

KUFRI KARAN-FIRST MULTIPLE DISEASE RESISTANT, HIGH YIELDING POTATO VARIETY FOR CULTIVATION IN HILLS AND PLATEAUX OF INDIA

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ABSTRACT : Kufri Karan is a 'First' potato variety developed by indigenous potato breeding program possessing resistance to multiple diseases, medium maturing and high yielding suitable for cultivation in hills and plateaux of the country. During the developmental stages, marker assisted selections were effected to ascertain the phenotypic resistances at genetic level to ensure the stacking of functional, multiple genes imparting resistance to different biotic stresses. The variety possesses high resistance to late blight, six viruses *i.e.* ToLCNDV-potato, PVY, PLRV, PVA, PVM and PVS and moderate resistance to Potato Cyst Nematode. The variety produces attractive, white cream, ovoid tubers with shallow eyes and creamy flesh, medium dormancy and good keeping quality. The tubers are easy to cook, has acceptable aroma post cooking with mealy texture. It yields higher than varieties Kufri Jyoti, Kufri Himalini and Kufri Girdhari, with an average yield of the variety is 25-30 t/ha under normal conditions of crop growth in the hills and plateaux, while in sub-tropical plains the tuber yield is >30 t/ha. This variety being resistant to multiple biotic stresses will be an economical alternative to earlier varieties being cultivated in the areas where late blight, viruses and PCN are major impediments to potato cultivation.

Keywords: biotic stresses, *Kharif* potato, marker assisted selection, resistance breeding

INTRODUCTION

Potato is an important *Kharif* crop in the hills and is also profitably grown in plateau regions. Although the area under potato cultivation in Indian hills and plateau regions is around 15% of total potato area of the country, yet the area is important in terms of supply of fresh potatoes for ware as well as for processing in the off-season. Besides, the supply of fresh potatoes for table consumption from these areas helps to manage consumer prices during off season. However, various

biotic stresses affect the production and quality of potato in these regions especially late blight in hills and viruses in plains (Bhardwaj et al., 2019; Sood et al., 2020). The late blight pathogen, *Phytophthora infestans*(Mont) de Baryis globally infamous for its notoriety to quickly bypass genetic resistances and adapt to new fungicides across the crops including potato. Consequently, the durable resistance to late blight remains elusive and the new varieties could remain resistant 5-7 years at the maximum before becoming

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susceptible to the new, virulent races and needed extra protection with chemical sprays. At CPRI, we followed a strategy to develop and release varieties having resistance genes from different sources (wild, semi-cultivated related species) to sustain durable resistance to late blight. This strategy proved successful and the latest varieties Kufri Himalini (Joseph et al., 2007) and Kufri Girdhari (Joseph et al., 2011) could withstand the onslaught for more than a decade, but the latter have also started showing disease prevalence in south Indian hills. Among viruses, PVY and PLRV affect the potato production largely. Besides, the cocktail of viruses not only cause economic losses in terms of significantly low tuber yields, but also heavily increases the production costs in terms of management of vectors in the quality seed production programs. Unfortunately, to add fuel to the fire, Potato Cyst Nematode is the latest addition to the list of biotic stresses affecting potatoes and has appeared as a threat in hills (Chandel et al., 2020). Thus, the major emphasis now is to develop future varieties with multiple resistances to all the major biotic stresses.

The late blight management strategy adopted at CPRI during last decade of 20th century and first decade of 21st century gave expected results in the form of development and release of resistant varieties Kufri Giriraj, Kufri Shailja, Kufri Himalini and Kufri Girdhari. However, during that period, the breeders used diverse sources of resistance but the selections were effected based on phenotypic resistance reactions both in the lab as well as under epiphytotic field conditions. The precise knowledge at the gene level was elusive as methods/ procedures were not available at that time. But in the early years of 21st century, the research on mapping and identification of QTLs for late blight resistance enhanced the knowledge at molecular level and soon genes responsible

for imparting resistance were identified and it became feasible to use Marker Assisted Selection (MAS) as a tool for deploying known sources of resistance not only for late blight but for other biotic stresses also. These efforts, spanning over a period of two decades, led to selection of multiple disease resistant clone "SM/00-42" that was released for commercial cultivation under the name Kufri Karan in 2020. This paper describes the salient features of this variety.

Pedigree

Kufri Karan (SM/00-42) is a selection from the progeny of a cross, Cruza 27 (CP 2376) and HB/83-39. The female parent Cruza 27 was received from CIP, Peru in 1987 and is moderately resistant to foliar and tuber blight, immune to wart, resistant to PVX, PVY & hopper burn, moderately resistant to stem necrosis. The tubers are white round with medium deep eyes and yellow cream flesh. The male parent HB/83-39 is an indigenous advanced breeding line developed from a cross between VB/A-64 and EB/A-152. HB/83-39 as well as its parental lines possess good tuber traits and resistance to biotic stresses. It is a good general combiner also. It has white-cream, ovate tubers with medium deep eyes and yellow-cream flesh and is resistant to late blight.

Selection procedure

The cross was made in the year 2000 at the Central Potato Research Station, Kufri (32°N 77°E, 2501 m amsl). The seedlings were raised in the year 2001 and screened under

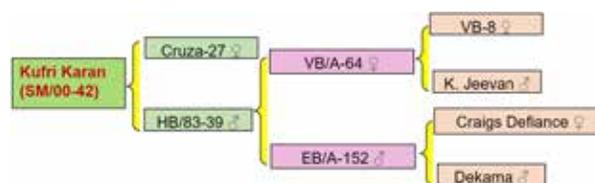


Fig. 1: Pedigree tree of Kufri Karan (SM/00-42)

controlled environment at Shimla against the complex races of *P. infestans* as per standard procedure (Singh et al., 1997). The late blight resistant clones were subjected to tuber multiplication and early generation selection (F_1C_2 - F_1C_4) at Kufri for tuber yield, tuber and plant traits. The clone SM/00-42 along with other selected clones were evaluated in replicated yield trials (F_1C_5 - F_1C_7) for tuber yield performance and late blight resistance under natural epiphytotic conditions from 2010-2014 at Kufri along with Kufri Jyoti, Kufri Himalini and Kufri Girdhari as controls. The clone SM/00-42 was tested in AICRP (Potato) multi-location trials in hills and plateau region from 2015-2017. The clone was also evaluated at the Central Potato Research Institute Campus, Modipuram (29°N, 76°E, 222 m amsl) during 2014-15 to 2017-18 for its adaptability under short days and irrigated conditions. The clone SM/00-42 also showed resistance to PVY, ToLCNDV-potato, PVA, PVM, PVS, PLRV, and moderate resistance to PCN. The resistance was confirmed both at phenotypic and genotypic level. The DNA markers linked to resistant genes confirmed the resistance of the clone to late blight, PVS, PLRV and PCN. The clone was recommended for release in 36th Annual Group Meet of the All India Co-ordinated Research Improvement Project (Potato) workers held during September 08-11, 2018 at SDAU, Sardarkrushinagar, Gujarat for cultivation as summer/ kharif season crop in north-western, north-eastern hills and plateau region of the country. The clone has been allotted IC 628163 as national identity number by ICAR-NBPGR, New Delhi. It was finally released and notified as variety 'Kufri Karan' in 2020 by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties of Horticultural Crops, Department of Agriculture and Co-operation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

Varietal description

Trait	Description
Plant	Medium tall, canopy semi-compact, stem medium thick, hollow, angular, predominantly green, wings poorly developed and straight
Foliage	Grey green, leaves close, leaflet length & width medium, leaflets ovate lanceolate, waviness weak, pubescence of apical rosette present, rachis green, midrib green.
Flower	Flowering intensity medium, inflorescence small, floral stalk green, floral stalk-pedicle articulation clearly visible and located above the middle, calyx green, corolla white, size medium, corolla shape semi-stellate, anther yellow, anther cone normally developed, stylar length longer than stamen column and stigma unilobed
Tuber	The variety produces attractive, white cream, ovoid tubers (6-9 numbers/plant) with shallow eyes and cream flesh. Tubers don't show deformities like cracking or hollow heart and have mealy texture.
Sprout	Sprout white-green, shape cylindrical, length medium, pubescence at sprout base is strong
Maturity	Main season variety with medium maturity (90-100 days)
Biotic stress resistance	Potato variety developed using molecular markers having stacked multiple resistance genes. The variety possesses high resistance to late blight, 6 viruses (ToLCNDV-potato, PVY, PLRV, PVA, PVM and PVS) and moderate resistance to PCN. The resistances were confirmed by challenge inoculation also.

Trait	Description
Quality traits	Medium dormancy and good keeping quality, easy to cook, cooked/boiled potato has acceptable aroma, mealy texture
Other attributes	High tuber dry matter (>21%), low reducing sugars (102.7mg/100g FW) and acceptable chips (3) under sub-tropical plains at Modipuram conditions indicate its multiple uses. The variety is day-neutral i.e. suitable for cultivation both in the hills and plains.

Yield performance

Kufri Karan(SM/00-42) was evaluated at Kufri for 4 years in randomized complete block design during 2010-11 to 2013-14 before multi-location trials. The hybrid was

evaluated along with Kufri Girdhari, Kufri Himalini, Kufri Jyoti (sprayed) and Kufri Jyoti (unsprayed) as controls. The hybrid consistently out yielded all the controls for total and marketable tuber yields at 100 days' crop duration during all the 4 years (Table 1). The hybrid out yielded the best control variety, Kufri Girdhari by margin of 14.24% and other controls like, Kufri Himalini by 22.74%, Kufri Jyoti (sprayed) by 29.53% and Kufri Jyoti (unsprayed) by 73.48% for total tuber yield on overall basis.

The yield performance of KufriKaran at different locations in the AICRP (Potato) hill and plateau centres (90-120 days crop duration) is presented in Tables 2 and 3. KufriKaran yielded significantly higher than the respective best controls at different locations over the years. The location-wise overall total tuber yield of Kufri Karan at all locations viz., Hassan (25.0 t/ha), Kufri (32.7

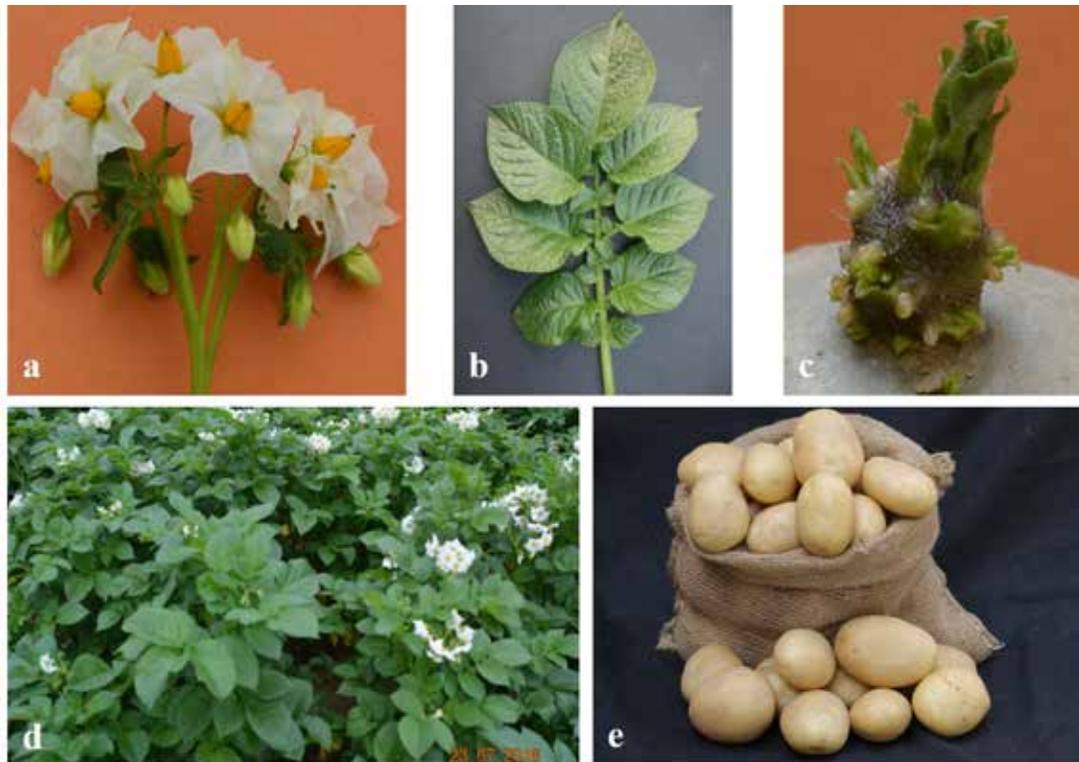


Fig. 2. Morphological features of Kufri Karan a) Flower b) Leaf c) Sprout d) Plants/crop view e) Tubers

Table 1. Performance of Kufri Karan (SM/00-42) at Kufri before introduction into AICRP (P)

Genotypes	Total tuber yield (q/ha)				Average	Late blight AUDPC average of four years*
	2010-11	2011-12	2012-13	2013-14		
Kufri Karan	115.96	145.29	212.1	107.6	145.2	74.8
Kufri Girdhari	83.12	143.55	185.4	96.5	127.1	29.4
Kufri Jyoti (S)	97.97	131.56	134.5	84.4	112.1	683.0
Kufri Jyoti (US)	91.22	75.64	100.8	67.3	83.7	898.1
KufriHimalini	93.95	139.48	154.4	85.2	118.3	456.7
CD _{0.05}	19.65	24.47	17.6	18.0		

S = Sprayed; US = Unsprayed; *Resistance ratings based on AUDPC: highly resistant (< 250), resistant (251-350), moderately resistant (351-650), susceptible (651-1200) and highly susceptible (>1200)

t/ha), Ooty (27.5 t/ha), Ranichauri (18.2 t/ha), Srinagar (27.3 t/ha) and Shillong (19.8 t/

Table 2. Year-wise yield performance of Kufri Karan in AICRP (P) trials in hills and Plateau regions

Hybrid/variety	2015	2016	2017	Mean
	Total yield (t/ha)			
Kufri Karan	22.8	24.9	27.6	25.1
Kufri Jyoti	16.2	14.7	14.7	15.2
KufriHimalini	16.9	20.3	21.1	19.4
KufriGirdhari*	15.9	20.1	21.9	19.3
% yield increase over Kufri Himalini	34.9	22.8	31.2	29.4
% yield increase over Kufri Girdhari	43.4	23.9	26.0	30.1
CD (0.05)	Year = 0.70; Genotype = 0.99; Year × Genotype = 1.72			

*Hassan: K Surya in place of K Girdhari in all the three years; Ranichauri & Shillong: LBY-17 in place of K Girdhari in the year 2015; Ranichauri: LBY-17 in place of K Girdhari in the year 2016

ha) was higher than the best control except at Srinagar. Overall total tuber yield of hybrid, Kufri Karan was the highest (25.1 t/ha) yielding 29.4% higher than the best control, KufriHimalini (Table 2). On an average, Kufri Karan could yield 25-30 t/ha under normal conditions of crop growth in the hills and plateau regions.

In sub-tropical plains at Modipuram, Kufri Karan was evaluated for two years along with control varieties. Based on the average of two years, Kufri Karan produced 5.8 and 7.9% higher tuber yield than KufriBahar and KufriHimalini, respectively (Table 4). At statistical level, Kufri Karan was statistically at par to KufriBahar and KufriHimalini in both the evaluation years. The results indicate that Kufri Karan is also suitable for Indian plains.

Table 3. Location-wise yield performance of Kufri Karan in AICRP (P) trials in hills and Plateau regions

Hybrid/ Locations	Kufri Karan	Kufri Girdhari*	Kufri Himalini	% Increase over Kufri Girdhari	% Increase over Kufri Himalini
Hassan	25.0	15.1	20.3	65.6	23.2
Kufri	32.7	24.8	20.6	31.9	58.7
Ooty	27.5	28.7	14.2	-4.1	94.0
Ranichauri	18.2	10.0	13.6	82.0	34.0
Srinagar	27.3	27.6	31.1	-1.1	-12.2
Shillong	19.8	9.6	16.6	106.25	19.3
Mean	25.1	19.3	19.4	30.05	29.4
CD _{0.05}	Location = 1.00; Genotype = 0.91; Location × Genotype = 2.24				

*Hassan: K Surya in place of K Girdhari in all the three years; Ranichauri & Shillong: LBY-17 in place of K Girdhari in the year 2015; Ranichauri: LBY-17 in place of K Girdhari in the year 2016

Table 4: Adaptability in sub-tropical plains (Modipuram)

Hybrid/ Control	Yield (t/ha)			
	2015-16	2016-17	Mean	Increase over control (%)
Kufri Karan	45.3	42.5	43.9	
Kufri Girdhari	35.5	31.2	33.4	31.4
Kufri Himalini	44.3	37.1	40.7	7.9
Kufri Jyoti	33.2	34.2	33.7	30.3
Kufri Bahar	44.1	38.9	41.5	5.8
CD _(0.05)	5.40	5.32	-	

Stability of Kufri Karan (SM/00-42) using GGE biplot

The yield data over 6 locations viz., Hassan, Kufri, Ooty, Ranichauri, Srinagar and Shillong for three years i.e. 2015, 2016 and 2017 was pooled for combined analysis including 3 hybrids viz., Kufri Karan (SM/00-42), SM/00-120 and VMT 5-1 and three controls viz., Kufri Himalini, Kufri Jyoti and Kufri Girdhari. Significant differences were observed among all the factors including treatments, years, locations and their interactions. Kufri Karan out yielded other hybrids as well as control genotypes for

both total as well as marketable tuber yield in the pooled analysis. In order to identify wide adaptable hybrid across locations, GGE biplot analysis was carried out. The GGE biplot analysis showed that Kufri Karan is best performer in terms of yield and stability across locations except Srinagar while all the three checks performed poorly (Fig. 3). Kufri Karan had highest mean total and marketable tuber yield as well as stability.

Multiple disease resistance

Late Blight:

The clone was evaluated for late blight reaction using detached leaf assay, whole plant resistance through artificial inoculation and late blight R gene linked markers as described earlier by Bhardwaj et al. (2019). Both under lab & natural epiphytotic conditions, Kufri Karan exhibited high foliar blight resistance against all races of late blight (*Phytophthora infestans*) (Table 5; Fig. 4).

Potato Cyst Nematode:

Screening for potato cyst nematode was carried out in pots for two consecutive years

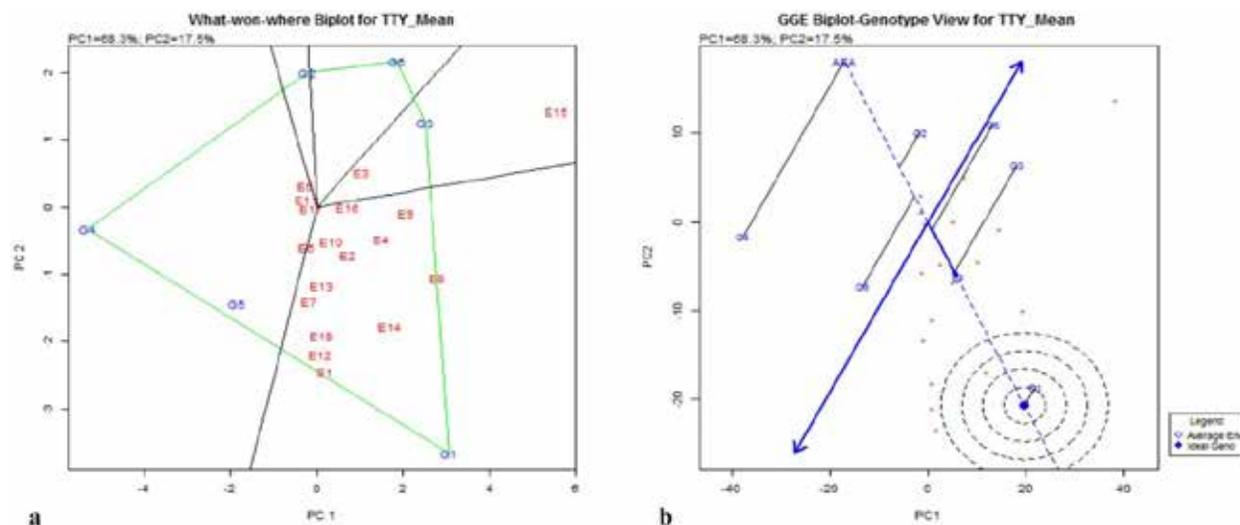


Fig. 3. GGE biplot exhibiting total tuber yield performance of potato genotypes across environments a) Which won where plot b) means performance and stability G1-Kufri Karan, G4-Kufri Jyoti, G5-Kufri Himalini, G6-Girdhari; E1 to E18- year wise six locations



Fig. 4: Field reaction late blight in Kufri Karan compared to moderately resistant control, Kufri Himalini (Kufri 2018)

Table 5: Phenotyping for late blight, viruses and PCN resistance at Shimla and Ooty (pooled for 2017 &18)

Genotype	Late blight		DAS-ELISA					PALCV screening through agro-inoculation	PCN	
	Severity (%)	PVY	PVX	PLRV	PVS	PVM	PVA		<i>G. rostochiensis</i>	<i>G. pallida</i>
Kufri Karan	10	-ve	+ve	-ve	-ve	-ve	-ve	R	MR	MR
Kufri Jyoti	60	+ve	+ve	+ve	+ve	+ve	+ve	S	S	S
Kufri Himalini	40	+ve	+ve	+ve	+ve	+ve	+ve	MS	S	S
Kufri Girdhari	0	+ve	+ve	+ve	+ve	+ve	+ve	-	HS	HS

as per the standard procedure described earlier by Sudha et al. (2019). The new variety, Kufri Karan along with control varieties were also evaluated for R gene linked markers of both the PCN species (Bhardwaj et al., 2019). Phenotyping results showed that Kufri Karan is moderately resistant to both species of PCN i.e. *G. pallida* and *G. rostochiensis* while two control varieties, Kufri Jyoti and Kufri Himalini were susceptible, and Kufri Girdhari was highly susceptible (Table 5 & Fig. 5).

Viruses:

One month old three plants of each genotype were mechanically inoculated

with PVY, PVX, PVS, PVA, PVM and PLRV using spray gun procedure. (Bhardwaj et al 2019).The phenotyping of Kufri Karan along



Fig. 5: Presence of PCN cysts in the root ball of cvs. Kufri Girdhari and Kufri Karan

with control varieties using spray gun and detection with both ELISA and PCR indicated its high resistance against 5 viruses (PVY, PLRV, PVA, PVM and PVS) (Table 5).

For ToLCNDV-potato, agro-inoculation method was used to create disease in the potato hybrids by following previously standardized method (Jeevalatha et al. 2017). The procedure for inoculation involve gentle pricking of seed potato sprouts with fine 5ml syringe needles, followed by incubation in a mixture of agrobacterium cells carrying infectious clones of ToLCNDV-[potato] isolate MOD-21 (DNA A and DNA B components in 1:1 ratio) for 4-5 hrs in a rotary shaker maintained at 28°C. The treated tubers were planted in pots under controlled conditions and inoculated again through stem injection with the same agrobacterium mixture. The ToLCNDV symptoms were observed 30 days after first inoculation and continued till 60 days at an interval of 15 days. Based on the mean of all observations, Kufri Karan showed resistant reaction, while Kufri Himalini and Kufri Jyoti recorded moderately susceptible and susceptible reaction, respectively.

Genotyping using R genes/ linked markers:

The leaf samples were collected from all the genotypes for DNA isolation. QIAGEN’s DNeasy Plant Mini Kit was used for the DNA extraction. The genes/linked markers and PCR condition were used as described

earlier (Bhardwaj *et al* 2019). For late blight resistance, the varieties Kufri Karan and Kufri Girdhari possesses two major genes against late blight, which corroborates the phenotype and genotype results for late resistance in Kufri Karan (Table 6). In Kufri Karan and Kufri Jyoti, the presence of two PCN resistance genes linked markers was observed, but the phenotype results were opposite in both the varieties, indicating that these two gene linked markers for PCN are not associated with resistance phenotype (Table 6).The variety Kufri Karan and control varieties were also screened for resistance gene linked markers to five viruses (PVY, PVX, PVM, PVS, PLRV). Kufri Karan recorded the presence of 7 viruses resistant gene linked markers but in most cases the control varieties were also positive for these markers. The genotyping results for viruses and PCN therefore were insufficient to discriminate between resistant and susceptible phenotypes (Table 6).

Dry matter and keeping quality

Kufri Karan produced high dry matter(18.8%)than the control Kufri Jyoti (17.5%) and was slightly lower than Kufri Himalini (19.1) and Kufri Girdhari (19.2%) in hills and plateaux in AICRP potato trials. The storage behaviour of Kufri Karan was studied at room temperature immediately after harvest upto 120 days duration

Table 6: Late blight, viruses & PCN resistance genes in Kufri Karan (SM/00-42) identified through linked markers (MAS)

Genotype	Late blight		Viruses							PCN	
	PVY		PVX		PVM			PVS		PLRV	
	R2	R3a	STM003	GM 339	GM 637	GM 250	SCG 17	NI1127	SCAR (RGASC850)	HC	TG432
Kufri Karan	+	+	+	+	+	+	+	+	+	+	+
Kufri Jyoti	-	-	-	+	-	-	+	+	+	+	+
Kufri Himalini	-	-	+	+	+	-	-	+	+	-	-
Kufri Girdhari	+	+	+	+	-	-	+	+	-	+	-

+ presence of marker; - absence of marker

at Modipuram. Kufri Karan had longer dormancy duration (80 days) than all the three control varieties i.e. Kufri Himalini (71 days), Kufri Girdhari (77 days) and Kufri Bahar (75 days). The total weight loss in Kufri Karan after 120 days of storage was much lower (22.2%) than all the three controls, Kufri Himalini (36.7%), Kufri Girdhari (30.2%) and Kufri Bahar (33.1%). The medium dormancy and good keeping quality attributes clearly indicate that the variety will help farmers to store potato produce under ambient conditions up to two months.

Agronomic management

The optimum tuber yield of Kufri Karan can be obtained by adopting standard agronomical practices for hills and plateau regions.

Planting time: High hills: April-May, Mid hills: Jan-Feb, Plateau: Throughout year

Seed rate: 3.5-4.0 t/ha; Seed size: 40-60 g

Spacing (Row × Plant): Hills: 60×20-25 cm; Plateau- 60×60 cm (summer crop), 40-50 × 20 cm (autumn crop)

Fertilizer:

In hills: Apply 120 kg N, 100 kg P and 100 kg K per hectare. Nitrogen is best applied in 2 split doses, 100 kg at planting and 20 kg at the time of earthing up.

In plateau: Apply 90kg N, 90kg P and 90 kg K. Nitrogen is best applied in 2 split doses, 60 kg at planting and 30 kg at the time of earthing up.

In plains: Apply 260 kg N, 80 kg P and 132 kg K/ha. Nitrogen is best applied in split doses, 130 kg at planting and 130 kg at the time of earthing up.

Crop protection: Foliar application of Imidacloprid 200 SL @ 0.4 or 0.5ml/litre or Thiamethoxam 25WG @ 0.5g/litre (for seed crop only).

CONCLUSION

High tuber yield, multiple diseases resistance and suitable quality traits of Kufri Karan clearly showed its superiority over existing varieties, Kufri Jyoti, Kufri Himalini and Kufri Girdhari for Kharif planting in hills and plateau regions. Adaptive trials in Modipuram also indicate its suitability in plains, where incidence of late blight and viruses is a major problem. The cultivation of this multiple disease resistant variety carrying multiple resistant genes will effectively combat late blight, viruses and PCN disease thus saving costs to the farmers and will promote safe environment by avoiding sprays of fungicides/ insecticides.

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