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SHORT COMMUNICATION

SPROUT SUPPRESSION OF POTATO TUBERS STORED AT 18 ^{0}C BY PRE- AND POST-HARVEST APPLICATION OF SUB-LETHAL DOSES OF GLYPHOSATE

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Glyphosate was tried at three concentrations for suppressing the sprout growth of potato (*Solanum tuberosum* L.) tubers in two cultivars differing in dormancy duration. Single pre-harvest foliar spray of glyphosate [0.833 kg (a.i.) ha^{-1}] at 70 days after planting was effective in suppressing the sprout growth with no adverse effect on tuber number and yield. The reduction in sprout growth was 74 % in Kufri Jyoti and 85 % in Kufri Bahar. Higher concentrations of glyphosate resulted in abnormal sprouts with cauliflower like appearance and increased incidence of cracking in larger tubers (>75 g), especially in variety Kufri Jyoti that showed 30 % of this incidence. Post-harvest application of glyphosate reduced sprout growth by 81 % and 78 % in Kufri Jyoti and Kufri Bahar respectively.

Key words: **Glyphosate, potato, *Solanum tuberosum*, sprouting, sub-lethal dose, tuber, tuber cracking.**

In the Indo-Gangetic plains of northern India, potato (*Solanum tuberosum* L.) crop is grown in winter and harvested in February-March. The harvest period is followed by hot summer-months. Generally, potatoes are stored in cold stores at 2-4 ^{0}C and 90-95 % RH. However, considerable quantity of potatoes is also stored on-farm under non-refrigerated conditions (Ezekiel *et al*. 1999). Storage of potatoes becomes a problem once the dormancy period is over and sprout growth begins. Sprouting lowers the quality of tubers and increases weight loss, as the epidermis of the sprout is 100 times more permeable to water than the tuber periderm. Sprout growth corresponding to 1 % increase in tuber area causes doubling of moisture loss from tubers and 50 % increase in respiration (Burton 1989). Potatoes are stored at different temperatures depending upon the purpose for which they are to be used. Seed potatoes are stored at 2-4 ^{0}C and at this temperature no sprout growth occurs but, ware and processing potatoes are stored at 8-12 ^{0}C which allows the sprout growth to takes place (Rastovski 1987). Therefore, sprout suppressants have to be used to check sprout growth at storage temperature of 8-12 ^{0}C. Further, in India and other sub-tropical countries potatoes are stored on-farm for 3-4 months under non-refrigerated conditions and sprout suppressants are needed to check sprout growth under these conditions also.

Many chemicals have been tried to check sprout growth and they include maleic hydrazide, several alcohols, aldehydes and volatile mono-terpenes (Beveridge *et al*. 1981, Afek *et al*. 2000, Paul and Ezekiel 2002). Isopropyl N-(3-chlorophenyl) carbamate (CIPC) is used commercially as sprout suppressants in the developed and developing countries (Sawyer and Malagamba 1987). Glyphosate [N-(phosphonomethyl) glycine] is an effective herbicide for mono and dicotyledonous weeds (Franz *et al*. 1997) and is known

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to be non-residual and environmentally benign (Hetherington *et al*. 1999). Glyphosate when given as a pre-harvest foliar treatment is reported to affect yield of potato tubers at higher doses (Lutman and Richardson 1978) but at lower doses it is not reported to affect the yield. It also has a strong effect on sprout growth of the treated tubers and as a result plant emergence was affected adversely when the treated tubers were planted in the next season (Worthington 1985). Keeping in view the safe nature of the chemical, the effect of pre-harvest foliar spray as well as post-harvest treatments on sprout growth in potatoes stored at high temperature of 18 ^{0}C were studied in the present investigation.

Experiments were carried out at the Central Potato Research Institute Campus, Modipuram (29ºN 76ºE.), Uttar Pradesh, India during 1999-2000 and 2000-2001 seasons. Experiment I: This experiment was carried out to determine the effect of pre-harvest application of three sub-lethal concentrations of glyphosate i.e. 0.277, 0.416 and 0.833 kg (a.i.) ha^{-1}. Seed tubers of two varieties viz. Kufri Jyoti and Kufri Bahar, weighing 75 to 150 g, were planted on 15-10-1999 at a spacing of 60 x 20 cm. Fertilizer was applied @ 150 kg N, 80 kg P_2O_5 and 100 kg K_2O ha^{-1} and recommended cultural practices were followed. Glyphosate (500 ml solution of three different concentrations) was applied as a foliar spray on a row of 15 plants in a plot having 8 such rows at 70 days after planting (DAP). Commercial preparation of glyphosate (trade name: Round up, Monsanto chemicals India Ltd., Mumbai) having 41 % a.i. (w/v) was used. The experiment was laid out in randomized block design with four replications. The haulms were cut at 90 days after planting and the crop was harvested after 10 days of haulm cutting to facilitate the skin set. At harvest, number and yield of tubers were recorded grade-wise. Observation on the incidence of tuber cracking was also recorded. The harvested tubers were further cured at room temperature (min. 9.8 ^{0}C, max. 26.7 ^{0}C) and the tubers were stored on 25-2-2000 in a walk-in-chamber maintained at temperature of 18 ±2 ^{0}C and RH 85 ±5 %. Each replication consisted of 60 tubers. Observation on sprouting was recorded at 80, 95, 115, 140 and 160 days after haulm cutting (DAHC). Experiment II: This experiment was carried out to determine the effect of post-harvest treatment of three sub-lethal doses of glyphosate on sprout growth in potatoes stored at temperature of 18 ±2 ^{0}C and RH 85 ±5 %. Potato crop was raised during 2000-2001 and haulms were cut 90 DAP. After allowing 10 days for skin set, the tubers were harvested and stored at room temperature (min. 10.2 ^{0}C, max. 26.0 ^{0}C). Well-cured tubers were stored on 26-2-2001 in a walk-in-chamber maintained at 18 ^{0}C and 85 % RH. Sprouts were allowed to grow after the break of dormancy and in order to get uniformity in sprout growth, tubers were desprouted on 20-6-2001 and these desprouted tubers were then sprayed with three concentrations of glyphosate i.e. 50, 100 and 150 mg (a. i.) of glyphosate in one litre of water (200 ml of solution was used to spray 60 tubers in each replication). Control tubers were sprayed with distilled water. The sprays were repeated at weekly intervals and in all four sprays were done. Observations were recorded on sprout number per tuber and length of the longest sprout after 45 days of first spray application. The replicated data were analysed statistically and the mean values were then separated by using Duncan's multiple range test procedures as described by Gomez and Gomez (1984).

Single pre-harvest foliar spray of glyphosate at three concentrations, had no significant effect on grade-wise (data not presented) as well as total tuber number and total yield (Table 1). Higher concentrations of glyphosate (T_2 and T_3) had a significant effect on cracking in tubers weighing more than 75 g and proportion of total number of tubers (Table 1). No cracking was observed in tubers weighing <25 g and 25-75 g (data not presented). The incidence of tuber cracking was more in Kufri Jyoti than the Kufri Bahar (Table 1). In control tubers, 80 % sprouting was observed at 95 DAHC in Kufri Jyoti, a cultivar with medium dormancy duration (Table 2). Lower concentration of glyphosate (T_1) stimulated sprouting slightly but at higher concentrations (T_2 and T_3) sprouting was reduced. However, 100 % sprouting was observed at 140 DAHC (Table 2). In Kufri Bahar, a short dormancy variety, glyphosate was less effective. It was effective up to 80 DAHC at lower concentrations (T_1 and T_2) and up to 95 DAHC at higher concentration (T_3). Sprouting was 100 % by 115 DAHC (Table 2). The number of sprouts per tuber increased up to 140 DAHC in both the varieties (Table 3). In Kufri Jyoti, glyphosate treatment had no significant effect on sprout number but

Table 1. Effect of different doses of glyphosate (kg of a.i. ha^{-1}) applied as a single pre-harvest foliar spray at 70 days after planting on total tuber number, total tuber yield and per cent of cracked tubers m^{-2} in two potato varieties.

Treatment	Kufri Jyoti				Kufri Bahar			
	Total tuber number	Total tuber yield (kg m^{-2})	Per cent of cracked tubers >75 g	Total	Total tuber number	Total tuber yield (kg m^{-2})	Per cent of cracked tubers >75 g	Total
C (Control)	98	5.702	12 [b]	14 [c]	108	5.302	0 [c]	0 [b]
T_1 (0.277 kg ha^{-1})	101	5.556	14 [b]	17 [c]	104	5.014	0 [c]	1 [b]
T_2 (0.416 kg ha^{-1})	95	5.658	25 [a]	29 [a]	102	5.210	4 [b]	6 [a]
T_3 (0.833 kg ha^{-1})	91	5.499	30 [a]	32 [a]	109	4.810	8 [a]	10 [a]
CD (P = 0.05)	NS	NS	5.0	7.2	NS	NS	2.2	4.1

Total tuber number and total tuber yield were recorded from a lot of tubers obtained from 8 plants sown in a row of 15 plants. Obtained values were then converted for m^{-2} and this made one replication. Presented values are average of four such replications.

Values followed by different alphabetic letter are significant over one another.

Table 2. Effect of single pre-harvest foliar spray of glyphosate (kg of a.i. ha^{-1}) at 70 days after plantation on subsequent sprouting percentage of potato tubers stored at 18 ^{0}C and 85 % RH.

Treatment	Kufri Jyoti					Kufri Bahar				
	Days after haulm cutting					Days after haulm cutting				
	80	95	115	140	Mean (T)	80	95	115	140	Mean (T)
C (Control)	4	80	97	100	70.3	32	97	100	100	82.5
T_1 (0.277 kg ha^{-1})	45	90	100	100	83.8	22	92	100	100	78.5
T_2 (0.416 kg ha^{-1})	0	22	47	100	42.3	12	82	100	100	73.5
T_3 (0.833 kg ha^{-1})	2	15	50	100	41.8	5	50	95	100	62.5
Mean (DAHC)	12.8	51.8	73.5	100.0		17.8	80.1	98.8	100.0	

Percentage values were obtained from a sample lot of 60 tubers.

in Kufri Bahar, sprout number increased at 0.416 kg ha^{-1} of glyphosate. Sprout length increased with increase in the storage period (Table 3). Sprout growth was stimulated when a lower concentration of glyphosate (0.277 kg ha^{-1}) was applied. But, at higher concentrations, significant reduction in sprout length was observed at 140 DAHC in Kufri Jyoti and 115 DAHC in Kufri Bahar (Table 3; Fig. 1A-B). As per the data in Table 3, Kufri Jyoti showed the reduction of 59 and 74 % in T_2 and T_3 whereas; Kufri Bahar recorded the decrease of 59, 71 and 85 % in T_1, T_2 and T_3 respectively.

Post-harvest treatment with glyphosate at sub-lethal concentrations i.e. 50, 100 and 150 mg (a.i.) per litre after desprouting of tubers resulted in significant reduction in sprout length in both the varieties (Table 4). The reduction in sprout length was 50-59 % with 50 mg of glyphosate $l^{-1}$and at higher concentration (150 mg of glyphosate l^{-1})

Table 3. Effect of single pre-harvest foliar spray of glyphosate at 70 days after plantation on subsequent sprouting behaviour of potato tubers stored at 18 ^{0}C and 85 % RH.

Treatment	Kufri Jyoti					Kufri Bahar				
	Days after haulm cutting (DAHC)					Days after haulm cutting (DAHC)				
	95	115	140	160	Mean (T)	95	115	140	160	Mean (T)
					Sprout number/tuber					
C (Control)	1.3^{g}	2.4^{c-g*}	3.5^{abc}	2.9^{b-f}	2.5	1.2	1.7	3.6	4.2	2.6^{b}
T_1 (0.277 kg ha^{-1})	1.5^{efg}	1.9^{d-g}	3.5^{abc}	3.3^{a-d}	2.5	2.1	2.6	3.5	3.7	2.9^{ab}
T_2 (0.416 kg ha $^{-1}$)	1.4^{fg}	2.4^{c-g}	3.3^{a-d}	3.0^{b-c}	2.5	2.2	3.5	4.1	4.8	3.6^{a}
T_3 (0.833 kg ha^{-1})	1.0^{g}	1.3^{g}	4.0^{ab}	4.7^{a}	2.7	2.1	2.8	4.0	5.1	3.5^{ab}
Mean (DAHC)	1.3^{c}	2.0^{b}	3.5^{a}	3.4^{a}		1.9^{b}	2.6^{b}	3.8^{a}	4.4^{a}	
CD (P = 0.01)	(T) = N.S., (DAHC) = 0.68, (T x DAHC) = 1.36					(T) = 0.81, (DAHT) = 0.81; (T x DAHC) = N.S.				
					Length (cm) of longest sprout					
C (Control)	1.0^{c}	1.4^{c}	2.7^{c}	6.3^{b}	2.8^{b}	1.7^{e}	3.4^{cde}	5.4^{bc}	16.1^{a}	6.6^{a}
T_1 (0.277 kg ha^{-1})	1.4^{c}	1.8^{c}	5.7^{b}	12.9^{a}	5.5^{a}	1.6^{e}	1.9^{de}	2.6^{de}	6.5^{b}	3.1^{b}
T_2 (0.416 kg ha $^{-1}$)	0.9^{c}	1.1^{c}	2.1^{c}	3.1^{c}	1.8^{c}	1.1^{e}	1.4^{e}	2.0^{de}	4.6^{bcd}	2.2^{bc}
T_3 (0.833 kg ha^{-1})	1.2^{c}	1.2^{c}	1.4^{c}	1.6^{c}	1.3^{c}	0.9^{e}	1.8^{e}	2.2^{de}	2.3^{de}	1.6^{c}
Mean (DAHC)	1.1^{c}	1.3^{c}	2.5^{b}	5.9^{a}		1.3^{c}	1.9^{bc}	3.0b	7.1a	
CD (P = 0.01)	(T) = 0.99, (DAHC) = 0.99 (T x DAHC) = 1.93					(T) = 1.24 (DAHT) = 1.24, (T x DAHC) = 2.48				

Each replicated value is an average of 10 observations recorded from 10 randomly selected tubers in a sample lot of 60 tubers. Presented values are average of four such replications.

Values followed by different alphabetic letter/s are significant over one another. * c-g means cdefg.

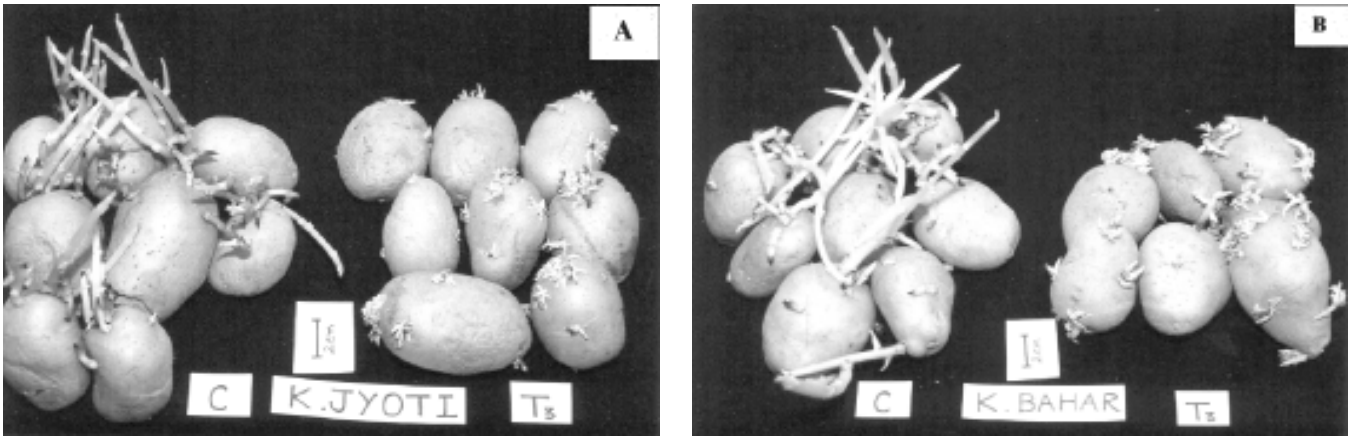

Fig. 1A-B: Effect of pre-harvest foliar spray of glyphosate on sprouting in Kufri Jyoti (A) and Kufri Bahar (B). Photos were taken 140 days after haulms cutting. C: Control (only water) and T_3: 0.833 kg a. i. of glyphosate ha^{-1}.

Table 4. Effect of post-harvest treatment of glyphosate on sprout number and length in potato tubers of two varieties stored at 18 ^{0}C and 85 % RH (data after 45 days of treatment).

Treatment	Sprout number/ tuber		Length (cm) of longest sprout	
	Kufri Jyoti	Kufri Bahar	Kufri Jyoti	Kufri Bahar
C (Control)	3.2^{ab}	2.5	3.2^{a}	3.2^{a}
T_1 (50 mg l^{-1})	3.8^{a}	2.9	1.6^{ab}	1.3^{b}
T_2 (100 mg l^{-1})	2.9^{b}	2.5	0.9^{b}	0.9^{b}
T_3 (150 mg l^{-1})	2.7^{b}	3.1	0.6^{b}	0.7^{b}
CD (P = 0.05*) or				
(P = 0.01**)	0.814 *	N.S.	1.650 *	1.581 **

Each replicated value is an average of 10 observations recorded from 10 randomly selected tubers in a sample lot of 60 tubers. Presented values are average of four such replications.

Values followed by different alphabetic letter/s are significant over one another.

the reduction was as high as 81 and 78 % in Kufri Jyoti and Kufri Bahar respectively. Since, there was no significant difference between 100 and 150 mg of glyphosate l^{-1} so it may be concluded that post-harvest application of glyphosate at a concentration of 100 mg l^{-1} would be sufficient to achieve significant reduction in sprout growth.

Pre-harvest foliar spray of glyphosate did not affect the tuber number and yield indicating that glyphosate was effective in suppressing the sprout growth (Table 2, 3) without affecting the tuber yield (Table 1). Glyphosate application also caused no adverse effect on the foliage of potato crop. However, tuber cracking at T_2 and T_3 doses of glyphosate increased by 52-56 % and 6-10 % (over the control) in Kufri Jyoti and Kufri Bahar respectively (Table 1). Tuber cracking is normally observed in oversize tubers and its incidence is particularly high in Kufri Jyoti (Lallan Singh 1989). This shows that glyphosate cannot be used in those varieties that are susceptible to tuber cracking. Lignin and suberin are the major structural component in the cell wall and the skin of the potato tuber (Borg and Monties 1993). Deposition of lignin and suberin provide a mechanism for sealing the wounded sites on the potato tuber (Dixon and Parva 1995). Normal lignin and suberin biosynthesis require efficient flow of carbon into phenylalanine biosynthesis via the shikimate and aromatic amino acid pathway (Herrmann 1995). Since glyphosate is known to adversely affect the shikimate pathway and therefore the availability of aromatic amino acids (Steinrucken and Amrhein 1980), it might have caused increased incidence of tuber cracking. Foliar applied glyphosate is translocated to the tubers where it affects the sprout growth adversely by inhibiting the meristematic development of sprouts (Cole *et al.* 1983). But, the sprout suppression effect was only partial as reflected by the presence of deformed and cauliflower like sprouts (Fig.1A-B). This is in agreement with the observation of earlier workers (Lutman and Richardson 1978, Worthington 1985), who reported that glyphosate treatment resulted in multiple sprouts with no main axis and resembling to cauliflower in appearance. Pre-harvest foliar spray of maleic hydrazide was also reported to result in deformed sprouts with cauliflower like appearance (Ezekiel *et al.* 1984).

Post-harvest application of many sprout suppressants have been tried before and CIPC has been found to be the most effective in suppressing the sprout growth of potato tubers (Sawyer and Malagamba 1987). The results reported here show that while post-harvest treatment with glyphosate may not be as effective as CIPC, as indicated by the presence of 0.6-0.9 cm long sprouts, but still it reduced the sprout growth by 72-81 % (Table 4). Thus, indicating that sub-lethal concentrations of glyphosate could also be used to reduce sprout growth of stored potato tubers.

From the above results, it may be concluded that both pre-harvest and post-harvest applications of glyphosate, at sub-lethal dose, were effective in suppressing the sprout growth in potato tubers. Pre-harvest application did not affect tuber yield but led to increased incidence of tuber cracking.

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