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Potato (*Solanum tuberosum* L.) seed tuber production as influenced by intra-row spacing, dehaulming time and nutrient management in lower Indo-Gangetic plains of India

S. K. DAS, A. SARKAR, [1]J. K. TARAFDAR AND A. CHAKRABORTY

AICRP on Potato, [1] AICRP on Tuber Crops, Directorate of Research
Bidhan Chandra Krishi Viswavidyalaya, Kalyani - 741235, Nadia, West Bengal, India

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ABSTRACT

For successful potato cultivation virus free quality planting material is the prime input, which accounts for nearly 40-50% of the total cost of cultivation. Field experiments were conducted during rabi seasons of 2016-17, 2017-18 and 2018-19 at BCKV, Kalyani, WB, India to determine the effects of intra-row spacing, dehaulming time and nutrient management on potato seed tuber production in lower Indo-Gangetic plains of India following seed plot technique. The experiment was laid out in a split split plot design with three replications having twelve treatment combinations viz. Main plot: intra row spacing 2 levels, sub plot: dehaulming time 2 levels and sub sub plot: nutrient management 3 levels. The results showed that with reduction in intra row spacing from 20 to 15cm, dehaulming at 65 DAP and decrease in nutrient levels from 100% RD of NPK to 50% RD of NPK seed grade size (< 75g) tuber yield and numbers and total tuber numbers were increased significantly. Intrarow plant spacing and nutrient levels had a marked effect on disease incidence and intensity. Haulm cutting at 65 days after planting was found to be safer considering the aphid population build up and transmission of viral disease through it. It was found from the indexing of the viruses in the tubers of Kufri Himalini (breeder seed and produced seed tuber) the seeds were free from PVY, PVX, PVS, PVM and PVLRV. The highest net return and B : C ratio (4.08) was obtained with 15 cm intra row spacing, dehaulming at 65 DAP and 50% RDF of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP followed by B : C ratio (3.99) with 15 cm intra row spacing, dehaulming at 75 DAP and 50% of RDF of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP.

Keywords: Dehaulming time, indexing of viruses, intra row spacing, nutrient management, potato, seed tuber

West Bengal is the second largest potato growing state in India with a production of 10.0 million tonnes from an area of 409.7 thousand hectares. (Anon., 2017). The state produces one-third of the country's total potato production. After cereals potato is the most popular crop in West Bengal. The crop is mostly grown during *rabi* season (November-March). For successful potato cultivation virus free quality planting material is the prime input, which accounts for nearly 40-50 per cent of the total cost of cultivation and if the seed is not of good quality, then optimum production could not be achieved. Potato farmers of lower Indo-Gangetic plains are facing acute problems regarding availability of quality planting material, over pricing and timely supply of planting material. Due to expansion of potato cultivation in the Indo-Gangetic plains (IGP) a huge demand of quality planting material has been created but normal seed producing areas particularly, the Indian hills cannot cope with the increasing demand for good quality seed. Darjeeling area of West Bengal and Nilgiri hills of south India have been restricted to produce potato seed due to prevalence of quarantine diseases like wart and syst nematode respectively. Potato seed procured from western hills of Himachal Pradesh, Jammu and Kashmir and Uttarakhand suffer from problems of true dormancy, long distance transportation and tuber rottage due to late blight infection. Thus, a full proof potato seed production technology for non traditional areas was the need of the hour to meet the growing seed tuber demand for sustaining the ever increasing areas in the lower IGPs. In West Bengal potato seed tuber can be produced if early planting is adopted. Moreover, the critical level of aphid population (20 aphids per 100 compound leaves) generally appears on 2nd week of January onwards. As a result, 8-9 weeks of low aphid pressure period is available, and the problem of viral disease infection is much lower during this period. Presently, the farmers of this state have no other option but to depend upon the homegrown seed or buy it from the cold stores open market or other states at higher prices. In most of the cases, poor quality of seed material causes lower yield. The only solution left for the farmers of this state is to produce their own seed by following the 'Seed Plot Technique' (Wurr, 1978) under open field condition or under net house. Approximately 30-40 per cent of the seed potato is procured from outside the state like Punjab, U.P etc. the quality of which is not always good enough resulting in rapid degeneration of tubers due to viral diseases (Mondal *et.al.*, 2015). Not only that, cost of such seed tubers is also very high resulting

Email : sanjibag@gmail.com

in huge monetary loss. Therefore, to save the farmers from losses and to make potato cultivation profitable an effort has been made to produce potato seed in the state itself. Keeping the above facts in view, this experiment was initiated with the objectives to study the effect of intra-row spacing, dehaulming time and nutrient management on seed grade tuber production of potato through 'Seed plot technique' in lower Indo -Gangetic plains of India.

MATERIALS AND METHODS

Field experiments were conducted for three years at C-unit research farm (Kalyani) of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India situated at 22º58' N latitude and 88º3'E longitude with an altitude of 9.75m above mean sea (MSL) during *rabi* 2016-17, 2017-18 and 2018-19. The soil of the experimental field was sandy loam in texture and slightly alkaline in reaction (pH 7.2) having an organic carbon content of 0.56%, 182.93 Kg available N ha^{-1}, 16.81 kg available P_2O_5 ha^{-1}, 132.25 kg available K_2O ha^{-1}. The experiment was laid out in a split split plot design with three replications having twelve treatment combinations *viz.* two levels of intra row spacing, S_1 - 60 x 20 cm and S_2- 60 x 15 cm were applied in main plots. Two levels of haulm cutting dates, H_1- 65 days after planting (DAP) and H_2- 75 days after planting were applied in sub plots and three levels of fertilizer management, F_1- 100% RDF (Recommended dose of fertilizer) of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP, F_2- 75% RDF of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP and F_3- 50% RDF of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP were applied in sub sub plots with a plot size of 5 x 3 m. Breeder seeds of potato variety Kufri Himalini was planted on 5th November using seed plot techniques. Tubers weighing 30-40 g each were planted in the furrows with a depth of planting of 3 – 4 cm and covered with soil. The recommended dose of fertilizer (RDF) was 200, 150 and 150 kg respectively of N, P_2O_5, and K_2O ha^{-1}. Nitrogen (N), phosphorus (P) and potassium (K) were applied through urea, single super phosphate and muriate of potash respectively. Half of nitrogen, full dose of phosphorus and potassium were applied as basal. Rest half N was top dressed at 30 days after planting (DAP) followed by earthing up. Pre-emergence application of Sencor (Metribuzin) @ 0.75 kg a.i. ha^{-1} was done at 3 DAP followed by 1 hand-weeding at 20 DAP to promote early crop growth. As a prophylactic measure, spraying (twice) with Dithane M-45 (Mancozeb) @ 0.2% at 40 and 60 DAP was done against late blight. Imidacloprid 17.8SL @0.03% was also sprayed (thrice) at 30, 40 and 60 DAP for controlling aphids and other sucking insects. Monitoring and roughing was done. Dehaulming was done as per treatments. In H_1 haulm cuttings were done on 09.01.17, 09.01.18 and 09.01.19, and in H_2 haulm cuttings were done on 19.01.17, 19.01.18 and 19.01.19 and harvesting was done 10 days after haulm cutting. Potato rows were opened with the help of plough. Tubers were dug out from each plot manually. Data on grade wise tuber number and yield, and total tuber number and yield were recorded at harvest from each net plot area. ELISA test for virus profiling of potato leaves, supplied breeder seed and produced seed tubers were conducted for PVY, PVX, PVS, PVM and PLRV in the samples using Immuno-strip (Agdia Incorporation, USA) specific to Potato Virus Y; Molecular method- Reverse Transcription-Polymerase Chain Reaction (RT-PCR) of PVY, PVX, PVS, PVM and Leaf roll Virus (PLRV). In all the detection time positive and negative control were maintained to cross check the infection and required primers were used (Table 6). The economic parameters (cost of cultivation, gross return and net returns) were worked on the basis of prevailing market prices of inputs and outputs. Analysis of variance of the data in the experimental design and comparison of means at $p \leq 0.05$ were carried out, using MSTAT-C software.

RESULTS AND DISCUSSION

Effect on plant emergence, plant height and number of shoots per plant

The results of the experiment revealed that plant emergence of potato was not significantly influenced by intra row spacing, dehaulming time and nutrient management and their interactions (Table.1). Height of plants at 60 DAP and number of shoots per plant of potato were not significantly affected by intra row spacing and dehaulming time but it was significantly affected by nutrient management. The highest plant height (73.33 cm) was recorded with 100% RDF of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP. Reduction in nutrient dose from 100% RDF of NPK to 50% RDF of NPK significantly reduced the height of the plant and number of shoots per plant of potato. Reduction in plant height and number of shoots per plant of potato with reducing fertility levels was confirmed by Das *et al.* (2016) and Mandal and Das (2020). Considering the effect of nutrient management the highest number of shoots per pant (3.30) was recorded with 100% RDF of NPK+ 0.1% boric acid as foliar application at 40, 50 and 60 DAP. However, the interaction effect of treatments on plant emergence, plant height and number of shoots per plant were found statistically nonsignificant.

Effect on tuber yield

The results of the experiment showed that, seed grade (<75g) tuber yield and total tuber yield of potato were

Table 1: Effects of spacing, haulm cutting dates and fertilizer management on emergence, plant height and no. of shoots per plant of potato (Pooled data of three years)

Treatment	Potato		
	Emergence (%)	Plant height (cm)	No. of shoots plant^{-1}
Spacing			
S_1	99.48	71.67	3.14
S_2	99.49	70.83	3.10
SEm (±)	**0.05**	**0.24**	**0.03**
LSD (0.05)	**NS**	**NS**	**NS**
Dates of haulm cutting cutting			
H_1	99.28	71.36	3.10
H_2	99.69	71.14	3.14
SEm (±)	**0.19**	**0.15**	**0.06**
LSD (0.05)	**NS**	**NS**	**NS**
Fertility			
F_1	99.58	73.33	3.30
F_2	99.60	71.08	3.12
F_3	99.28	69.34	2.94
SEm (±)	**0.19**	**0.30**	**0.05**
LSD (0.05)	**NS**	**0.90**	**0.15**

Table 2: Effects of spacing, haulm cutting dates and fertilizer management on grade wise and total tuber yield of potato (Pooled data of three years)

Treatment	Grade-wise yield of tubers (t ha^{-1})					Yield on dry weight basis (t ha^{-1})	
	0-25g	25-50g	50-75g	>75g	Total	Tuber	Haulm
Spacing							
S_1	2.97	6.47	7.11	13.46	30.02	5.76	3.45
S_2	3.80	7.18	8.80	13.24	33.02	5.81	3.49
SEm (±)	**0.15**	**0.11**	**0.11**	**0.13**	**0.27**	**0.08**	**0.05**
LSD (0.05)	**NS**	**0.66**	**0.66**	**NS**	**1.64**	**NS**	**NS**
Dates of haulm cutting							
H_1	3.67	6.84	7.89	12.28	30.69	5.70	3.42
H_2	3.09	6.81	8.02	14.42	32.34	5.87	3.52
SEm (±)	**0.06**	**0.08**	**0.18**	**0.21**	**0.28**	**0.06**	**0.03**
LSD (0.05)	**0.22**	**NS**	**NS**	**0.82**	**1.11**	**NS**	**NS**
Fertility							
F_1	2.87	6.42	7.09	19.22	35.60	6.41	3.85
F_2	3.19	6.75	8.22	13.04	31.20	5.68	3.41
F_3	4.09	7.31	8.56	7.79	27.76	5.26	3.16
SEm (±)	**0.13**	**0.19**	**0.31**	**0.30**	**0.53**	**0.11**	**0.07**
LSD (0.05)	**0.39**	**0.56**	**0.92**	**0.91**	**1.60**	**0.33**	**0.21**

significantly influenced by intra row spacing, dehaulming time and nutrient management. Results revealed that 25-50g, 50-75g grade and total tuber yield of potato was significantly influenced by intra row spacing (Table. 2). With the decrease in plant to plant spacing seed grade tuber yield and total tuber yield were significantly increased but > 75 g grade (marketable grade) tuber yield was significantly reduced. Lower spacing also increased the 0-25g grade tuber yield, which was desirable to produce more amount of seed grade size tuber of potato. The result corroborated with the findings of Dua *et al.* (2008), Das *et al.* (2016) and Mandal and Das (2020).

Table 3: Effects of spacing, haulm cutting dates and fertilizer management on grade wise and total tuber number of Potato (Pooled data of three years)

Treatment	Grade-wise number of tubers (nos. ha^{-1})				
	0-25g	**25-50g**	**50-75g**	**>75g**	**Total**
Spacing					
S_1	180093	161574	105093	96759	543518
S_2	231019	200463	141204	85185	657870
SEm (±)	**5792**	**4428**	**982**	**1823**	**9729**
LSD (0.05)	**35731**	**27321**	**6059**	**11245**	**60024**
Dates of haulm cutting					
H_1	220833	189352	126389	86111	622685
H_2	190278	172685	119907	95833	578704
SEm (±)	**7768**	**7371**	**1669**	**1464**	**11871**
LSD (0.05)	**30327**	**NS**	**NS**	**5716**	**NS**
Fertility					
F_1	171528	161806	102778	109722	545833
F_2	206250	182639	127778	93056	609722
F_3	238889	198611	138889	70139	646528
SEm (±)	**6371**	**5720**	**5475**	**1985**	**11305**
LSD (0.05)	**19103**	**17149**	**16417**	**5950**	**33896**

Table 4: Observation on disease incidence in the experimental field of potato (Mean data of three years)

Treatment	Phoma (%)		Early blight (%)		Late Blight (%)		Viral Disease
	Incidence	**Intensity**	**Incidence**	**Intensity**	**Incidence**	**Intensity**	
$S_1H_1F_1$	8.35	2.00	3.55	2.30	0.00	0.00	0.00
$S_1H_1F_2$	8.00	1.65	4.00	2.50	0.00	0.00	0.00
$S_1H_1F_3$	7.35	1.65	4.50	2.50	0.00	0.00	0.00
$S_1H_2F_1$	10.30	2.50	5.00	2.50	0.00	0.00	0.00
$S_1H_2F_2$	7.45	2.00	6.00	3.00	0.00	0.00	0.00
$S_1H_2F_3$	6.75	1.65	7.50	3.70	0.00	0.00	0.00
$S_2H_1F_1$	11.50	2.80	5.50	3.00	0.00	0.00	0.00
$S_2H_1F_2$	10.45	2.00	5.75	3.50	0.00	0.00	0.00
$S_2H_1F_3$	10.00	1.65	6.25	3.50	0.00	0.00	0.00
$S_2H_2F_1$	15.60	3.15	6.50	3.00	0.00	0.00	0.00
$S_2H_2F_2$	10.00	3.00	10.00	4.00	0.00	0.00	0.00
$S_2H_2F_3$	9.00	2.35	10.35	4.25	0.00	0.00	0.00

Dehaulming at 65 DAP enhanced the seed grade size (<75g) tuber yield over dehaulming at 75 DAP. However, haulm cutting at 75DAP significantly increased the marketable tuber (> 75 g) yield (14.42 t ha^{-1}) and total tuber yield (32.34 t ha^{-1}). Similar findings were also reported by Das *et al.* (2016) and Mandal and Das (2020). With the reduction in nutrient doses from 100% RD of NPK to 50% RD of NPK the seed grade (< 75 g) tuber yield was significantly enhanced but marketable grade tuber yield (> 75 g), total tuber yield and tuber dry weight yield were significantly reduced which might be due to reduced intra row spacing enhanced the tuber numbers by reducing the tuber size. This result was confirmed by Dua *et al.* (2008), Chakraborty *et al.* (2013), Das *et al.* (2016) and Mandal and Das (2020). The maximum total tuber yield (35.60 t ha^{-1}) was recorded with 100% RD of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP. Though the interaction effects of treatments were found nonsignificant.

Effect on tuber numbers

Results showed that, grade wise tuber numbers and total tuber numbers of potato were significantly influenced by intra row spacing (Table. 3). With the reduction of plant to plant spacing from 20 to 15cm seed

Table 5: Observation on aphid infestation in the experimental field of potato (Mean data of three years)

Treatment	Population of aphid per 100 compound leave								
	03.01.17	03.01.18	03.01.19	10.01.17	10.01.18	10.01.19	17.01.17	17.01.18	17.01.19
$S_1H_1F_1$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_1H_1F_2$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_1H_1F_3$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_1H_2F_1$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25
$S_1H_2F_2$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
$S_1H_2F_3$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75
$S_2H_1F_1$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_2H_1F_2$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_2H_1F_3$	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
$S_2H_2F_1$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40
$S_2H_2F_2$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.15
$S_2H_2F_3$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.80

Table 6: List of primers used

SL.No	Oligo name	Sequence (5'-3')
1)	PVXF	CACTGCAGGCGCAACTCC
2)	PVXR	GTCGTTGGATTGCGCCCT
3)	PLRVF	CTAACAGAGTTCAGCCAGTG
4)	PLRVR	GCACTGATCCTCAGAAGAAT
5)	PVMF	GCATATATGTGAACCTGGAG
6)	PVMR	GCGTATTGTGAGCTACCTT
7)	PVSF	CGTAGAGGAGCATAGAGTTG
8)	PVSR	GCACACATGATCACCACT
9)	PAMVF	CCTAGATGAGATTGCTTACG
10)	PAMVR	GTCTGGAATCTCATGCTTC

Table 7: Comprehensive results on the produced seed tuber samples for the presence of infection of potato Virus Y, PVX, PLRV, PVM, PVS

Sample No.	Name of the crop plant	Reaction to Immuno-strip		Reaction to PCR		Reaction to PCR			
		Potato Virus Y		Potato Virus Y		PVX	PLRV	PVS	PVM
		sample	+ve control	sample	+ve control				
1	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
2	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
3	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
4	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve

Table 8: Comprehensive results on the leaf samples at 65 DAP for the presence of infection of potato Virus Y, PVX, PLRV, PVM, PVS

Sample No.	Name of the crop plant	Reaction to Immuno-strip		Reaction to PCR		Reaction to PCR			
		Potato Virus Y		Potato Virus Y		PVX	PLRV	PVS	PVM
		sample	+ve control	sample	+ve control				
1	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
2	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
3	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve
4	Potato	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve

Table 9: Comprehensive results on the leaf samples at 75 DAP for the presence of infection of potato Virus Y, PVX, PLRV, PVM, PVS

Sample No.	Name of the crop plant	Reaction to Immuno-strip Potato Virus Y		Reaction to PCR Potato Virus Y		Reaction to PCR			
		sample	+ve control	sample	+ve control	PVX	PLRV	PVS	PVM
1	Potato	-ve	+ve	-ve	+ve	+ve	-ve	-ve	-ve
2	Potato	-ve	+ve	-ve	+ve	+ve	-ve	-ve	-ve
3	Potato	-ve	+ve	-ve	+ve	+ve	-ve	-ve	-ve
4	Potato	-ve	+ve	-ve	+ve	+ve	-ve	-ve	-ve

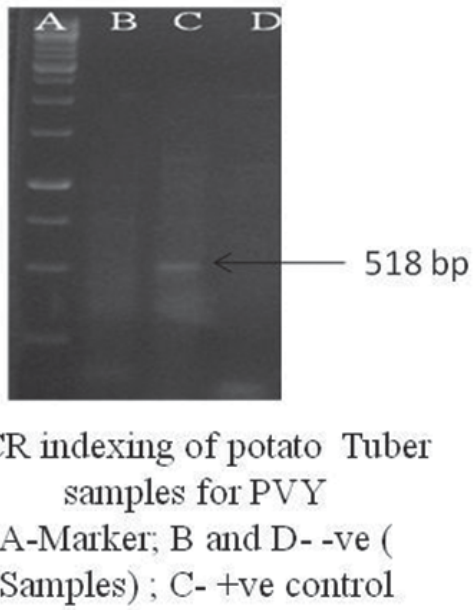

Fig. 1: Lane M – 1kb DNA Ladder, Lane-B and C (-ve to PVY) Lane C- Positive control

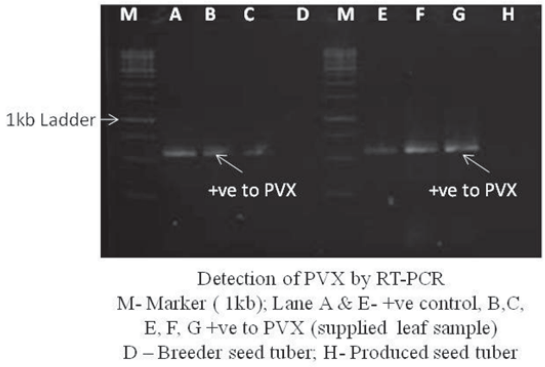

Fig. 2: RT-PCR Testing of Tuber and leaves of potato by RT-PCR for PVX

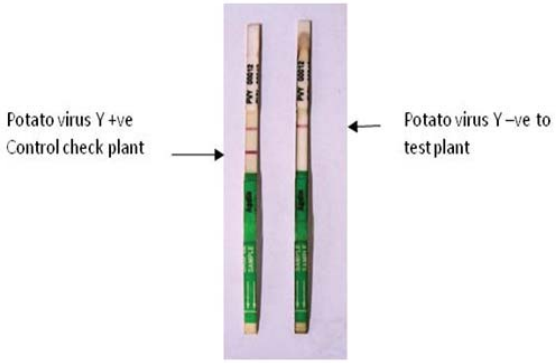

Fig. 3: Potato virus Y infection as confirmed by immunostrip diagnosis method

size (< 75g) tuber numbers and total tuber numbers were significantly increased but marketable grade (> 75 g) tuber number was significantly reduced, which is necessary for production of higher numbers of seed size tubers of potato. Similar findings were also reported by Dua *et al.* (2008), Das *et al.* (2016) and Mandal and Das (2020). Dehaulming at 65 DAP enhanced the seed size (<75g) tuber numbers and total tuber numbers of potato and significantly decreased the marketable grade (> 75 g) tuber numbers. Similar findings were also reported by Das *et al.* (2016), Mahmud *et al.* (2009) and Garg *et al*. (1999). However, the effect of dehaulming time on total tuber number was found statistically nonsignificant. Nutrient management had a significant effect on grade wise and total tuber numbers of potato. With the reduction in nutrient doses from 100% RD of NPK to 50% RD of NPK the seed size (< 75 g) tuber numbers along with total tuber numbers were significantly enhanced but marketable grade (>75g) tuber numbers were significantly reduced. This was confirmed by the reports of Das *et al.* (2016) and Mandal and Das (2020). It was utmost important for potato seed tuber production as large sized tubers (>80g) are discarded under potato seed certification process in the state of West Bengal. Benefits of small sized tubers to be treated as seed was also reported by Wurr *et al.* (2001). Though, interaction effects were found non significant.

Table 10: Economics and Net Return of potato seed tuber production

Treatment	Seed grade tuber yield (t ha^{-1})	Marketable grade (>75g) tuber yield (t ha^{-1})	Total tuber Yield (t ha^{-1})	Cost of cultivation (Rs. ha^{-1}) Seed	Fertilizer	Common cost	Cost Inputs	(Rs ha^{-1}) Produce	Marketable tuber Sale price (Rs.t^{-1})	Seed tuber sale price (Rs.t^{-1})	Net returns* (Rs.ha^{-1})	B:C ratio (Seed+ Marketable)	B:C ratio (Only Seed)
$S_1H_1F_1$	16.00	17.95	33.95	72000	14614	50000	136614	619700	6000	32000	483086	3.54	2.75
$S_1H_1F_2$	16.52	11.92	28.44	72000	10961	50000	132961	600160	6000	32000	467199	3.51	2.98
$S_1H_1F_3$	17.68	7.45	25.13	72000	7307	50000	129307	610460	6000	32000	481153	3.72	3.38
$S_1H_2F_1$	15.16	20.97	36.13	72000	14614	50000	136614	610940	6000	32000	474326	3.47	2.55
$S_1H_2F_2$	16.44	14.03	30.47	72000	10961	50000	132961	610260	6000	32000	477299	3.59	2.96
$S_1H_2F_3$	17.52	8.45	25.97	72000	7307	50000	129307	611340	6000	32000	482033	3.73	3.34
$S_2H_1F_1$	17.33	17.94	35.27	93600	14614	50000	158214	662200	6000	32000	503986	3.19	2.51
$S_2H_1F_2$	20.15	12.06	32.21	93600	10961	50000	154561	717160	6000	32000	562599	3.64	3.17
$S_2H_1F_3$	22.76	6.39	29.15	93600	7307	50000	150907	766660	6000	32000	615753	4.08	3.83
$S_2H_2F_1$	17.03	20.00	37.03	93600	14614	50000	158214	664960	6000	32000	506746	3.20	2.44
$S_2H_2F_2$	19.51	14.16	33.67	93600	10961	50000	154561	709280	6000	32000	554719	3.59	3.04
$S_2H_2F_3$	21.88	8.89	30.77	93600	7307	50000	150907	753500	6000	32000	602593	3.99	3.64

Disease incidence and intensity

Results revealed that late blight disease was not observed at all in all the three years of study (Table 4) because in all the three years of study the crop was dehaulmed before appearance of late blight. Leaf spot diseases like phoma and early blight were recorded in all the three years. Both intra row spacing and nutrient management had a considerable effect on disease incidence and intensity. Highest phoma leaf spot incidence (15.60%) and intensity (3.15%) was observed when spacing was 60 x 20 cm and 100% RD of NPK. With same spacing the disease incidence and intensity decreased with decreasing dose of fertilizers *i.e.* 75% RD of NPK and 50% RD of NPK respectively. When the intra row spacing was increased to 60 x 20 cm from the spacing 60 x 15cm the disease incidence and intensity started decreasing. Minimum disease incidence (6.75%) and intensity (1.65%) was observed when the spacing was 60 x 20cm with 50% RDF of NPK. It was interesting to note that for early blight, the disease incidence and intensity was enhanced with reducing nutrient doses. Barclay *et al.* (1973) also reported that both high nitrogen and low phosphorus treatments significantly reduced the incidence of early blight and the combination of high nitrogen and low phosphorus consistently gave the lowest incidence of the disease. Highest early blight incidence (10.35%) and intensity (4.25%) were observed when spacing was 60 x 15cm and fertilizer dose was 50% RD of NPK. Lowest early blight incidence (3.55%) and intensity (2.30%) were observed at a spacing of 60 x 20cm and fertilizer dose 100% RD of NPK. Decrease in early blight incidence with enhanced nutrient doses was also reported by Mitra *et al.* (2014). Viral disease did not occur during all three years of study. It might be due to scheduled insecticide applications followed under seed plot technique which started from twenty five days after planting of potato.

Incidence of aphid

The aphid population data revealed (Table 5) that aphid infestation was nil during the entire crop season in the first two years. Some aphid population (1.75 – 2.40 aphids per 100 compound leaves) build up was noticed in the third year of experiment on 17th January. It was much below the critical level (20 aphids per 100 compound leaves) and it was easily controlled by the prophylactic measures taken and through continuous roughing operations. Therefore the chances of viral disease transmission through aphids was nil. In the state of West Bengal dehaulming at 65 days after planting was found best to avoid the chances of viral disease transmission by the sucking pests. The data showed that up to 10th January aphid infestation was nil in all the three years of experiment and the crop was dehaulmed on 9th January after completing 65 days crop growth

period. When the crop was allowed to grow for 75 days duration, then in first two years no aphid infestation was noticed but in the third year little aphid population build up was noticed which was controlled by spray schedules followed in seed plot technique.

Virus indexing of leaves and tubers of potato

The results showed that, from the indexing of the viruses in the tubers of Kufri Himalini (breeder seed and produced seed tuber), the seeds were free from PVY, PVX, PVS, PVM and PVLRV (Table 7 and Fig. 1 and 2). The potato breeder seed and produced seed tuber and leaves supplied were found negative to potato virus Y infection as confirmed by immunostrip diagnosis (Fig. 3) method as well as by RT-PCR. The PCR results for one virus specific primers of PVX amplified the bands in the test leaf samples (leaf sample at 75 DAP) (Table 9 and Fig. 2), whereas the positive control plants amplified the bands. The leaf samples collected at 65 DAP were found negative to PVX (Table 8). But potato breeder seed and produced seed tuber did not amplify the PVX specific band; however the seed tubers were found free from PVX. Potato breeder seed and produced seed tuber and leaves were performed RT-PCR using gene specific primer pairs and all the samples were found negative to RT-PCR detection of PVM and PVS. No samples of potato breeder seed and produced seed tuber and leaves showed positive to PLRV. Few leaf samples showed positive to PVX infection which were collected during harvest at 75 DAP but the produced seed tuber samples collected from the seed tuber production field were negative to PVX. It is concluded from the indexing of the viruses in the tubers of Kufri Himalini that the supplied breeder seed tubers and produced seed tubers from the breeder seed were free from PVY, PVX, PVS, PVM and PVLRV.

Economics

It was noticed that the net return of potato production (seed + marketable) varied from Rs. 467199 ha^{-1} to Rs. 615753 ha^{-1} (Table 10). The highest net return (467199 ha^{-1}) and B : C ratio (4.08) were recorded with 15 cm intra row spacing, dehaulming at 65 DAP and nutrient management with 50% of RD of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP followed by 15 cm intra row spacing, dehaulming at 75 DAP and nutrient management with 50% of RD of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP. The lowest net return (Rs. 467199 ha^{-1}) was recorded with 20 cm plant to plant spacing, and dehaulming at 65 DAP and nutrient management with 75% RD of NPK+ 0.1% boric acid as foliar application at 40, 50 and 60 DAP. Considering only seed grade tuber production excluding marketable grade the highest B : C ratio (3.83) was recorded with 15 cm intra row spacing, dehaulming at 65 DAP and nutrient management with 50% of RD of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP followed by B : C ratio (3.64) with 15 cm intra row spacing, dehaulming at 75 DAP and nutrient management with 50% of RD of NPK + 0.1% boric acid as foliar application at 40, 50 and 60 DAP.

From the experiment it may be concluded that, for virus free (PVY, PVX, PVS, PVM and PVLRV) potato seed tuber production application of 60 x 15cm spacing and haulm cutting at 65 days after planting, when planted on 5th November and fertilized with 50% RD of NPK i.e. 100:75:75 kg $N:P_2O_5:K_2O$ ha^{-1} + 0.1% boric acid as foliar application at 40, 50 and 60 DAP, was found best in lower Indo-Gangetic plains of India.

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