darjeel Round GM = Clonal selection of Darjeel Round GM = Serkov GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		- 1987 1959 1963 1961 1991 N.A. 1972
 30. Kufri Shailaja (SM/87-185) 31. Kufri Sheetman (C3745) 32. Kufri Sherpa (F5242) 33. Kufri Sindhuri (C140) 34. Kufri Bahar (E3797) 35. Kufri Surya (HT/92-621) 36. Kufri Sutlej (15857) 37. Kufri Swarna (O 5) 38. Kufri Anand (MS/92-717) 39. Kufri Anand (MS/92-717) 30. Advanced hybrid lines -chloroplast andmitochondri 	ance ar a	<u>~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ </u>	GM = 3069 d(4) Kufri Shailaja: tuberosum × andigena hybrid GM = Rhode Star, GGM = Prof. Wohltman GM = Clonal selection of Darjeel Round GM = Clonal selection of Darjeel Round GM = Serkov GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		1987 1959 1963 1961 1991 N.A.
 31. Kufri Sheetman (C3745) Craig's Del 32. Kufri Sherpa (F5242) Ultimus 33. Kufri Sindhuri (C140) Kufri Red 34. Kufri Bahar (E3797) Kufri Red 35. Kufri Surya (HT/92-621) Kufri Lauv 36. Kufri Sutlej (I5857) Kufri Baha 37. Kufri Swarna (O 5) Kufri Byoti 38. Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri 	ar ar	<i>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</i>			1959 1963 1959 1961 N.A. 1972
32. Kufri Sherpa (F5242) 33. Kufri Sindhuri (C140) 34. Kufri Bahar (E3797) 35. Kufri Surya (HT/92-621) 36. Kufri Surlej (15857) 37. Kufri Swarna (O 5) 38. Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri	ar a	<i>a a a a a a</i>	GM = Rhode Star, GGM = Prof. Wohltman GM = Clonal selection of Darjeel Round GM = Clonal selection of Darjeel Round GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		1963 1959 1961 1991 N.A. 1972
33. Kufri Sindhuri (C140) 34. Kufri Bahar (E3797) 35. Kufri Surya (HT/92-621) 36. Kufri Sutlej (15857) 37. Kufri Swarna (O 5) 38. Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri	ar a	<i>a a a a a</i> a	GM = Clonal selection of Darjeel Round GM = Clonal selection of Darjeel Round GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		1959 1961 1991 N.A. 1972
 34. Kufri Bahar (E3797) 35. Kufri Surya (HT/92-621) 36. Kufri Sutlej (15857) 37. Kufri Swama (O 5) 38. Kufri Anand (MS/92-717) 39. Kufri Anand (MS/92-717) 30. Kufri Ashoital lines -chloroplast andmitochondri 	ar a	<i>a</i> aaa a	GM = Clonal selection of Darjeel Round GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		1961 1991 N.A. 1972
35. Kufri Surya (HT/92-621) Kufri Lauvi 36. Kufri Sutlej (15857) Kufri Bahaa 37. Kufri Swarna (O 5) Kufri Jyoti 38. Kufri Anand (MS/92-717) Kufri Asho (b) Advanced hybrid lines -chloroplast andmitochondri	ar a	<i>~~~~</i>	GM = Serkov GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree GM = EM/C 1020		1991 N.A. 1972
36. Kufri Sutlej (15857) Kufri Baha 37. Kufri Swarna (O 5) Kufri Jyoti 38. Kufri Anand (MS/92-717) Kufri Asho (b) Advanced hybrid lines -chloroplast andmitochondri	æ	<i>Q Q Q</i>	GM = Kufri Red Male parent (VTn) ² 62.33.3 has <i>S</i> in pedigree $GM = EM/C 1020$		N.A. 1972 1991
37. Kufri Swarna (O 5) Kufri Jyoti 38. Kufri Anand (MS/92-717) Kufri Asho (b) Advanced hybrid lines -chloroplast andmitochondri		8 8	Male parent $(VTn)^2$ 62.33.3 has <i>S</i> in pedigree $GM = EM/C$ 1020		1972
38. Kufri Anand (MS/92-717) Kufri Ashoi (b) Advanced hybrid lines -chloroplast andmitochondri		β		000	1991
(b) Advanced hybrid lines -chloroplast andmitochondri				1999	
	al genome type				
Name Maternal parent C	Cp-type Mt-type	pe Remarks	Y tr	Year of introduction to AICPIP trials	Year of crossing
I. 83-P-47 JI 5857 T	θ	GM = Kt	GM = Kufri Bahar	1994	1983
2. 94-P-31 86-P-40 T	β	$GM = K_1$		2001	1994
		94-P-31 :	а		
	β	Cruza-27	Cruza-270 (Peruvian accession)	2001	1994
4. B-420(2) 387415.47 T	β	387415.47 (CIP)		2002	1995
5. Ex/A 680-16 N0.507.14 A	83	I	2	2002	1993
6. HB/83-39 VB/A-64 W	8	GM = VB-8		1992	1982
7. HT/93-707 Kufri Laukar T	β	GM = Serkov		2001	1992
8. J/92-13 JN2207 T	β	GM = JF4920		2000	1661
9. J/92-164 JN2207 T	β	GM = JF4920		2000	1991
10. J/92-167 JN2207 T	β	GM = JF4920		2000	1991
11. J/93-139 Croft T	β	GM: 2895F(G)		2000	1992
12. J/93-4 Kufri Jyoti T	β	GM = 3069 d(4)		2001	1992



Table 1 continued

13. D93-58 National parent CP-type Mt-type Remarks National Action CP-type Mt-type Remarks National Action National Actional	Advanced hybrid	Solution of the second of the	t emonen leinbuche	ou.			
Kufri Pukhraj T Metype Remarks Year of introduction Croft T β GM = Croig's Defiance 2002 Croft T β GM = 2895F(G) 2001 Croft T β GM = 2895F(G) 2001 MSR2-GS8 T β GM = TN46 2001 MSR2-GS8 T β GM = TN46 2002 MSR2-GS8 T β GM = TN46 2002 MSR2-GS8 T β GM = TN46 2002 Krime T β GM = AZ708 2002 MFR12 T β GM = AZ708 2003 MP92-35 W a GGM: Mariamaza (CIP) 2003 MP92-35 W a GGM: Mariamaza (CIP) 2003 MP91-35 W a GGM: GGM: GGM: GGM: GGM: GGM: GGM: GGM:	(U) Auvaliceu IIyullu	IIIIcs -ciii010piast anuiii100	iloliuliai geliolile t	ype			
Kufir Palkraj T β GMA = Cang's Definee 2002 Croft T β GM = 2895F(G) 2001 Croft T β GM = 2895F(G) 2001 MSR2-G88 T β GM = IN46 2001 MSR2-G88 T β - 2002 MSR2-G89 T β - 2002 Krime T β - 2002 Krime T β - 2003 JY712 T β GMI- AZ708 1996 MRP02-35 W x GMI- GA7-4 2003 MRP02-35 W x GMI- GA7-4 2003 MRP02-35 W x GMI- GA7-4 2003 MRP02-36 W x GMI- GA7-4 20	Name	Maternal parent	Cp-type	Mt-type	Remarks	Year of introduction to AICPIP trials	Year of crossing
Croft T β GM = 2895FGO) 2001 MSR92-438 T β GM = 1895FGO) 2000 MSR92-438 T β GM = 1N46 2000 MSR92-438 T β - 2000 EB/C 899 T β - 1992? Krime T β - 2003 JY712 T β - 2003 MP92-35 W α GMI Mutranzara(IP) 2003 MP92-35 W α GMI Mutranzara(IP) 2003 MP93-50 W α GMI Mutranzara(IP)	13. J/93-58	Kufri Pukhraj	Т	β	GM = Craig's Defiance	2002	1992
Croft T β GM = 2895FGO) 2000 MSR82-638 T β GM = 1N46 2001 BBC 899 T β - 1992? BBC 899 T β - 1992? Krime T β - 2003 JY712 T β - 2003 JW712 T β GMI-A2708 1996 JW712 T β GMI-A2708 1996 MP92-35 W z GMI-Muriamazara(CIP) 2003 MP92-35 W z GMI-GMI-GA-A-5 2003 MP92-35 W z GMI-GMI-GA-A-5 2003 MP91-16 T β GMI-GMI-GA-A-5 2004 <	14. J/93-77	Croft	Т	β	GM = 2895F(G)	2001	1992
MS/82-638 T β GM = 1N46 2001 BMS/82-638 T β - 2000 BMS/82-638 T β - 1992? Krimme T β - 2003 NY12 T β GM = A2708 1996 NP92-35 W Z GMi G-ZA-5 2003 NP92-35 W Z GMi Murimuzara(CIP) 2003 NP91-84 W Z GGHi G-ZA-5 2003 NP91-85 W Z GGHi G-ZA-5 2003 NP91-80 T β GGHi G-ZA-5 2003 NP91-81 W Z GGHi G-ZA-5 2003 NP91-82 T β GAHi G-ZA-5 2004 NP91-82 T β GAHi G-ZA-5	15. J/93-81	Croft	Т	β	GM = 2895F(G)	2000	1992
MSN82-638	16. J/93-86	MS/82-638	Т	β	GM = JN46	2001	1992
EB/C 899 T β — 2002 Krimme T β — 1992? JY712 T β — 2003 JY712 T β — 2003 JY712 T β GM = A2708 1996 MP92-35 W a GMi GM = A2708 1996 MP92-35 W a GMi GM = A2708 1996 MP92-35 W a GMi GM = A2708 1996 MP91-83 W a GMi GM = A2708 2003 MP91-84 W a GMi GM = A2708 2003 MP91-85 W a GMi GM = GAL - S 2003 MP91-87 W a GMi GM = GAL - S 2003 MP91-88 W a GM: GM: GM = GAL - S 2005 MP91-76 T β GM: GM: GM = GAL - S 2005 Kufi Jyoti T β GM: GM: GM = GAL - S 2004 MS82	17. J/93-87	MS/82-638	Т	β	GM = JN46	2000	1992
Krirme T β - 1992? JY712 T β - 2003 JY712 T β - 2003 JY712 T β - 2003 JY712 T β GM: Abritamizara (CIP) 2003 JE812 T A GM: Muziramzara (CIP) 2003 MP92-35 W z GM: Muziramzara (CIP) 2003 MP92-154 W z GM: GB/B 924 2003 MP91-154 W z GGM: GB/B 924 2003 MP91-154 W z GGM: GB/B 924 2003 MP91-156 W z GGM: GB/B 924 2003 MP91-16 T β GGM: GB/B 924 2003 MF91-16 T β GM: GB/B 924 2003 MF91-16 T β GM: GB/B 924 2003 MF91-16 T β GM: GB/B 924 2003 MS81-16 T <td>18. J/94-90</td> <td>EB/C 899</td> <td>Т</td> <td>β</td> <td>I</td> <td>2002</td> <td>1993</td>	18. J/94-90	EB/C 899	Т	β	I	2002	1993
HY712 T β - 2003 HY712 T β - 2003 HY712 T β - 2003 JF812 T β GM = A2708 1996 MP92-35 W z GMi G-ZA-5 2003 MP92-154 W z GMi G-ZA-5 2003 MP91-83 W z GMi G-ZA-5 2003 MP91-76 W z GMi G-ZA-5 2005 MP91-76 T β GMi G-ZA-5 2005 MP91-76 T β GMi G-ZA-5 2005 MP91-76 T β GMi G-ZA-5 2005 MF91-76 T β GMi G-ZA-5 2005 MS91-76 T β GMi G-ZA-5 <td>19. JX/108</td> <td>Krirrne</td> <td>Т</td> <td>β</td> <td>I</td> <td>1992?</td> <td>1985?</td>	19. JX/108	Krirrne	Т	β	I	1992?	1985?
JY712 T β – 2003 JF712 T β – 2003 JE812 T β GM = A2708 1996 MP92-35 W z GM: Muziranzara(IP) 2003 MP92-35 W z GM: Muziranzara(IP) 2003 MP92-35 W z GM: GAX-A-5 2003 MP91-30 W z GM: GBM 92-4 2003 MP91-31 W z GM: GBM 92-4 2003 MP91-30 W z GM: GBM 92-4 2003 MP91-31 W z GM: GBM 92-4 2003 MP91-30 W z GM: GBM 92-4 2003 MP91-30 W z GM: GBM 92-4 2003 MF01-16 T β GM: GBM: GBM 44 1998 MF081-145 T β GM = JN46 2003 MS/82-638 T β GM = JN46 2003 MS/83-539	20. J/95-227	JY712	Т	β	I	2003	1994
JY712 T β — 2003 JE812 T β GM = A2708 1996 MP92-35 W α GM: Muziranzara(CIP) 2003 MP92-35 W α GM: Muziranzara(CIP) 2003 MP92-36 W α GM: GSM: 65-ZA-5 2003 MP91-37 W α GM: GBB 92-4 2003 MP91-38 W α GM: GBB 92-4 2003 MP91-39 W α GM: GBB 92-4 2003 MP91-30 W α GM: GBB 92-4 2003 MP91-30 W α GM: GBB 92-4 2003 MP91-30 W α GM: GBB 92-4 2003 MP91-46 T β GM: GBB 92-4 2003 MS/81-145 T β GM: GBB 1N46 2003 MS/82-638 T β GM: GBB 1N46 2003 MS/82-639 W α CM: GBB 1N46 2003 MS/	21. J/95-229	JY712	Т	β	I	2003	1994
JEB12 T β GM = A2708 1996 MP/92-35 W z GM: Muziranzara(CIP) 2003 MP/92-35 W z GM: Muziranzara(CIP) 2003 MP/92-154 W z GM: GA: A-5 2003 MP/91-83 W z GM: GB/B 92-4 2003 MP/91-94 W z GM: GB/B 92-4 2003 MP/91-154 W z GM: GB/B 92-4 2003 MP/91-156 T β GM: 3069 d(4) 1908 MP/91-176 T β GM: 3069 d(4) 1908 MS/81-145 T β TS4 (from Peru) 1908 MS/81-145 T β TS4 (from Peru) 2001 MS/82-038 W z GM = JN46 2003 MS/82-398 W z 2013 2003 MS/83-398 W z 2013 2003 MS/83-39 T β GM = MI24-2 1993	22. J/95-242	JY712	Т	β	I	2003	1994
MP/92-35 W α GGM: 65-ZA-5 2003 MP/92-35 W α GGM: 65-ZA-5 2003 MP/92-154 W α GGM: 65-ZA-5 2003 MP/92-154 W α GGM: 65-ZA-5 2003 MP/92-154 W α GGM: QB/B 92-4 2003 MP/92-154 W α GGM: QB/B 92-4 2003 MP/91-164 T β GM: QB/B 92-4 2003 MP/91-165 T β GM: QB/B 92-4 2003 Kufri Jyoti T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/82-GS T β GM: 3069 d(4) 1998 MS/82-GS T β GM: 3069 d(4) 2001 MS/83-GS T β GM: 3069 d(4) 2002 MS/83-SS W α T GM: 3069 d(4) 2002 MS/83-SS W α GM: 3069 d(4)	23. JX/576	JE812	Т	β	GM = A2708	1996	1985
MP/92-35 W z GGM: 65-ZA-5 MP/92-154 W z GGM: 65-ZA-5 MP/92-154 W z GGM: 65-ZA-5 MP/91-83 W z GM: QB/B 92-4 2003 MP/91-83 W z GM: QB/B 92-4 2003 MP/91-83 W z GM: QB/B 92-4 2003 MP/91-76 T β GM: QB/B 92-4 2005 MP/91-76 T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β GM: 3069 d(4) 1998 MS/81-145 T β GM: 3069 d(4) 1998 MS/81-145 T β GM: 3069 d(4) 1998 MS/82-638 T β GM: 3069 d(4) 2002 MS/83-398 W x x 2002 MS/83-39 T β <td>24. MP/97-625</td> <td>MP/92-35</td> <td>×</td> <td>8</td> <td>GM: Muziranzara(CIP)</td> <td>2003</td> <td>1996</td>	24. MP/97-625	MP/92-35	×	8	GM: Muziranzara(CIP)	2003	1996
MP/92-35 W α GM: Muziranzara(CIP) 2003 MP/92-154 W α GGM: 65-ZA-5 2003 MP/91-83 W α GM: QB/B 92-4 2003 MP/91-83 W α GM: QB/B 92-4 2005 MP/91-76 T β CM: QB/B 92-4 2005 MP/91-76 T β GM: 3069 d(4) 1908 MP/91-76 T β GM: 3069 d(4) 1908 MP/91-76 T β GM: 3069 d(4) 1908 MS/81-145 T β GM: 3069 d(4) 1908 MS/81-145 T β GM: 3069 d(4) 1908 MS/81-145 T β GM: 3069 d(4) 1908 MS/82-638 T β GM: 3069 d(4) 2001 MS/82-638 T β GM: 3069 d(4) 2002 MS/83-106 W α CM: 3060 d(4) 2002 MS/83-108 W α CM: 3060 d(4) 2003					GGM: 65-ZA-5		
MP/92-154 W α GGM: QB/B 92-4 2003 MP/91-83 W α GM: QB/B 92-4 2003 MP/91-83 W α GM: QB/B 92-4 2005 MP/92-30 W α GM: QB/B 92-4 2005 MP/92-30 W α 2005 2005 MP/91-76 T β GM: 3069 d(4) 1998 2005 Kufri Jyoti T β GM: 3069 d(4) 1998 2005 MS/81-145 T β TS4 (from Peru) 2005 2006 TS4 T β GM = JN46 2001 2002 MS/82-638 T β GM = JN46 2002 2004 MS/82-398 W α 2002 2003 MS/83-279 W α 27/15 (from Peru) 2003 SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VM/46+4 2002	25. MP/97-644	MP/92-35	Α	ষ	GM: Muziranzara(CIP)	2003	1996
MP/92-154 W z GM: QB/B 92-4 2003 MP/91-83 W z GM: QB/B 92-4 2005 MP/91-83 W z 2005 MP/91-30 W z 2005 MP/91-76 T β GM: 3069 d(4) 2005 MP/91-76 T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β GM: 3069 d(4) 1998 MS/82-638 T β GM: 3069 d(4) 2003 MS/83-398 W α α α MS/83-379 W α α α α SLB/1132 <td></td> <td></td> <td></td> <td></td> <td>GGM: 65-ZA-5</td> <td></td> <td></td>					GGM: 65-ZA-5		
MP/91-83 W α 2005 MP/92-30 W α 2005 MP/91-76 T β 2005 MP/91-76 T β GM: 3069 d(4) 2005 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β GM: 3069 d(4) 1998 MS/82-638 T β GM: 3069 d(4) 1998 MS/82-638 T β GM: 3069 d(4) 2000 JEX/C1-66 T β GM: 3069 d(4) 2001 MS/82-638 T β GM: 3069 d(4) 2002 MS/83-398 T β GM: 3069 d(4) 2002 MS/83-398 W α CM: 3060 2002 MS/83-398 W α CM: 3060 2003 MS/83-398 W α CM: 3060 2003 MS/83-398 W α CM: 3060 2003 SLM132 T β	26. MP/97-921	MP/92-154	M	ខ	GM: QB/B 92-4	2003	1996
MP/92-30 W α 2005 MP/91-76 T β 2005 MP/91-76 T β 2005 Kufri Jyoti T β GM: 3069 d(4) 1998 Kufri Jyoti T β TS4 (from Peru) 2000 MS/81-145 T β TS4 (from Peru) 2001 TS4 T β GM = JN46 2002 MS/82-638 T β GM = JN46 2002 JEX/C-166 T β GM = JN46 2002 MS/83-398 W α 2002 MS/83-279 W α 2016 MS/83-398 W α 2016 2003 SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	27. MP/98-172	MP/91-83	M	8		2005	1997
MP/92-30 W α 2005 MP/91-76 T β 2005 MP/91-76 T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β TS4 (from Peru) 2000 TS4 T β GM = JN46 2001 JEX/C-166 T β GM = JN46 2002 MS/83-398 W α 2002 MS/83-379 W α 2003 SLB/J132 A κ 27/15 (from Peru) 2003 SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	28. MP/98-31		Т	β		2005	1997
MP/91-76 T β 2005 MP/91-76 T β GM: 3069 d(4) 1998 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β TS4 2000 TS4 T β TS4 (from Peru) 2001 MS/82-638 T β GM = JN46 2002 JEX/C-166 T β GM = JN46 2002 MS/83-279 W α 2002 MS/83-279 W α 2003 SLB/J132 T β GM = WI24-2 1993 HB/83-39 T β GM = VB/A-64 2002	29. MP/98-71	MP/92-30	×	8		2005	1997
MP/91-76 T β GM: 3069 d(4) 2005 Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β TS4 (from Peru) 2000 TS4 T β TS4 (from Peru) 2001 MS/82-638 T β GM = JN46 2002 JEX/C-166 T β GM = JN46 2002 MS/83-398 W α 2002 MS/83-279 W α 2003 SLJ/15 A ϵ 27/15 (from Peru) 2003 SLJ/15 A ϵ CM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	30. MP/99-322	MP/91-76	Т	β		2005	1998
Kufri Jyoti T β GM: 3069 d(4) 1998 MS/81-145 T β TS4 (from Peru) 2000 TS4 T β TS4 (from Peru) 2001 MS/82-638 T β GM = JN46 2002 JEX/C-166 T β CM 2002 MS/83-398 W α 2002 MS/83-279 W α 2003 SLJ/15 A ϵ 27/15 (from Peru) 2003 SLB/1132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	31. MP/99-406	MP/91-76	Т	β		2005	1998
MS/81-145 T β TS4 (from Peru) 2000 TS4 T β TS4 (from Peru) 2001 MS/82-638 T β GM = JN46 2002 JEX/C-166 T β CM 2002 MS/83-398 W α 2003 MS/83-279 W α 27/15 (from Peru) 2003 SLB/1132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	32. MS/92-1090	Kufri Jyoti	Т	β	GM: 3069 d(4)	1998	1991
TS4 T β TS4 (from Peru) 2001 MS/82-638 T β GM = JN46 2000 JEX/C-166 T β α 2002 MS/83-398 W α	33. MS/93-1344	MS/81-145	Т	β		2000	1992
MS/82-638 T β GM = JN46 2000 JEX/C-166 T β GM = JN46 2002 MS/83-398 W α 2002 MS/83-279 W α 27/15 (from Peru) 2003 SLB/115 A ϵ 27/15 (from Peru) 2003 SLB/1132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	34. MS/94-1118	TS4	Т	β	TS4 (from Peru)	2001	1993
JEX/C-166 T β 2002 MS/83-398 W α 2002 MS/83-279 W α 2003 27/15 A ϵ 27/15 (from Peru) 2003 SLB/1132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	35. MS/94-899	MS/82-638	Т	β	GM = JN46	2000	1993
MS/83-398 W α 2002 MS/83-279 W α 2003 27/15 A ϵ 27/15 (from Peru) 2003 SLB/1132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	36. MS/95-117	JEX/C-166	Т	β		2002	1994
06 MS/83-279 W α 2003 1 27/15 A ϵ 27/15 (from Peru) 2003 SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	37. MS/95-1309	MS/83-398	*	8		2002	1994
1 27/15 A ϵ 27/15 (from Peru) 2003 SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	38. MS/97-1606	MS/83-279	*	8		2003	1996
SLB/J132 T β GM = M124-2 1993 HB/83-39 T β GM = VB/A-64 2002	39. MS/97-621	27/15	A	ಬ	27/15 (from Peru)	2003	1996
HB/83-39 T β GM = VB/A-64 2002	40. SM/85-50	SLB/J132	Т	β	GM = M124-2	1993	1985
	41. SM/94-44	HB/83-39	Т	β	GM = VB/A-64	2002	1994



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(b) Advanced hybrid	(b) Advanced hybrid lines -chloroplast andmitochondrial genome type	ndrial genome	type				
Name	Maternal parent	Cp-type	Mt-type	Remarks		Year of introduction to AICPIP trials	Year of crossing
42. SM/87-151	Kufri Jyoti	T	β	GM = 3069 d(4)	(4)	2000	1987
43. SM/87-55	Kufri Jyoti	T	β	GM = 3069 d(4)	(4)	1996	1987
44. SM/88-343	Kufri Megha	W	8	GM = SLB/K-37	75-37	1997	1988
				GGM = Z-443	13		
45. SM/88-991	I 1062 (Sita)	H	β			1997	1988
46. SM/90-45	HB/82-372	W	ช	GM: VB/A-64	4	2000	1990
47. SM/92-168	HB/82-372	W	ช	GM: VB/A-64	4	2001	1992
48. SM/93-237	SS/C-562	W	ង	DM = 22%		2002	1993
49. SM/94-137	I	T	β			N.A.	1994
50. SM/95-43	CP2380	W	λ	DM = 22%		2005	1995
51. SM/94-82		W	8			N.A.	1994
52. SM/96-127	Kufri Jyoti	Т	β	DM = 22%;	= 22%; GM = 3069 d(4)	2005	1996
(c) Predicted advance	(c) Predicted advanced hybrids -chloroplast and mi	mitochondrial genome type	ome type				
Name	Maternal parent	Cb-	Cp-type N	Mt-type N	Maternal parents	AICPIP	Year of
					pedigree	introduction	crossing
1. OP1	EX/A680-16 selfed	A	ట	9	GM = N0.507.14	N.A.	N.A.
2. PS/M-75	Kufri Jawahar	W	8		GM = Kufri Neelamani	1990	N.A.
3. PS/M-98	Kufri Jawahar	W	8		GM = Kufri Neelamani	1989	N.A.
4. 83-P-12	Kufri Jawahar	W	8		GM = Kufri Neelamani	1994	1983
5. 85-P-621	Kufri Bahar	T	β		GM = Kufri Red	1993	1985
6. 85-P-670	Kufri Bahar	T	β	9	GM = Kufri Red	1993	1985
7. 85-P-718	Kufri Bahar	T	β		GM = Kufri Red	1993	1985
8. 83-P-47	Kufri Sutlej	T	β	5	GM: Kufri Bahar	1994	1983
9. 86-P-111	Kufri Chandramukhi	T	β		GM = Sd.4485	1995	1986
10. 94-P-5	86-P-40	Т	β		GM: Kufri Chandramukhi	2001	1994
11. J/93-68	Kufri Pukhraj	Т	β		GM = Craig Defiance	2001	1992
12. J/92-159	JN2207	T	β		GM = JF4920	1999	1991
13. JX1	Kufri Jyoti	T	β		GM = 3069 d(4)	1994	N.A.
14. JX23	Kufri Jyoti	L	β		GM = 3069 d(4)	1995	N.A.
15. JX24	Kufri Jyoti	T	β	D	GM = 3069 d(4)	1994	N.A.



Table 1 continued

(c) Predicted advanced hy	(c) Predicted advanced hybrids -chloroplast and mitochondrial genome type	al genome type				
Name	Maternal parent	Cp-type	Mt-type	Maternal parents pedigree	AICPIP introduction	Year of crossing
16. JX14	JE812	Т	β	GM = A 2708	1993	N.A.
17. JX123	JE812	T	β	GM = A 2708	1992	N.A.
18. JX161	JE812	T	β	GM = A 2708	1993	N.A.
19. JX216	JE812	T	β	GM = A 2708	1995	N.A.
20. JX254	JE812	T	β	GM = A 2708	1994	N.A.
21. MS/95-117	Kufri Pukhraj	Т	β	GM = Craig Defiance	2002	1994
22. MS/85-163	Kufri Lalima	T	β	GM = Kufri Red	1992	1984
23. MS/92-3128	MS/82-638	Т	β	GM = JN46	1998	1991
24. MS/72-3146	MS/82-638	Т	β	GM = JN46	1999	1971
25. MS/98-1095	Kufri Jawahar	W	8	GM = Kufri Neelamani	N.A.	1997
26. MP/97-637	MP/92-35	W	8	GM: Muziranzara	2003	1996
27. MP/97-699	MP/91-65	W	8	GM: POOS16	2003	1996
28. MP/90-94	MEX750826	W	8		1996	1989
29. MP/91-23(G)	F6	W	8		1996	1990
30. HB/82-372	VB/A-64	W	8	GM: VB-8	1991	1982
31. HB/83-185	VB/A-132	W	8	GM: VB-8	1993	1983
32. SM/85-50	SLB/J132	T	β	GM: M-124-2	1993	1985
33. SM/85-41	SLB/J132	T	β	GM: M-124-2	1994	1985
34. SM/85-45	SLB/J132	L	β	GM: M-124-2	1995	1985
35. SM/85-60	SLB/J132	Т	β	GM: M-124-2	1995	1985
36. SM/87-55	Kufri Jyoti	L	β	GM: 3069D	1996	1987
37. SM/85-162	VB/A-85	W	8	GM: VB-8	1995	1985
38. SM/92-338	HB/82-372	W	8	GM: VB/A-64	2001	1992

Bold indicate non tuberosum type cytoplasm

T-tuberosum type plastid genome; W- wild type plastid genome; A-andigena type plastid genome

GM-Maternal grandmother; GGM-Matrilineal Great Grandmother

DM = dry matter (given only in genotypes not developed specifically for Processing purpose)

N.A. = not available

AICPIP—All India Coordinated Potato Improvement Project



Table 2 Details of markers used for plastid genome/mitochondrial genome analysis

Marker	Se	quence	Region amplified	Туре
H1 marker	F R	5' GGAGGGGTTTTTCTTGGTTG 3' 5' AAGTTTACTCACGGCAATCG 3'	ndhlC/trn intergenic	241 bp cpDNA deletion specific PCR
H2 marker	F	5' GCATCGAGCGTGTTGTTGGA 3'	rbcL gene	PCR -RFLP (HaeIII)
H3 marker	R F	5' AGTCCACCGCGAAGACATTC 3' 5' CAGGGGTCCATTCCCTTGAC 3'	ycf4 and ycf10	PCR-RFLP (DraI)
NTCP6	R F	5' AGAAAGAAATCCACCAGGGC 3' 5' GGT TCG AAT CCT TCC GTC 3'	rps16/trnQ intergenic	Chloroplast SSR
NTCP8	R F	5' GAT TCT TTC GCA TCT CGA TTC 3' 5' ATA TTG TTT TAG CTC GGT GG 3'	trnG intron	Chloroplast SSR
NTCP9	R F	5' TCA TTC GGC TCC TTT ATG 3' 5' CTT CCA AGC TAA CGA TGC 3'	trnG/trnR intergenic region	Chloroplast SSR
NTCP14	R F	5' CTG TCC TAT CCA TTA GAC AAT G 3' 5' AATCCGTAGCCAGAAAAATAAA 3'	psbM/trnD intergenic	Chloroplast SSR
ALM1	R 5′	5' CCGATGCATGTAATGGAATC 3' CAC AAA TCC ATC TTT GTT TAT GC 3'	atp6	$\alpha + \gamma$ types = 1.2 kb Others = nil
ALM3 ALM4		GCG TTG GCT TAC ACG GAA ACT AG 3' AAT AAT CTT CCA AGC GGA GAG 3'	cob, rps10	α type = 2.4 kb, β type = 1.6 kb,
ALM5 ALM6	_	AAG ACT CGT GAT TCA GGC AAT 3' AAT TAG GCC CGG CTA GGA ACA 3'	cob	Others = nil γ types = 2.4 kb, Others = nil
ALM7	5′	AAC CCA GTC CCT ATG GTA TCT CCT 3'		

however, ssp. *tuberosum* is known to amplify fragment of 205 bp size, thereby indicating a 241 bp deletion. These were evaluated by 1.6% agarose gel electrophoresis stained with ethidium bromide.

Similarly, in H2 and H3 markers, PCR amplification products were ethanol precipitated before digestion with *Hae*III and *Dra*I respectively. For mitochondrial genome analysis, three mitochondrial DNA specific markers mentioned above were used for PCR amplification and evaluated by 1.2% agarose gel electrophoresis.

Four cpSSR markers were analysed by semiautomated capillary-based electrophoresis. Two cpSSR forward primers, viz., NTCP6 and NTCP8 were labelled with 5' FAM and the other two forward primers, viz., NTCP9 and NTCP14 with JOE. PCR reactions and GeneScan capillary electrophoresis based genotyping was done on the ABI Prism310 Genetic analyzer as described in our earlier studies (Chimote et al. 2004). The runs were performed at 60°C for 24 min at 15 kV with 5 s injection time. All genotypes were analyzed twice to check reproducibility of results.

Prediction analysis

Information based on organelle genome analysis in the above study and common matrilineal pedigree was used to predict cytoplasm type in 38 other advanced hybrid lines, as shown in Table 1c.

Results

Chloroplast deletion markers

Most of the varieties and advanced hybrids have T cp-type chloroplast DNA, similar to Chilean cultivated potato as revealed by H1 marker. T cp-type 241 bp chloroplast deletion typical of *tuberosum* type was found in 32 varieties and 37 advanced hybrids analyzed. T cp-type deletion was observed in all 17 early bulking hybrids (J series), 3 hybrids for East Indian plains (P series) and two heat tolerant hybrids (HT series). However, this deletion was absent in 6 varieties (Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Jawahar, Kufri Megha and Kufri



Himalini), 5 out of 8 processing hybrids (MP series), 7 out of 14 late blight resistant hill hybrids (SM/HB series), 3 medium maturing hybrids for North Indian plains (MS series) and *andigena* clone EX/A 680-16. Exotic processing cultivar Atlantic also showed T-type cytoplasm.

The grouping pattern of varieties and hybrids was the same with the H2 markers (Table 3). All genotypes showing T cp-type yielded two fragments of 193 and 141 bp on *Hae*III digestion with H2 marker, while in non-T cp-type genotypes only an undigested 334 bp fragment was observed. In case of H3 marker, all genotypes yielded 1018 bp fragment except two advanced hybrids (MS/97-621 and EX/A680-16), which gave two fragments of 575 and 443 bp, with rejoined fragment being also observed in them.

Chloroplast microsatellite markers

Four cpSSR markers (NTCP6, NTCP8, NTCP9 and NTCP14) together amplified a total of 6 fragments, with NTCP6 and NTCP9 giving only a single fragment each. These studies classified them into three clear groupings with first major group comprising of T cp-type genotypes, second group comprising genotypes with W cp-type and last group comprising of MS/97-621 and EX/A680-16. The differences in their peak patterns are given in Table 3. Three possible allelic combinations were observed at each

loci except NTCP6 (150/151), thereby clustering all genotypes into 3 groups (T, W and A cp-type).

Mitochondrial typing studies

ALM1 + ALM3 primer combination amplified atp6 region resulting in 1.2 kb band specific to $\alpha + \gamma$ mt-types in W cp-type (Table 4). ALM4 + ALM5 primer combination yielded 2.4 kb fragment specific to α type in the same genotypes with a sole exception of SM/94-43. SM/94-43 amplified 2.4 kb fragment of cob gene with ALM6 + ALM7 primer combination specific to γ mt-type.

Mitochondrial DNA specific ALM4 + ALM5 marker yielded 1.6 kb PCR product in all genotypes with T and A plastid genomes types. There are reports that β mitochondrial type coincides with Ttype chloroplast (Rasmussen et al. 2000; Lossl et al. 2000). Based on these reports, all genotypes having T-type plastid genome and yielding 1.6 kb PCR product with ALM4 + ALM5 combinations were assigned β mt-type. These include 32 Indian varieties, 37 advanced hybrids and cv. Atlantic. Similarly, both A-cp-type genotypes, EX/A680-16 and MS/97-621, also yielded 1.6 kb PCR product with ALM4 + ALM5 and were assigned ε mt-type i.e. typical of ssp. andigena (Table 4). On this basis, we concluded that out of 90 varieties and hybrids analyzed, 69 are of β type, 17 of α type, 10f γ type and 2 of ε type.

Table 3 Details of band/peak pattern obtained in varieties and hybrids

Cp-type/Marker	H1	H2	Н3	NTCP6		NTCP8		NTCP9	NTCP14
				Medium	Large	Small	Large		
Tuberosum (T)	202	193 + 141	1011	150	172	220	253	279	146
Wild (W)	443	334	1011	151	173	222	255	309	147
Andigena (A)	443	334	575 + 443	150	174	218	251	289	148

All figures are in bps

Table 4 Details of PCR amplification pattern with mt-type specific primers

Primers	Amplified region	Mitochondrial genome type
ALM1 + ALM3 ALM4 + ALM5 ALM6 + ALM7	atp6 cob, rps10	$\alpha + \gamma$ types = 1.2 kb; Others = nil α type = 2.4 kb; γ type- nil; Others (β/ϵ) type = 1.6 kb
ALM6 + ALM7	cob	γ types = 2.4 kb; Others = nil



Prediction analysis

Matrilineal pedigree similarity based prediction of organelle genome types using above information was used to conclude that 25 out of 38 advanced hybrid lines are T/β type; 12 are of W/α type and one is of A/ϵ type (Table 1c). All 10 early bulking hybrids (J/Jx series), 6 hybrids for East Indian plains (-P- series) and four medium maturing hybrids (MS series) showed *tuberosum* type cytoplasm. However, T-type deletion was absent in all 4 processing hybrids (MP series), 4 late blight resistant hybrids (SM/HB series) and three other hybrids (OP1, PS/M75, PS/M78).

Discussion

Organelle genome typing in Indian potato varieties/ advanced hybrids revealed that divergence was observed only in a few recently released genotypes developed during the last 15 years primarily for specific breeding purposes like processing quality and late blight resistance, which involved wild gene introgression in their maternal pedigree.

Amplification/restriction pattern with H1, H2, H3, NTCP6 and NTCP9 matched with earlier reports (Bryan et al. 1999; Powell et al. 1999; Hosaka 2003; Sukhotu et al. 2004). However, in all the three haplotypes (T/W/A), fragments sizes were 1 bp larger with NTCP8 and 3 bp smaller with NTCP14 than reported (Hosaka, 2003; Sukhotu et al. 2004). This may be due to different electrophoresis techniques used for resolution.

In the present study the majority (73.4%) of genotypes (94 out of 128) had T-type chloroplast and β type mitochondrial genome. Present day potato cultivars have predominantly T-type organelle DNA typical of Chilean germplasm (Powell et al. 1993; Hosaka 1995; Provan et al. 1999). The predominance of T-type cytoplasm in most potato cultivars can be traced back to the 19th century Chilean introduction, Rough Purple Chili and its derived progenies i.e. Garnet Chili and Early Rose. These genotypes exhibit cytoplasmic male sterility so that they were used as female parents in a large proportion of crosses in North American and European potato breeding (Glendinning 1983).

Analysis of Indian potato varieties revealed 32 out of 38 had T-type deletion, with the only exceptions

being six recently released varieties (Kufri Chipsona-1, Kufri Chipsona-2 Kufri Chipsona-3, Kufri Jawahar, Kufri Megha and Kufri Himalini). This is contrary to early reports that the Indian varieties are more like andigena type than that of tuberosum type (Swaminathan 1958; Sinha and Pushkarnath 1964). T-type marker typical of ssp. tuberosum was present in almost all improved Indian varieties, except in Kufri Jawahar and Kufri Megha and three landraces i.e., Phulwa, Gulabia, Lalmutti (Spooner et al. 2005). On nuclear SSR analysis, all Indian cultivars and landraces clustered along with Chilean landraces (ssp. tuberosum) rather than with Andean andigena accessions as expected, suggesting that Indian cultivars are not true andigena but are of neo-tuberosum type. Provan et al. (1999) reported that the extreme cytoplasm bottleneck in most European cultivars was not reflected in nuclear divergence analysis, thereby pointing towards their wide paternal base. Most of the modern Japanese cultivars had T-type cytoplasm; with a few W-type and old cultivars of A-type (Hosaka 1993). Mitochondrial genome type analysis revealed that out of 144 German potato varieties characterized, 79, 46 and 19 varieties respectively had β , α and γ mitochondrial genome type (Lossl et al. 2000).

In the present study, 34 non T-type genotypes formed 2 groups, i.e. larger W- type (31) and smaller A-type (3). EX/A680-16, MS97-621 and predicted OP1 have A/ ε cp/mt DNA type typical of ssp. andigena type. The frequency of A-type cytoplasm was very low (2.34%) as expected because of the negative role played by andigena cytoplasmic factors (Maris 1989). These three genotypes showed a pattern typical of A-cp-type with NTCP6 (174 bp), NTCP14 (148 bp) and NTCP8 (218 bp + 251 bp fragment). Further, they also yielded 575 and 454 bp fragments with H3 marker and 289 bp fragments with NTCP9. H3 (575 and 454 bp) and NTCP9 (289 bp) markers were perfectly correlated and are observed in almost all cultivated species (except ssp. tuberosum and S. juzepczukii) of S-, Aand most C-cp types (Sukhotu et al. 2006).

None of the genotypes studied showed 127 bp band typical of S-cp-type indicating its total absence in matrilineal pedigree of Indian potato breeding. Only a few Indian varieties and hybrids are known to have either *S. phureja* or *S. stenotomum* in their pedigree (e.g. POOS16 (in MP/97-921), I1062 (in



Kufri Himalini) and MEX32, etc). Kufri Jyoti's maternal grandparent GM 2182ef7 traces back to *S. phureja* × *S. demissum* on male side. *S. phureja* shows cytoplasmic barrier with reciprocal differences on crossing with ssp. *tuberosum* (Amoah et al. 1988; Grun et al. 1977).

 W/α cytoplasm type was observed in all three chipping varieties (Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3) and nine out of twelve hybrids bred specifically for processing purpose. Late blight resistant variety Kufri Himalini and hybrid SM/92-168 with good processing qualities also have W/α cytoplasm type. Interestingly most of them have Central/South American accessions like MEX-750826, F6, Muziranazara, POO16, I1062 and VB/ A 64 in their matrilineal pedigree, involving wild species with good processing attributes in pedigree. There is higher variability in wild potato species than in cultivated potatoes for characters like dry matter, starch content, amylose content, mean diameter of starch granules, etc (Jansen et al. 2001). W/ α genotypes identified could help in narrowing down selection for introgression of processing quality trait. However, high dry matter and processing attributes are also present in genotypes with T/β type cytoplasm i.e. in Chipping cultivar Atlantic, three processing hybrids (i.e. MP/98-31, MP/99-322 and MP/99-406) and two heat tolerant hybrids (HT-series hybrids and B-420). Atlantic has cv. Lenape cytoplasm with S. chacoense in paternal pedigree.

In case of late blight resistance breeding programme, two recent varieties (Kufri Megha and Kufri Himalini) and almost half of SM/HB-hybrids (11 of 23) developed for North Indian hills (where the duration of crop is long and late blight infection is epidemic) had W/α type cytoplasm. Wild species especially *S. demissum*, play an important role in incorporation of late blight resistance in potato breeding. However, most of the earlier Indian varieties (SLB series) with R gene derived late blight resistance had T/β cytoplasm as they are derived from resistant breeding material of Scottish Plant Breeding Station with *S. demissum* in paternal pedigree.

All of the early bulking hybrids studied had T/β type cytoplasm typical of *tuberosum* ssp. This can be explained by the fact that any potato breeding involving wild species/*andigena* results in delayed tuberization and thereby a late maturation crop which

defeats the basic purpose of this breeding programme. In potato breeding programme for regular maturation crop in Indo-Gangetic plains, with yield being main objective, 3 out of 7 recent hybrids lack *tuberosum* typical T-type cytoplasm.

Our study highlights the importance of wild gene introgression in potato breeding for specific purposes like late blight resistance and processing. Current diversified uses of potato in processing, demands introgression of wild gene pool for improving quality characters such as cold chipping, high dry matter and starch content of tubers. Desirable genes for many quality traits can be found in Andean potato genotypes, whereas for abiotic and biotic stresses, breeding could well benefit from use of wild species.

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