

Screening and selection of ten potato genotypes (*Solanum tuberosum* L.) for their relative tolerance and susceptibility to the fumigation of the elevated O₃ levels

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ABSTRACT : Ozone (O₃) is a phytotoxic air pollutant as well as a hidden threat to food security in South Asia and reduces the crop yield to an extent of 20 to 35 per cent. Projections of future global O₃ trends show that the present mean global concentration of 50 ppb in the ambient air will increase rapidly over the next 20 to 30 years with an annual increase of 7.2 ppb. The study on impact of three elevated O₃ levels (100, 150 and 200 ppb) during the tuber initiation stage of ten potato genotypes (Kufri Surya, Kufri Swarna, Kufri Jyothi, Kufri Chipsona, Kufri Jawahar, Kufri Giriraj, Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini) on their growth, physiology and yield characteristics in open-top chamber showed that the potato genotype Kufri Surya recorded the highest green leaf area per cent (84.50 - 95.75), photosynthetic rate (26.56 - 24.85 μmol CO₂ m⁻¹ s⁻¹), stomatal conductance (0.625 - 0.595 cm s⁻¹), tuber fresh weight (0.650 kg plant⁻¹) and number of tubers with the lowest visual leaf injury per cent (4.25 - 15.5) proved its moderately resistant nature to all the three elevated O₃ levels. Among ten potato genotypes, Kufri Himalini showed the highest visible injury per cent (99.5) with lowest growth, physiological characteristics with no tuber formation at 150 and 200 ppb elevated O₃ levels.

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Low level or surface ozone is not emitted directly by car engines or industrial operations but formed by the reaction of sunlight on air containing hydrocarbons and nitrogen oxides that react to form ozone directly at the pollution site or many kilometers downwind (Hagerman *et al.*, 1997). There is evidence of significant reduction in agricultural yields because of increased ground level ozone and pollution which interferes with photosynthesis and stunts overall growth of plant species (NASA, 2003). Certain examples of cities with elevated ozone

readings are Texas and Mexico City have a reading around 41 ppb and 125 ppb, respectively (Mutters and Randall, 1999). The New Delhi City in India showing eight hour O₃ concentration exceeded the World Health Organization (WHO) mean standard of 51 to 102 ppb by 10 to 40 per cent. So, the increase in the tropospheric ozone has been identified to be a serious threat and critical cause of concern world over (Agrawal, 2000).

Studies showed that the impact of O₃ increased with developmental stages, and the largest detrimental effect during critical stage

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of crop (Feng *et al.*, 2010). Moreover, elevated O₃ tends to decrease stomatal functioning and photosynthetic rate leading to concurrent reduction of crop yield (Saurer *et al.*, 1991). Moreover, knowledge of the relative susceptibility of different cultivars of crop plants to elevated ozone is, therefore, necessary for the recommendation of tolerant cultivars for a particular region of relatively high concentrations.

So the present study aims to (i) study the relative susceptibility / resistance of ten genotypes of potato at three elevated levels of ozone fumigation (ii) study the physiological responses like photosynthetic rate and stomatal conductance (iii) recommend the tolerant as well as high yielding genotypes of potato (*Solanum tuberosum* L.) based on their yield parameters even when exposed to elevated ozone levels.

EXPERIMENTAL METHODOLOGY

An experiment was conducted under controlled open-top chamber condition to evaluate the impact of three elevated levels of ozone (O₃) (100, 150 and 200 ppb @ 4 h d⁻¹) fumigated during the most important critical stage, tuber initiation stage of various genotypes of potato (*Solanum tuberosum* L.) on their physiological and yield characteristics. Moreover, the study is based on the fact that sudden exposure of ozone is more dangerous to crops than chronic long term exposure. The study aims to characterize the relative susceptibility / resistance of ten genotypes of potato (Kufri Surya, Kufri Swarna, Kufri Jyothi, Kufri Chipsona, Kufri Jawahar, Kufri Giriraj, Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini).

Visual scoring method :

After exposure with elevated ozone levels @ 100, 150 and 200 ppb during the critical stage of crop (tuber initiation stage), the visible injury symptom of potato namely “speckle leaf” symptom were studied by the following visual scoring method (Table A). Plant damage is recorded by visual scoring method. An index for each assessment was expressed as a percentage of the maximum possible damage as follows:

$$\text{Injury index} = \frac{100 (w < 2x < 3y < 4z)}{4 (v < w < x < y < z)}$$

where, v= leaves in class 1, w= leaves in class 2, x= leaves in class 3, y= leaves in class 4 and z= leaves in class 5.

Table A : Classification of ozone injury symptoms based on visual scoring method		
Per cent damage (%)	Resistant/sensitive	Class/injury index
0	Resistant	1
25	Moderately resistant	2
25 – 50	Moderately sensitive	3
50 – 75	Sensitive	4
> 75	Very sensitive	5

(Burke *et al.*, 2001)

After the fumigation study, the potted potato plants allowed to grow upto harvest. At the time of harvest, the number of tubers plant⁻¹, tuber fresh weight plant⁻¹ and tuber yield hectare⁻¹ were also calculated.

Study on the physiological parameters :

During the fumigation study with three elevated levels of ozone on ten genotypes of potato plants in pots, the physiological responses of crop was considered as an important criteria of the crop growth and yield. So, the IRGA- Portable Photosynthetic System (PPS) was used to measure the physiological parameters like photosynthetic rate and stomatal conductance for the treated (fumigated with O₃ at 3 elevated levels) as well as control (healthy) sets of 10 potato genotypes. The damaged speckle leaf symptom leaves of treated potted plants were selected for the purpose of studying the physiological parameters *viz.*, photosynthetic rate and stomatal conductance. The physiological parameters were also studied for healthy set of plants for the purpose of comparison.

The fumigated potato plants were allowed to grow up to harvest and the yield parameters *viz.*, the number of tubers plant⁻¹ and tuber fresh weight plant⁻¹ were also calculated. A health set of potato plants were also maintained from planting to harvest for the purpose of comparison with performance of fumigated potato plants.

EXPERIMENTAL FINDINGS AND DISCUSSION

The results of the controlled open-top chamber experiment with three elevated O₃ levels (*i.e.*, 100, 150 and 200 ppb) on ten potato genotypes showed that at 100 ppb of O₃ fumigation level, among the ten genotypes of potato Kufri Surya, Kufri Swarna, Kufri Jyothi, Kufri Chipsona, Kufri Jawahar recorded the visual injury up to 25 per cent and falls in the injury index 2, whereas Kufri Giriraj and Kufri Muthu developed visual injury up to 25–50 per cent which falls in injury index 3. But, Kufri

Table 1 : Impact of elevated ozone levels viz., 100, 150 and 200 ppb on green leaf area per cent during tuber initiation stage of potato genotypes

Potato genotypes	Treatments	Green leaf area (%)	Mean values	Transformed green leaf (%) values	Potato genotypes	Treatments	Green leaf area (%)	Mean values	Transformed green leaf (%) values	
Kufri Surya	T ₁	95.75	91.03	78.10±0.02	Kufri	T ₁	73.5	46.13	58.98±0.04	
	T ₂	92.85		74.48±0.01		Giriraj	T ₂	40.4		39.44±0.07
	T ₃	84.50		66.82±0.06			T ₃	24.5		29.65±0.03
Kufri Swarna	T ₁	83.5	69.40	66.02±0.03	Kufri	T ₁	63.5	37.50	52.82±0.03	
	T ₂	67.2		55.06±0.01		Muthu	T ₂	30.2		33.31±0.03
	T ₃	57.5		49.31±0.03			T ₃	18.8		21.67±0.04
Kufri Jyothi	T ₁	81.4	65.43	64.44±0.04	Kufri	T ₁	43.5	24.16	41.22±0.06	
	T ₂	60.5		51.04±0.03		Himsona	T ₂	21.5		27.57±0.04
	T ₃	54.4		47.49±0.05			T ₃	7.5		15.92±0.09
Kufri Chipsona	T ₁	79.4	59.80	62.98±0.04	Kufri	T ₁	34.2	14.16	35.81±0.06	
	T ₂	56.5		48.73±0.03		Giridhari	T ₂	6.8		15.05±0.10
	T ₃	43.5		41.25±0.03			T ₃	1.5		7.08±0.06
Kufri Jawahar	T ₁	77.5	55.16	61.70±0.02	Kufri	T ₁	29.8	11.60	33.06± 0.03	
	T ₂	53.5		46.98±0.03		Himalini	T ₂	4.5		12.36± 0.11
	T ₃	34.5		35.96±0.03			T ₃	0.5		4.29 ± 0.21

S.E. ± C.D. (P=0.05)

Genotypes (G) 0.275 0.605

Treatments (T) 0.170 0.270

G × T 0.445 0.875

(T₁ - 100 ppb O₃ @ 4 h d⁻¹, T₂ - 150 ppb O₃ @ 4 h d⁻¹, T₃ - 200 ppb O₃ @ 4 h d⁻¹), Mean values for T₁=66.21%, T₂=43.4% and T₃=32.7%.

Table 2 : Impact of elevated ozone levels viz., 100, 150 and 200 ppb on the photosynthetic rate (µmol CO₂ m⁻¹ s⁻¹) during tuber initiation stage of potato genotypes

Potato genotypes	Treatments	Photosynthetic rate (µmol CO ₂ m ⁻¹ s ⁻¹)	Mean values	Per cent difference between	Potato genotypes	Treatments	Photosynthetic rate (µmol CO ₂ m ⁻¹ s ⁻¹)	Mean values	Per cent difference between	
Kufri Surya	T ₁	26.56	25.72	-11.96	Kufri	T ₁	22.65	20.789	-25.10	
	T ₂	25.75		-14.65		Giriraj	T ₂	20.36		-32.35
	T ₃	24.85		-17.63			T ₃	19.38		-35.65
	T ₄	30.17		--			T ₄	30.11		--
Kufri Swarna	T ₁	23.98	22.83	-20.46	Kufri	T ₁	19.80	18.89	-33.5	
	T ₂	22.78		-24.44		Muthu	T ₂	19.17		-35.6
	T ₃	21.75		-27.86			T ₃	17.80		-40.2
	T ₄	30.15		--			T ₄	29.78		--
Kufri Jyothi	T ₁	23.37	22.28	-21.01	Kufri	T ₁	19.81	17.81	-34.2	
	T ₂	22.34		-24.5		Himsona	T ₂	18.73		-37.8
	T ₃	21.15		-28.5			T ₃	14.90		-50.5
	T ₄	29.59		---			T ₄	30.12		--
Kufri Chipsona	T ₁	23.64	22.44	-21.50	Kufri	T ₁	19.37	15.11	-35.8	
	T ₂	22.40		-25.62		Giridhari	T ₂	14.34		-52.5
	T ₃	21.29		-29.30			T ₃	11.62		-61.5
	T ₄	30.12		--			T ₄	30.18		--
Kufri Jawahar	T ₁	22.42	21.30	-24.20	Kufri	T ₁	19.23	14.85	-38.2	
	T ₂	21.15		-28.50		Himalini	T ₂	13.87		-55.4
	T ₃	20.35		-31.20			T ₃	11.45		-63.2
	T ₄	29.58		--			T ₄	31.12		--

S.E. ± C.D. (P=0.05)

Genotypes (G) 0.325 0.670

Treatments (T) 0.205 0.410

G × T 0.525 1.080

(T₁ - 100 ppb O₃ @ 4 h d⁻¹, T₂ - 150 ppb O₃ @ 4 h d⁻¹, T₃ - 200 ppb O₃ @ 4 h d⁻¹, T₄ - Untreated). Mean values for T₁= 22.1, T₂=20.09 and T₃= 18.5.

Giridhari and Kufri Himalini recorded maximum damage up to 70.2 per cent (Table 1) and falls in the injury index category 4. At 150 ppb of O₃ fumigation level, the only potato genotype which recorded below 25 per cent visual damage and falls in the injury class 2 was Kufri Surya whereas Kufri Swarna, Kufri Jyothi, Kufri Chipsona, Kufri Jawahar recorded up to 50 per cent damage and comes under the injury category of 3 and Kufri Giriraj and Kufri Muthu recorded up to 75 per cent visual damage which falls in injury category of 4. The potato genotypes Kufri Himsona, Kufri Giridhari and Kufri Himalini recorded maximum damage per cent of > 75 per cent and falls under the injury category of 5. At 200 ppb level of O₃ fumigation, Kufri Surya recorded 15.5 per cent damage (Fig. 2) and falls under the injury category of class 2 whereas Kufri Swarna and Kufri Jyothi recorded 42.5–45.6 per cent damage and Kufri Chipsona and Kufri Jawahar recorded 56.5 - 65.5 per cent visual damage, and falls in the injury class of 3 and

4, respectively. Potato genotypes Kufri Giriraj, Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini recorded > 75 per cent damage which varies between 75.5 - 99.5 per cent (Table 1). and comes under the category of injury class. Fumigation at 200 ppb O₃ showed the highest visible injury (99.5 %) in potato genotype Kufri Himalini (Fig. 1).

The results showed that at 100, 150 and 200 ppb levels of O₃ fumigation, significantly the highest photosynthetic rates was recorded by Kufri Surya which were 26.56, 25.75 and 24.85 $\mu\text{mol CO}_2 \text{ m}^{-1} \text{ s}^{-1}$, respectively whereas the lowest photosynthetic rates was recorded by Kufri Himalani which were 19.23, 13.87 and 11.45 $\mu\text{mol CO}_2 \text{ m}^{-1} \text{ s}^{-1}$, respectively (Table 2).

Regarding the yield parameters, the number of tubers per plant (Table 3) was significantly the highest (6 / plant) at 100 ppb O₃ for Kufri Surya, followed by Kufri Swarna, Kufri Jyothi (4 / plant), and for Kufri Chipsona, Kufri Jawahar, Kufri Giriraj (3 / plant) whereas

Table 3 : Impact of elevated ozone levels viz., 100, 150 and 200 ppb on the average number of tubers plant during tuber initiation stage of potato genotypes

Potato genotypes	Treatments	Average no. of tubers plant ⁻¹	Mean values	Per cent difference between healthy plant	Potato genotypes	Treatments	Average no. of tubers plant ⁻¹	Mean values	Per cent difference between healthy plant	
Kufri Surya	T ₁	6	4.33	-25	Kufri Giriraj	T ₁	3	1.33	-57.14	
	T ₂	4		-50		T ₂	1		-87.5	
	T ₃	3		-62.5		T ₃	0		-100	
	T ₄	8				T ₄	7			
Kufri Swarna	T ₁	4	2.33	-50	Kufri Muthu	T ₁	2	1.0	-66.66	
	T ₂	2		-75		T ₂	1		-83.33	
	T ₃	1		-87.5		T ₃	0		-100	
	T ₄	8				T ₄	6			
Kufri Jyothi	T ₁	4	2.33	-50	Kufri Himsona	T ₁	2	1.0	-66.66	
	T ₂	2		-75		T ₂	1		-83.33	
	T ₃	1		-87.5		T ₃	0		-100	
	T ₄	8				T ₄	6			
Kufri Chipsona	T ₁	3	2.0	-57.14	Kufri Giridhari	T ₁	2	0.66	-75	
	T ₂	2		-71.43		T ₂	0		-100	
	T ₃	1		-87.5		T ₃	0		-100	
	T ₄	7				T ₄	8			
Kufri Jawahar	T ₁	3	1.33	-57.14	Kufri Himalini	T ₁	2	0.66	-75	
	T ₂	1		-87.5		T ₂	0		-100	
	T ₃	0		-100		T ₃	0		-100	
	T ₄	7				T ₄	8			
							S.E. ±	C.D. (P=0.05)		
							Genotypes (G)	0.195	0.405	
							Treatments (T)	0.231	0.264	
							G × T	0.426	0.669	

(T₁ - 100 ppb O₃ @ 4 h d⁻¹, T₂ - 150 ppb O₃ @ 4 h d⁻¹, T₃ -200 ppb O₃ @ 4 h d⁻¹, T₄ - Untreated). Mean values for T₁=3.1 T₂= 1.4 and T₃=0.6.



Fig. 1 : Fumigation at 200 ppb O₃ showed the highest visible injury (99.5 %) followed by the lowest photosynthetic rate, stomatal conductance in potato genotype Kufri Himalini



Fig. 2 : Kufri Surya showed the lowest visible injury (15.5%) with highest photosynthetic rate, stomatal conductance even at 200 ppb O₃ fumigation

the lower number of tubers (2 / plant) was recorded by Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini as shown in Table 3. At 150 ppb level of O₃, the number of tubers per plant was (4 / plant) for Kufri Surya, and Kufri Swarna, Kufri Jyothi, Kufri Chipsona showed 2 per plant whereas Kufri Jawahar, Kufri Giriraj and Kufri Muthu and Kufri Himsona showed a single tuber per plant and tubers were not formed for Kufri Giridhari and Kufri Himalini genotypes. At 200 ppb O₃ fumigation, significantly the highest tubers formed in Kufri Surya (3 / plant) and the minimum number of tubers were formed *i.e.*, (1 / plant) for Kufri Swarna, Kufri Jyothi, Kufri Chipsona and there was no tubers formation in other potato genotypes Kufri Jawahar, Kufri Giriraj, Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri

Himalini.

From the above results it was concluded that, the highest tuber formation was noticed in Kufri Surya at all three fumigation levels, whereas Kufri Giridhari and Kufri Himalini recorded significantly the lowest number of tuber per plant at 100 ppb O₃ and no tuber formation was noticed at 150 and 200 ppb O₃ levels. Moreover, majority of varieties did not show tuber formation at 200 ppb O₃ (Table 3).

Loss of photosynthetic capacity is an early effect of ozone exposure which is due to accelerated senescence with down-regulation of photosynthetic genes (McKee *et al.*, 1997). Inhibition of CO₂ assimilation can also result from direct or indirect inhibition of stomatal opening (Overmyer *et al.*, 2008). Reductions in carbon acquisition are likely to result in a reduction of whole plant biomass, inducing yield reduction in crops by reducing the availability of leaf surface area to fix and provide carbon for reproductive parts which is stemming from reduced photosynthetic efficiencies and / or stomatal conductances (Betzberger *et al.*, 2010). Ozone induced reductions in yield of potato tubers is the direct consequence of ozone-induced reductions in photosynthesis and photosynthate allocation to the reproductive structures (Wilkinson *et al.*, 2011).

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