Journal of Experimental Biology and Agricultural Sciences

<http://www.jebas.org>

ISSN No. 2320 – 8694

POTASSIUM SCHOENITE: AN EMERGING SOURCE OF POTASSIUM FOR IMPROVING GROWTH, YIELD AND QUALITY OF POTATO

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Received – January 23, 2017; Revision – March 22, 2017; Accepted – April 23, 2017

Available Online – May 12, 2017

DOI: [http://dx.doi.org/10.18006/2017.5\(2\).173.182](http://dx.doi.org/10.18006/2017.5(2).173.182)

KEYWORDS

Potassium schoenite

Foliar Spray

Potato

Yield

Quality

ABSTRACT

A field experiment with potato (*Solanum tuberosum* L.) crop was carried out on an alluvial soil in West Bengal, India with the focal aim of assessing the relative effect of soil and foliar application of indigenously produced potassium schoenite (PS) in relation to that of muriate of potash (MOP) during winter seasons of 2014-15 and 2015-16 using a randomized complete-block design. The following treatment factors were evaluated: two sources of K (MOP and PS), two doses of K (100 and 75% of recommended K as basal) and foliar application of PS (without and with). Experimental findings showed that different sources, doses and foliar application of PS significantly altered plant growth, yield and quality parameters (ascorbic acid, specific gravity and reducing sugar). Regarding, combination of different factors recommended doses of NPK (either PS or MOP as source of K) along with foliar PS fertilization was the best combination that resulted in the highest plant growth (height, dry matter accumulation), tuber number and yield of potato with respect to rest of the fertilization treatments. The same treatment combination exerted best potato quality parameters like ascorbic acid content, specific gravity and reducing sugar content. So, for getting higher yield and quality produce from potato, PS may be a good option for the potato-growers.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher India [HPI]
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1 Introduction

Potato (*Solanum tuberosum* L.) is one of the most important crops grown both in sub-tropical and temperate regions of the world. It is the only crop having the potential like rice, wheat and maize to supplement the need for foods, of any nation (Alva et al., 2011). Potatoes are usually used for a wide range of table and processed foods, feeds and also for industrial purposes. India is the largest potato producer among the south-west Asian countries (Kadian et al., 2007) and globally ranks second after China in total potato production (FAO, 2014). Producing 12 mt of potato from 0.41 m ha with a productivity of 29.7 t ha⁻¹ West Bengal, amongst all the potato growing states of India, holds the second position nationally (Horticulture Statistics Division, GOI, 2014).

Potato requires a numbers of macro and micro plant nutrients for its growth and development. Nitrogen (N), phosphorus (P) and potassium (K) are the most essential plant nutrients that are largely required by potato (Banerjee et al., 2016a). Being a strong K-loving crop, potato mines K in larger amounts than it consumes N and P (Panagiotopoulos, 1995). Further, Moinuddin et al. (2004) reported that for producing 29 t ha⁻¹ of tubers, potato removed 91 kg K₂O ha⁻¹. K is essentially required for the synthesis of sugars and starch and also for translocation of carbohydrates; it also plays an important role in maintaining growth and vigor of the plants (Singh et al., 1996; Banerjee et al., 2016b). Potassium is also responsible for higher yield and quality tuber production (Alva et al., 2011). Being a vegetative part of the plant, potato clicks with more nutrient inputs yielding more tubers; encouraging the farmers of the studied area to apply more and more chemical fertilizer to have more tuber yield without thinking of the tuber quality, soil health and environmental safety as a whole. Though the most widely used form of K fertilizer is K-chloride (KCl) in potato cultivation, Kumar et al. (2007) have reported that chloride form of K fertilization in potato above the recommended dose impacts dry-matter percentage negatively, with reduced processing quality. Sulfate form of K fertilizers usually results in a higher dry-matter percentage in potato tubers than equivalent quantities of K in the chloride form (Smith, 1987); but it is less used by the potato growers because of its limited availability and relatively high price.

Indian potato fertilization system is mainly based upon N, P and K. Among them for K fertilizers, mainly muriate of potash (MOP) is completely dependent on import. Every year India has to spend a bulk of foreign exchange for importing potassium fertilizers. The country imported 3797 thousand tons of K fertilizer during 2014–15 (Department of Fertilizer, GOI, 2016). Indigenously, extraction process of sulphate of potash (K₂SO₄) and schoenite (K₂SO₄, MgSO₄) from sea bittern was developed by Central Salt and Marine Chemicals Research Institute, Bhavnagar, Gujarat (Rathore et al., 2014) and some private agri-input agencies. Among them, indigenously produced double salts of K, i.e., potassium schoenite (molar mass 415 g/mol) have been found to be beneficial on acidic and alluvial soils which provides a readily available supply of Potassium, Magnesium and Sulfur to growing plants in an ideal ratio.; although very little work has been reported so far (Sharma et al., 1998). Therefore, keeping the above facts in background, relative effect of soil and foliar application of

indigenously produced potassium schoenites compared to that of MOP on potato were studied in the present investigation.

2 Materials and Methods

2.1 Climatic Conditions of the Study area

The field trial was carried out at District Seed Farm-C Unit, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India (22°58' N latitude, 88°25' E longitude, 8.5 m above mean sea level) during the winter season of 2014–15 and 2015–16. In the studied area the respective maximum and minimum temperature fluctuated between 37.3 – 24.8°C and 20.3 – 9.6°C in 2014–15, and 35.1 – 23.7°C and 21.8 – 9.3°C in 2015–16. The maximum and minimum relative humidity of the experimental area prevailed between 89 and 34% in 2014–15 and 97 and 34% in 2015–16 respectively. The rainfall during the experimental period was 24.2 (5 rainy days) and 112.3 mm (14 rainy days) in both of the experimental year, respectively. It is evident from the above data that weather conditions were quite congenial for growth and development of potato crop during both the years of experimentation. The soil of study area was, sandy clay loam (56.5 % sand, 24.7 % silt and 21.6 % clay) type with the following key properties for the 0–30 cm layer: pH 6.76 (in 1:2.5:: Soil : Water), EC 0.25 dS m⁻¹ (in 1:2.5:: Soil : Water), organic carbon 0.57 % (Wet oxidation method), available N 82.1 kg ha⁻¹ (Hot alkaline KMnO₄ Method), available P 18.81 kg ha⁻¹ (0.5 M NaHCO₃ extract) and available K 167.3 kg ha⁻¹ (Neutral N NH₄OAc extract).

2.2 Treatments and experimental design

The experiment was designed in randomized complete block with three factors being two sources of K viz. MOP and potassium schoenite (PS), two doses of K (100 and 75% of recommended K as basal) and foliar application of PS (without and with). The total treatment combinations were eight replicated thrice. Individual plot size for each treatment was 6 m × 5 m. Seed tubers of cv. *Kufri Jyoti*, a medium maturing (90–100 days) high yielding potato variety popularly grown in West Bengal, weighing about 30–40 g each were hand planted at a depth of 15 cm on 21 and 24 November of 2014 and 2015 respectively in tyne-made furrows at a spacing of 60 cm × 20 cm, and finally covered with soil. A uniform recommended dose (RD) of N-P i.e. 200-150 kg.ha⁻¹ was applied in all the plots through urea [50 % before sowing and 50 % at 30 days after planting (DAP)] and single super phosphate (100 % before sowing). Both the potassic fertilizers were applied along with NK fertilizer, as per treatment combinations. As foliar application 1.0% PS solution was applied at 30 and 50 DAP according to the treatment combination by a knapsack sprayer with a spray volume of 16 L capacity; the volume of water being 500 L ha⁻¹. For the good germination and establishment of the crop two light irrigations were applied at 7 days interval within 12 DAP. Six more irrigations were given at an interval of 7–8 days. For the purpose of weed management, metribuzin at 750 g ha⁻¹ was applied as pre-emergence at 3 DAP, and subsequent weed flushes were managed through manual measures in both the years of study. Earthing up was done at 30 DAP and ridges were made manually with spade.

No major insect pests and disease were observed during the cropping season in both of the experimental years. To check aphid infestation at later stages of crop growth dehauling (removal of above ground biomass i.e. haulms) by sickle was performed at 15 days before harvesting of tubers. Potato was harvested on 23 and 24 February in 2015 and 2016, respectively.

2.3 Plant sampling and observations

In each plot, the second rows on either side were marked for destructive sampling *vis-a-vis* for recording other biometric observations and the middle four rows were marked for determination of tuber yield. To determine the germination percentage (%) the plants germinated from tubers was randomly counted at 30 DAP from five rows of each plot and expressed in percentage (%). Biometric observations *viz.* plant height, number of haulms hill^{-1} and number of compound leaves plant^{-1} are taken from the five randomly selected plants from each plots at 30, 50, 70 and 90 DAP. Leaf area index (LAI) for each treatment was calculated at 30, 50, 70 and 90 DAP by using the following formula (Watson, 1947).

$$\text{LAI} = \frac{\text{Area of total number of leaves}}{\text{Ground area of sampled plants}}$$

For recording dry weight, plants from the penultimate row in each plot were uprooted carefully and then sun-dried and oven dried (70°C) to obtain a constant dry weight, and finally expressed in g plant^{-1} . Crop growth rate (CGR) was computed using following formula (Gardner, 1985):

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times \text{GA g/m}^2/\text{day}$$

Where, W_2 and W_1 are the final and initial dry weights of plant material per unit area at times t_2 (final time) and t_1 (initial time) respectively and GA is the ground area (m^2).

Tuber bulking rate (TBR) was calculated as described by Mozumder et al. (2014).

$$\text{TBR} = \frac{W_2 - W_1}{t_2 - t_1} \times \text{GA g/m}^2/\text{day}$$

Where, W_2 and W_1 are the final and initial fresh weights of tuber per unit area at times t_2 (final time) and t_1 (initial time) respectively and GA is the ground area (m^2).

To determine the tuber yield and number five rows of 4 m length in the centre of each treatment plot was taken and finally represented in t ha^{-1} .

2.4 Determination of biochemical parameters

After harvesting of potato tubers, some biochemical analysis were done to judge the quality parameters as influenced by different sources, doses and methods of application of potassium fertilizers. Ascorbic acid content of potato was estimated by using 2, 6 *di-chlorophenolindophenol* dye titration method (Casanas et al., 2002). The reducing sugar (dry weight basis) of potato tuber was determined by following the method of Nelson (1944). Specific weight of potato was determined by hydrometer method using a sample of 3.63 kg of processing grade tubers from each plot (Gould, 1999).

2.5 Statistical analysis

The statistical analysis of data was done using SAS Windows Version 9.3 applying analysis of variance (PROC GLM) with subsequent multiple comparisons of means for both of the experimental years. The effect of the years was non-significant and there were no significant interactions between treatments and years. Therefore, the data were combined over the years and subjected to ANOVA. Treatment means were separated with the use of Tukey's Honestly Significant Difference test at the 5% level of significance.

3 Results

3.1 Potato Growth traits

Plant germination recorded at 30 DAP revealed that neither the source nor the dose of K fertilization affected the final plant stand (Table 1); even combination of different factors recorded non-significant response to germination (Table 2). Source and dose of K fertilization significantly ($p \leq 0.05$) influenced plant height of the crop at later growth stages (50, 70 and 90 DAP). Basal application of PS improved plant height significantly ($p \leq 0.05$) than the MOP did (Table 1). A reduction in the dose K fertilizer ($\text{RD}_{\text{NPK}}\text{34K}$) resulted in a reduced plant height at 50 and 70 DAP by 6.1 and 6.3% respectively with respect to the crop fertilized with RD_{NPK} . On other hand, the plant height of potato recorded at different growth stages excepting 70 DAP was more when the plants received two foliar spray of PS than without foliar spray (Table 1).

Regarding combination of different factors, application of $\text{RD}_{\text{NPK}}\text{K}_{\text{MOP}}/\text{b}$ 2 FS recorded significantly higher plant height at 30 DAP and it was 16% higher than that the conventional nutrient management ($\text{RD}_{\text{NPK}}\text{K}_{\text{MOP}}$) recorded (Table 2). But at later stages of crop growth (50, 70 and 90 DAP) application of $\text{RD}_{\text{NPK}}\text{K}_{\text{PS}}/\text{b}$ 2 FS recorded the maximum plant height among the different treatment combinations. As evident from Table 1, different sources and dose of K fertilization did not significantly influence the number of compound leaves plant^{-1} throughout the crop growth period, though two sprayings with PS exerted positive response on the number of compound leaf at active growth periods (50 and 70 DAP).

Table 1 Direct effect of source, dose and method of potassium fertilization on germination, plant height, number of compound leaves plant⁻¹ and leaf area index (LAI) of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Germination	Plant height (cm)					Number of compound leaves plant ⁻¹					LAI		
	%	Days after planting												
	30	30	50	70	90	30	50	70	90	30	50	70	90	
Source of K fertilization														
†MOP	96.7	14.8	26.6 ^b	40.1 ^b	51.0 ^b	32.5	52.3	47.2	28.3	0.89	3.20 ^b	3.01 ^b	2.62 ^b	
††PS	96.7	14.9	27.7 ^a	42.7 ^a	53.0 ^a	35.4	54.2	48.3	31.4	0.84	3.40 ^a	3.18 ^a	2.84 ^a	
SEm±	0.51	0.19	0.28	0.37	1.17	1.68	1.53	1.57	1.31	0.05	0.04	0.03	0.05	
CD (p≤0.05)	NS	NS	0.85	1.14	0.38	NS	NS	NS	NS	NS	0.12	0.10	0.15	
Dose of K fertilization														
*RD _{NPK}	97.3	15.0	28.0 ^a	42.8 ^a	52.1	33.4	54.3	49.2	31.8	0.88	3.36 ^a	3.13	2.81 ^a	
RD _{NP¾K}	96.1	14.8	26.3 ^b	40.1 ^b	51.9	34.5	52.1	46.3	27.9	0.85	3.24 ^b	3.06	2.65 ^b	
SEm±	0.52	0.19	0.28	0.38	0.38	1.68	1.53	1.57	1.31	0.05	0.04	0.03	0.05	
CD (p≤0.05)	NS	NS	0.85	1.14	NS	NS	NS	NS	NS	NS	0.12	NS	0.15	
Foliar of K fertilization														
Without foliar spray	96.9	14.5	25.1 ^b	40.9	50.1 ^b	34.4	45.9 ^b	42.3 ^b	30.3	0.84	3.09 ^b	2.94 ^b	2.50 ^b	
§Two spray with PS	96.6	15.2	29.2 ^a	41.9	54.0 ^a	33.5	60.5 ^a	53.2 ^a	29.4	0.89	3.51 ^a	3.25 ^a	2.96 ^a	
SEm±	0.52	0.18	0.27	0.38	0.38	1.67	1.52	1.57	1.30	0.05	0.04	0.03	0.05	
CD (p<0.05)	NS	NS	0.85	NS	1.18	NS	4.64	4.78	NS	NS	0.11	NS	0.15	

^{††}MOP, Muriate of potash (KCl); ^{††}PS, Potassium schoenite (K₂SO₄, MgSO₄); ^{*}RD_{NPK}, Recommended dose of N:P₂O₅:K₂O::200:150:150 kg ha⁻¹;

[§]Two foliar spray of 1% PS at 30 and 50 days after planting; NS, Non-significant; Means followed by a different letter are significantly different at $p \leq 0.05$ by Tukey's HSD (honest significant difference) test].

Table 2 Interaction effect of source, dose and method of potassium fertilization on germination, plant height, number of compound leaves/plant and leaf area index (LAI) of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Germination %	Plant height (cm)				Number of compound leaves plant ⁻¹					LAI			
	Days after planting													
	30	30	50	70	90	30	50	70	90	30	50	70	90	
RD _{NPK} MOP	97.6	13.7 ^b	25.1 ^{de}	41.7 ^{ab}	48.9 ^b	32.0	46.7 ^{bc}	44.3 ^{ab}	33.7	0.83	3.15 ^b	2.94 ^c	2.48 ^c	
RD _{NPK} MOP/ <i>fb</i> 2 FS*	97.0	15.9 ^a	29.8 ^{ab}	41.6 ^{ab}	53.1 ^{ab}	32.7	59.7 ^{ab}	52.0 ^{ab}	28.7	0.94	3.39 ^{ab}	3.23 ^{abc}	2.97 ^{ab}	
RD _{NPK} ³ / ₄ K _{MOP}	94.7	14.6 ^{ab}	22.8 ^e	37.6 ^b	49.2 ^b	32.3	43.3 ^{bc}	40.7 ^b	24.3	0.84	3.09 ^b	2.95 ^c	2.54 ^{bc}	
RD _{NPK} ³ / ₄ K _{MOP} <i>fb</i> 2 FS	97.7	15.0 ^{ab}	28.5 ^{abc}	39.7 ^{ab}	53.0 ^{ab}	33.0	59.3 ^{ab}	51.7 ^{ab}	26.7	0.96	3.16 ^b	2.93 ^c	2.49 ^a	
RD _{NPK} K _{PS}	98.3	14.6 ^{ab}	26.6 ^{bcd}	43.0 ^{ab}	51.2 ^{ab}	34.3	48.0 ^{bc}	44.7a ^b	32.7	0.85	3.08 ^b	2.99 ^{bc}	2.62 ^{bc}	
RD _{NPK} K _{PS} / <i>fb</i> 2 FS	96.4	15.6 ^{ab}	30.4 ^a	44.9 ^a	55.2 ^a	34.7	63.0 ^a	55.7 ^a	32.3	0.91	3.82 ^a	3.37 ^{ab}	3.17 ^a	
RD _{NPK} ³ / ₄ K _{PS}	96.9	15.0 ^{ab}	25.8 ^{cde}	41.4 ^{ab}	50.9 ^{ab}	39.0	45.7 ^{bc}	39.7 ^b	30.7	0.85	3.05 ^b	2.88 ^c	2.36 ^c	
RD _{NPK} ³ / ₄ K _{PS} / <i>fb</i> 2 FS	95.4	14.5 ^{ab}	28.1 ^{abcd}	41.6 ^{ab}	54.6 ^a	33.7	60.0 ^{ab}	53.3 ^{ab}	30.0	0.74	3.66 ^a	3.47 ^a	3.22 ^a	
SEm±	1.02	0.37	0.56	0.75	0.77	3.37	3.01	3.15	2.61	0.10	0.08	0.06	0.10	
CD (<i>p</i> ≤0.05)	NS	1.90	3.32	5.13	5.11	NS	18.9	14.5	NS	NS	0.59	0.30	0.30	

[RD/recommended dose of fertilizer (N:P₂O₅), 200:150 kg ha⁻¹; NS, Non-significant; Means followed by a different letter are significantly different at $p \leq 0.05$ by Tukey's HSD (honest significant difference) test; * 2 FS, Two foliar spray of 1% PS at 30 and 50 days after planting]

Table 3 Direct effect of source, dose and method of potassium fertilization on haulm dry weight, tuber dry weight and total (haulm + tuber) dry weight of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Haulm dry weight (g m ⁻²)				Tuber dry weight (g m ⁻²)				Total dry weight (g m ⁻²)			
	Days after planting											
	30	50	70	90	50	70	90	30	50	70	90	
Factor A: Source												
[†] MOP	9.04	118 ^a	187 ^b	164 ^b	534	969	2072 ^b	9.04	652 ^a	1156	2236 ^b	
^{††} PS	8.96	92.4 ^b	199 ^a	174 ^a	538	978	2154 ^a	8.96	630 ^b	1177	2329 ^a	
SEm±	0.15	1.52	2.11	2.52	3.70	8.92	14.76	0.15	3.42	8.69	15.70	
CD (<i>p</i> ≤0.05)	NS	4.61	6.40	7.63	NS	NS	44.75	NS	10.38	NS	47.61	
Factor B: Dose												
[*] RD _{NPK}	9.08	121 ^a	199 ^a	174 ^a	540	1007 ^a	2165 ^a	9.08	661 ^a	1206 ^a	2339 ^a	
RD _{NP¾K}	9.91	88.7 ^b	187 ^b	164 ^b	532	940 ^b	2062 ^b	9.91	621 ^b	1127 ^b	2226 ^b	
SEm±	0.15	1.52	2.11	2.51	3.71	8.90	14.77	0.15	3.46	8.90	15.69	
CD (<i>p</i> ≤0.05)	NS	4.60	6.40	7.61	NS	27.05	44.70	NS	10.38	26.38	47.60	
Factor C: Method												
Without	8.36 ^b	115 ^a	182 ^b	159 ^b	533	939 ^b	2047 ^b	8.36 ^b	647 ^a	1120 ^b	2206 ^b	
[§] Two spray	9.64 ^a	95.3 ^b	204 ^a	179 ^a	540	1008 ^a	2180 ^a	9.64 ^a	635 ^b	1213 ^a	2359 ^a	
SEm±	0.15	1.52	2.12	2.50	3.73	8.90	14.79	0.15	3.41	8.70	15.70	
CD (<i>p</i> ≤0.05)	0.45	4.60	6.35	7.63	NS	27.06	44.40	0.45	10.30	26.39	47.63	

[[†]MOP, Muriate of potash (KCl); ^{††}PS, Potassium schoenite (K₂SO₄, MgSO₄); ^{*}RD_{NPK}, Recommended dose of N:P₂O₅:K₂O::200:150:150 kg ha⁻¹; [§]Two foliar spray of 1% PS at 30 and 50 days after planting; NS, Non-significant; Means followed by a different letter are significantly different at $p \leq 0.05$ by Tukey's HSD (honest significant difference) test.]

Table 4 Interaction effect of source, dose and method of potassium fertilization on haulm dry weight, tuber dry weight and total (haulm + tuber) dry weight of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Haulm dry weight (g m ⁻²)				Tuber dry weight (g m ⁻²)			Total dry weight (g m ⁻²)				
	Days after planting											
	30	50	70	90	50	70	90	30	50	70	90	
RD _{NPK} MOP	8.37 ^c	118 ^{ab}	174 ^d	154 ^{cd}	533	974 ^{bcd}	2072 ^b	8.37 ^c	650 ^{bc}	1148 ^{cd}	2226 ^c	
RD _{NPK} MOP <i>fb</i> 2FS*	9.14 ^{abc}	125 ^a	212 ^{ab}	182 ^{ab}	539	1007 ^{ab}	2164 ^{ab}	9.14 ^{abc}	664 ^{ab}	1219 ^b	2346 ^b	
RD _{NPK} ^{3/4} K _{MOP}	8.23 ^c	106 ^b	172 ^d	148 ^d	532	904 ^d	1999 ^b	8.23 ^c	639 ^c	1077 ^e	2147 ^e	
RD _{NPK} ^{3/4} K _{MOP} <i>fb</i> 2FS	10.40 ^{ab}	120 ^{ab}	189 ^{cd}	171 ^{bcd}	531	991 ^{bc}	2053 ^b	10.40 ^{ab}	652 ^{bc}	1180 ^{bc}	2225 ^c	
RD _{NPK} K _{PS}	8.23 ^c	115 ^{ab}	185 ^{cd}	160 ^{bcd}	531	964 ^{bcd}	2081 ^b	8.23 ^c	646 ^{bc}	1149 ^{cd}	2241 ^c	
RD _{NPK} K _{PS} <i>fb</i> 2FS	10.60 ^a	127 ^a	225 ^a	201 ^a	555	1082 ^a	2340 ^a	10.60 ^a	682 ^a	1307 ^a	2541 ^a	
RD _{NPK} ^{3/4} K _{PS}	8.60 ^{abc}	119 ^{ab}	195 ^{bc}	174 ^{bc}	534	911 ^{cd}	2035 ^b	8.60 ^{abc}	652 ^{bc}	1106 ^{de}	2210 ^d	
RD _{NPK} ^{3/4} K _{PS} <i>fb</i> 2FS	8.42 ^{bc}	123 ^{ab}	190 ^{cd}	161 ^{bcd}	532	952 ^{bcd}	2160 ^b	8.42 ^{bc}	655 ^{bc}	1142 ^{cd}	2322 ^b	
SEm±	0.29	3.04	4.22	5.03	7.40	17.84	29.51	0.29	6.85	17.40	31.40	
CD (<i>p</i> ≤0.05)	0.89	9.31	18.2	25.3	NS	51.26	179.2	0.89	41.5	53.29	96.14	

[RD_F/recommended dose of fertilizer (N:P₂O₅), 200:150 kg ha⁻¹; NS, Non-significant; Means followed by a different letter are significantly different at $p \leq 0.05$ by Tukey's HSD (honest significant difference) test; * 2 FS, Two foliar spray of 1% PS at 30 and 50 days after planting.]

In harmony to these findings, results obtained from different treatment combinations revealed that, potato fertilized with RD_{NPK}PS fb 2 FS produced significantly ($p \leq 0.05$) higher number of compound leaves plant⁻¹ at 50 and 70 DAP and these were 35 and 26% higher than those in potato fertilized with conventional nutrient management (Table 2). At the stage of maturity (90 DAP), senescence resulted in lowering in the number of compound leaves naturally, reflecting the non significance of all the fertilization treatments. LAI increased progressively over the time upto 50 DAP irrespective of source, dose and foliar application of K fertilizers,

and then it declined gradually (Table 1). Plants fertilized with PS exerted positive response on LAI throughout the growth period except at early growth stage (30 DAP). Reduction in the K fertilizer dose (RD_{NPK}^{3/4}K) recorded significantly lower LAI value at 50 and 90 DAP over recommended dose. The addition of PS through foliar application increased the growth of potato leaf up to 90 DAP as compared to without foliar PS application. As depicted from Table 2, different treatment combinations has no impact on LAI at the earlier crop growth stage; whereas, at later stages the maximum LAI was observed with RD_{NPK}PS fb 2FS.

Table 5 Direct effect of source, dose and method of potassium fertilization on crop growth rate (CGR), tuber bulking rate (TBR), tuber number and tuber yield of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Crop growth rate (g m ⁻² day ⁻¹)		Tuber bulking rate (g m ⁻² day ⁻¹)		Tuber number ha ⁻¹ (×10 ⁵)	Tuber yield (t ha ⁻¹)	
	Days after planting						
	30-50	50-70	70-90	50-70			70-90
Factor A: Source							
†MOP	5.43	3.47	-1.16	86.1 ^b	26.4 ^b	4.42 ^b	22.4 ^b
††PS	5.61	3.90	-1.23	88.8 ^a	27.4 ^a	4.58 ^a	23.0 ^a
SEm±	0.09	0.15	0.07	0.84	0.26	0.02	0.13
CD (<i>p</i> ≤0.05)	NS	NS	NS	2.57	0.78	0.07	0.39
Factor B: Dose							
*RD _{NPK}	5.61	3.89	-1.24	88.3	27.3 ^a	4.55 ^a	23.5 ^a
RD _{NP} ^{3/4} K	5.42	3.84	-1.46	86.6	26.5 ^b	4.45 ^b	21.9 ^b
SEm±	0.08	0.15	0.07	0.83	0.25	0.02	0.13
CD (<i>p</i> ≤0.05)	NS	NS	NS	NS	0.79	0.06	0.39
Factor C: Method							
Without foliar spray	5.32 ^b	3.35 ^b	-1.12	86.3	25.7 ^b	4.19 ^b	21.9 ^b
§Two spray with PS	5.71 ^a	4.02 ^a	-1.27	88.6	28.0 ^a	4.81 ^a	23.5 ^a
SEm±	0.09	0.16	0.06	0.83	0.25	0.02	0.14
CD (<i>p</i> ≤0.05)	0.26	0.46	NS	NS	0.78	0.07	0.40

[[†]MOP, Muriate of potash (KCl); ^{††}PS, Potassium schoenite (K₂SO₄, MgSO₄); *RD_{NPK}, Recommended dose of N:P₂O₅:K₂O::200:150:150 kg ha⁻¹;

[§]Two foliar spray of 1% PS at 30 and 50 days after planting; NS, Non-significant; Means followed by a different letter are significantly different at p≤0.05 by Tukey's HSD (honest significant difference) test.]

Table 6 Interaction effect of source, dose and method of potassium fertilization on crop growth rate (CGR), tuber bulking rate (TBR), tuber number and tuber yield of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Crop growth rate (g m ⁻² day ⁻¹)			Tuber bulking rate (g m ⁻² day ⁻¹)		Tuber number ha ⁻¹ (×10 ⁵)	Tuber yield (t ha ⁻¹)
	Days after planting						
	30-50	50-70	70-90	50-70	70-90		
RD _{NPK} MOP	5.48 ^{ab}	2.80 ^c	-1.00	86.6a	25.3 ^c	4.18 ^{cd}	22.0 ^{bcd}
RD _{NPK} MOP/ <i>fb</i> 2FS*	5.79 ^a	4.35 ^{ab}	-1.50	87.6	27.7 ^b	4.67 ^{ab}	24.2 ^a
RD _{NPK} 3/4K _{MOP}	4.92 ^b	3.28 ^{bc}	-1.22	85.3	26.1 ^{bc}	4.00 ^d	21.3 ^{cd}
RD _{NPK} 3/4K _{MOP} / <i>fb</i> 2FS	5.51 ^{ab}	3.45 ^{bc}	-0.92	84.9	26.3 ^{bc}	4.83 ^a	22.1 ^{bcd}
RD _{NPK} K _{PS}	5.36 ^{ab}	3.48 ^{bc}	-1.23	86.0	25.4 ^{bc}	4.45 ^{bc}	22.8 ^b
RD _{NPK} K _{PS} / <i>fb</i> 2FS	5.82 ^a	4.93 ^a	-1.23	92.9	30.7 ^a	4.90 ^a	25.0 ^a
RD _{NPK} 3/4K _{PS}	5.52 ^{ab}	3.82 ^{abc}	-1.03	87.4	26.2 ^{bc}	4.12 ^{cd}	21.5 ^d
RD _{NPK} 3/4K _{PS} / <i>fb</i> 2FS	5.73 ^{ab}	3.35 ^{bc}	-1.42	88.9	27.3 ^{bc}	4.83 ^a	22.6 ^{bc}
SEm±	0.17	0.30	0.14	1.70	0.51	0.05	0.26
CD (<i>p</i> ≤0.05)	0.53	0.93	NS	NS	1.58	0.14	0.79

[RD_F/recommended dose of fertilizer (N:P₂O₅), 200:150 kg ha⁻¹; NS, Non-significant; Means followed by a different letter are significantly different at p≤0.05 by Tukey's HSD (honest significant difference) test; * 2 FS, Two foliar spray of 1% PS at 30 and 50 days after planting.]

Haulm dry weight (above ground biomass) was increased upto 70 DAP and after that it was declined (Table 3). Moreover, different source, dose and foliar K fertilization exerted significant effect (p≤0.05) on haulm dry matter production. As compared to the crop fertilized with MOP or reduced dose of K fertilizer or even with no

foliar application, the crop receiving PS or RD_{NPK} or foliar PS spray exhibited positive response regarding haulm dry weight at later growth stages. The crop fertilized with RD_{NPK}/fb 2FS recorded higher haulm dry weight throughout the crop growth period (Table 4).

Table 7 Direct effects of source, dose and method of potassium fertilization on tuber quality attributes of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Ascorbic acid (mg 100 g ⁻¹ of fresh weight of tuber)	Specific weight (g cm ⁻³)	Reducing sugar content (%)
<i>Factor A: Source</i>			
[†] MOP	13.5 ^b	1.063	0.241 ^a
^{††} PS	13.8 ^a	1.059	0.230 ^b
SEm±	0.05	0.002	0.002
CD (<i>p</i> ≤0.05)	0.14	NS	0.007
<i>Factor B: Dose</i>			
[*] RD _{NPK}	13.7 ^a	1.061	0.230 ^b
RD _{NP³/4K}	13.5 ^b	1.061	0.241 ^a
SEm±	0.05	0.002	0.003
CD (<i>p</i> ≤0.05)	0.15	NS	0.007
<i>Factor C: Method</i>			
Without foliar spray	13.1 ^b	1.045 ^b	0.236
[§] Two spray with PS	14.1 ^a	1.077 ^a	0.235
SEm±	0.05	0.002	0.003
CD (<i>p</i> ≤0.05)	0.14	0.005	NS

[[†]MOP, Muriate of potash (KCl); ^{††}PS, Potassium schoenite (K₂SO₄, MgSO₄); ^{*}RD_{NPK}, Recommended dose of N:P₂O₅:K₂O::200:150:150 kg ha⁻¹; [§]Two foliar spray of 1% PS at 30 and 50 days after planting; NS, Non-significant; Means followed by a different letter are significantly different at *p*≤0.05 by Tukey's HSD (honest significant difference) test.]

Table 8 Interaction effect of source, dose and method of potassium fertilization on tuber quality attributes of potato (cv. *Kufri Jyoti*). Values represent mean of pooled data of 2014-15 and 2015-16.

Fertilizer treatment	Ascorbic acid (mg 100 g ⁻¹ of fresh weight of tuber)	Specific weight (g cm ⁻³)	Reducing sugar content (%)
RD _{NPK} MOP	13.32 ^{ab}	1.051 ^{ab}	0.249 ^a
RD _{NPK} MOP <i>fb</i> 2FS*	13.80 ^{ab}	1.071 ^{ab}	0.229 ^{ab}
RD _{NP³/4K} MOP	12.81 ^b	1.034 ^b	0.237 ^{ab}
RD _{NP³/4K} MOP <i>fb</i> 2FS	13.95 ^{ab}	1.086 ^{ab}	0.244 ^{ab}
RD _{NPK} PS	13.18 ^{ab}	1.034 ^b	0.221 ^b
RD _{NPK} PS <i>fb</i> 2FS	14.57 ^a	1.088 ^a	0.221 ^b
RD _{NP³/4K} PS	13.16 ^{ab}	1.061 ^{ab}	0.231 ^{ab}
RD _{NP³/4K} PS <i>fb</i> 2FS	14.25 ^{ab}	1.070 ^{ab}	0.245 ^a
SEm±	0.09	0.003	0.005
CD (<i>p</i> ≤0.05)	1.58	0.053	0.020

[RDF/recommended dose of fertilizer (N:P₂O₅), 200:150 kg ha⁻¹; NS, Non-significant; Means followed by a different letter are significantly different at *p*≤0.05 by Tukey's HSD (honest significant difference) test; * 2 FS, Two foliar spray of 1% PS at 30 and 50 days after planting.]

Tuber dry weight also increased with the crop growth (Table 3), but at the later part of crop growth (i. e. 70 DAP) the rate of increment was more due to higher TBR. Source of K exhibited non-significant impact on tuber dry weight at earlier growth stages, whereas, at maturity (90 DAP) more tuber dry weight was obtained from the plots receiving PS. Dose and foliar application of K had no effect on tuber dry weight at initial crop growth period (30 DAP), but a significant effect was observed at later growth stages (Table 4). Regarding treatment combinations, tuber dry weight did not differ significantly at earlier crop growth stage (30 DAP); on the contrary, the plants receiving RD_{NPK}*fb* 2FS recorded higher tuber dry weight at 70 and 90 DAP. As haulm and tuber dry matter were influenced significantly with source, dose and foliar K

fertilization, naturally total dry matter (haulm + tuber) accumulation was also influenced significantly (Table 3). The maximum total dry weight was recorded with RD_{NPK}PS*fb* 2FS throughout the crop growth period.

As evident from Table 5, different source and dose of K revealed non-significant response to CGR throughout the crop growth period, whereas, foliar application of PS significantly improved the CGR at earlier or active crop growth stages, though at the later part it was reflected to be non significant. Though the variation in CGR amongst varied treatment combinations did not follow any specific trend the highest CGR was registered from the plant receiving RD_{NPK}PS*fb* 2FS (Table 6). And at the maturity stage the treatment

combinations reflected non significance over CGR showing negative values irrespective of the treatment combinations. Regarding the source of K, PS influenced TBR throughout growth period; the dose of K as well as foliar spray of it significantly influenced the TBR at later growth stage of potato (Table 5). Up to 70 DAP, treatment combinations revealed non-significant ($p \leq 0.05$) response for TBR of potato, whereas, at later growth stage application of $RD_{NP}K_{PS}/b$ 2FS resulted in significantly higher TBR as compared to the rest of the combinations (Table 6).

3.2 Tuber number and yield

Source, dose and foliar feeding of potassium had positive impact on tuber number as well as yield of potato (Table 5). Reduction of 25% K irrespective of source along with two foliar sprays through PS not only produced significantly higher tuber number as compared to RD_{NPK} or $RD_{NP}^{3/4}K$ (irrespective of source) but also performed statistically at par with RD_{NPK}/b 2 FS (Table 6). Unlike the effect of different treatment combinations on tuber number ha^{-1} , the tuber yield received under the treatment combinations RD_{NPK} (irrespective of K source) along with two foliar sprays of PS was recorded significantly higher than those received under the rest treatment combinations.

3.3 Quality parameters of potato tubers

Different post-harvest quality parameters of potato altered significantly by source, dose and foliar feeding of K (Table 7). Ascorbic acid content of potato tuber increased significantly using PS as K source, while reduction of K fertilization dose ($RD_{NP}^{3/4}K$) reduced Ascorbic acid content significantly. The ascorbic acid content was more ($14.57 \text{ mg } 100 \text{ g}^{-1}$ of fresh weight) in potato tubers harvested from plants treated with $RD_{NP}K_{PS}/b$ 2FS (13.74 % more than $RD_{NP}^{3/4}K_{MOP}$) and it was statistically at par with rest other K fertilization treatments (Table 8). Source and dose of K fertilization revealed non-significant impact on specific weight of potato but foliar PS fertilization significantly improved specific weight than without K fertilization (Table 7). The specific gravity was more in potato tubers harvested from plants treated with $RD_{NP}K_{PS}/b$ 2FS (Table 8). The reduction in specific gravity was observed with reduced K fertilization dose and $RD_{NP}K_{PS}$. Source and dose of K fertilization significantly influenced reducing sugar content of potato but foliar spray of PS failed to record any change in reducing sugar content of tuber (Table 7). The lowest reducing sugar content (0.221% of dry weight) was recorded in potatoes harvested from the plants fertilized with $RD_{NP}K_{PS}/b$ 2FS (Table 8).

4 Discussions

Different source, dose as well as combination of different factors of K fertilization failed to record any significant changes in the final plant stand of potato (Table 1 and Table 2). These finding reflects that K has meagre or no-impact on plant germination. Researchers advocated that even omission of NPK did not exert any significant response to the germination of potato seed tuber (Kumar et al., 2008; Banerjee et al., 2016a). In another experiment Kumar et al. (2007) also suggested that different sources (chloride

and sulphate) as well as time of application of K fertilizer have no significant role on plant emergence.

Source and dose of K fertilization significantly increased plant height of potato at later growth stages viz. 50, 70 and 90 DAP (Table 1). Amongst various fertilizer combinations, $RD_{NP}K_{MOP}/b$ 2 FS increased the plant height by 16% over the conventional nutrient management practice i.e. $RD_{NP}K_{MOP}$ (Table 2). Apart from its K_2O content, presence of 11% Mg in PS plays an important role in vegetative growth of potato by increasing chlorophyll content in leaves and accumulating more photosynthates in plant tissue. This may be one of the major reasons behind such increment of plant height at later stages of growth of this tuber yielding plant (Sharma et al, 1998; Kumar et al., 2007).

As a matter of fact the number of compound leaves $plant^{-1}$ was not significantly influenced by different sources and dose of K fertilization; while foliar application of PS exerted positive response on the number of compound leaf at active growth periods i.e. 50 and 70 DAP by 31.8 and 25.8% respectively over without foliar spraying. Different treatment combinations has a little impact on LAI at the earlier crop growth stage, whereas, at later stages the maximum LAI was observed with $RD_{NP}K_{PS}/b$ 2 FS (Table 2). Similar results were observed by Rathore et al. (2014) who reported the non-significance of application of potassium schoenite on the number of leaves of groundnut. The findings like non-significance of different source and time of K fertilizer application on number of stem and compound leaf of potato cv. *Kufri Chipsona-2* observed by Kumar et al. (2007) also corroborate these facts.

It is evident from Table 3 that schoenite fertilization either basal or foliar produced higher haulm, tuber as well as total dry matter accumulation. Plants receiving $RD_{NP}K_{PS}/b$ 2FS recorded the maximum tuber dry weight at later growth stages (70 and 90 DAP) by 11 and 13% respectively over conventionally grown potato tubers receiving K from chloride bearing K-fertilizer. The higher uptake of chloride ion rather than K having negative impact on dry matter content of tuber may be the partial explanation behind such lower tuber dry-matter percentage associated with K-chloride fertilization (Toolangi, 1995). Unlike this potassic fertilizer reflecting a negative role of chloride as explained, the presence of sulphur in PS apart from K has a dual role in altering the metabolic activities of potato (Kumar et al., 2007).

The hydrolytic activity of carbohydrases like invertase, amylase and beta glucosidase are inhibited by chloride ions, whereas, increased by sulphate ions. In addition, sulphur has no negative role like chloride in the uptake of K (Smith, 1987). Thus, as a whole PS being a source of K and sulphur enhances the assimilation of metabolites and judicious translocation of photosynthates from source to sink and ultimately enhanced the dry matter accumulation. Although at later growth stages different fertilizer combinations recorded non-significant response to the CGR (Table 5), the application of $RD_{NP}K_{PS}/b$ 2FS resulted in 21.6% higher TBR over the $RD_{NP}K_{MOP}$ did at 70–90 DAP (Table 6).

Source, dose and foliar fertilization of potassium recorded positive impact on both the number of tuber and yield of potato (Table 5). As matter of importance, two foliar applications of schoenite along with 25% reduced dose of K fertilizer produced significantly higher number of tuber as compared to RD_{NPK} or $RD_{NPK}^{3/4}$. On other hand application of $RD_{NPK}^{3/4}$ 2FS resulted highest tuber production (13.34% higher) than conventionally grown potato (RD_{NPK}^{MOP}) (Table 6).

Moreover, for higher production foliar sprays with PS in combination with recommended basal doses were superior to omission of foliar spray. It may be due to the continuous supply of the essential plant nutrients like K, S and Mg for a longer period of crop growth which possibly facilitates a steady translocation of the photosynthates to the underground parts resulting in an increase in tuber number and yield (Sarkar et al., 2007). In harmony to such findings, the observations of Rathore et al. (2014) may be cited. They recorded similar results in groundnut with potassium schoenite fertilization. The increment of tuber yield with sulphate form of K fertilizer i.e. PS may be attributed to the production of larger sized tubers having higher dry matter content than that produced by the crop fertilized with chloride form of K fertilizers i.e. MOP (Khan et al., 2012).

The processing quality of potato is mainly influenced by quality characters like specific gravity, dry matter and reducing sugar content in tubers (Abbas et al., 2011). Therefore, improvement of these quality parameters is the primary concern for potato processing industries. It is evident from the present study that quality of potato was improved with using PS as K source (Table 7). Ascorbic acid (vitamin C) is an essential vitamin in potato tubers (Hamouz et al., 2009) and K fertilization with PS significantly improves its content in tubers (Table 7). Application of increased amount of chloride of potash decreased the ascorbic acid concentration in potato tubers (Manolov et al., 2015). Specific weight is one of the most important factors to the potato processors, as the recovery of the finished product is directly linked to it. The maximum specific weight of potato tubers was recorded from the plots receiving $RD_{NPK}^{3/4}$ 2FS, while reduction in specific weight was observed with reduced doses of K fertilizer (Table 8). As compared to chloride form, sulphate form of K-fertilizer has positive impact on tuber specific weight (Kumar et al., 2007) through higher accumulation of dry matter.

Reducing sugar content in potato tubers greatly influences processing quality parameters of potato by regulating the colour of chips as well as nutritive and processing quality (Nikolova & Blagoeva, 2000). Reducing sugars are critical precursors for acrylamide formation during frying which is considered carcinogenic and neurotoxic for humans (Zorb et al., 2014). Free reducing sugars also participate in Maillard reaction; thus, contribute to develop unfavourable colour and flavour. In present study, source and dose of K fertilization helps in decreasing reducing sugar content of potato tuber (Table 7). Kumar et al. (2007) also suggested that K-sulphate fertilization can be effectively adopted instead of K-chloride, as it increases tuber dry-matter percentage and chips recovery and decreases chips oil percentage without yield compensation.

Conclusions

Thus from the results cited in detail and the facts discussed analytically it may be concluded that PS, being a source of good amount of potassium, magnesium and sulphur, helps in balanced assimilation, translocation and finally accumulation of photosynthates in potato. Recommended dose of NPK along with two foliar spray of PS improves the plant growth, yield and quality of potato tubers. So, farmers can use this fertilizer successfully in potato and PS may be an alternative choice as a source of potassium.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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