Environment and Ecology 40 (3A) : 1384—1388, July—September 2022
ISSN 0970-0420

Fluoride Toxicity Effects on Phenology, Yield and Yield Attributes of Wheat (*Triticum aestivum* L.)

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Received 29 April 2022, Accepted 20 June 2022, Published on 6 August 2022

ABSTRACT

Fluoride toxicity, created by adding 0 (T_1), 50 (T_2), 100 (T_3), 200 (T_4), 250 (T_5) and 300 (T_6) mg fluoride (NaF) kg^{-1} soil, was examined in pot grown wheat plants. Fluoride toxicity, even at 50 mg kg^{-1} soil, had deleterious effects on different parameters of wheat and effect intensified with an increase in the concentration of applied fluoride in soil. Fluoride toxicity affected the phenology of wheat as it caused extension in durations of days to 50% ear emergence and days to 50% anthesis but a decrease in grain growth period and crop growth duration. Significant reduction ($P \leq 0.05$) in ears $plant^{-1}$, spikelets ear^{-1}, grains ear^{-1}, test weight (1000 grain weight) and harvest index were the major effects of fluoride toxicity on yield attributes of wheat. It is also to be investigated that which of the processes, i. e., pollen viability, stigma receptibility or both, are affected by fluoride toxicity leading to reduced grains ear^{-1}. Examining the mechanism by which fluoride toxicity retards translocation of photoassimilates to grains shall be helpful in better understanding the fluoride toxicity effects on crop productivity.

Keywords Fluoride, Phenology,Wheat,Yield attributes.

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INTRODUCTION

Wheat (*Triticum aestivum*) is a key crop of the green revolution and post-green revolution era. It is a widely grown cereal crop that provides >20% daily protein intake and calories worldwide. Fluoride (F^-) is the 13th most plentiful element present in the earth crust (Thippeswamy *et al.* 2021 and Tian *et al.* 2021) and one of the 12th most dangerous elements in the biosphere (Kimambo *et al*. 2019 and Toolabi *et al*. 2020). Choudhary *et al.* (2008) investigated the effect of different levels of sodium fluoride (0, 10, 25, 50, 100 and 200 ppm) on yield parameters of wheat varieties, WL 75 and UP 2003. The result revealed that 100 ppm and 200 ppm were toxic for both varieties of wheat.

Agarwal and Chauhan (2015) studied the effects of different concentrations of sodium fluoride on different yield components in barley (*Hordeum vulgare*). The effect of sodium fluoride toxicity was also studied by Singh *et al.* (2014) on number of tillers, number of ears, yield of seeds and test weight (1000 seeds weight) in two varieties of barley viz., DL-69 and K-24 and in two varieties of wheat viz., HD-2009 and PBW-226. While working with various levels of waterborne fluoride on wheat var. Raj 3675 by Joshi and Bhardwaj (2012) observed a reduction in dry weights, number of tillers and growth. It was suggested that susceptibility to fluoride might differ greatly in varieties, clones, and even in cultivars of the same species.

Though fluoride is becoming a problem for plant and human health and the situation is further deteriorating with increased environmental pollution, little is known about the effect of fluoride toxicity on phonological, yield and yield attributes of wheat; the second most important staple food crop globally. Therefore, present investigation was aimed with these objectives in view.

MATERIALS AND METHODS

Experiment was conducted during *rabi* (winter season) 2016-17 and 2017-18 in pots (diameter 25 and height 25 cm) filled with 7.50 kg pulverized dry soil collected from the field and mixed with FYM (4:1). Pots used in this experiment were without hole at bottom. Soil was supplemented with N, P and K @ 120:60:40 kg ha^{-1}, respectively. 50% N was applied as basal and rest in two equal split doses at 21 days after sowing (DAS) and at boot stage.

Pots were divided into 6 sets and supplemented with 0 (T_1), 50 (T_2), 100 (T_3), 200 (T_4), 250 (T_5) and 300 (T_6) mg fluoride kg^{-1} soil using NaF. Required amount of NaF was dissolved in 1.5 L water and applied to the respective pots five days before sowing wheat variety HUW-234. After 7 days of sowing, thinning was done to maintain 5 plants of uniform growth in each pot. Fluoride treatments were again repeated at 25, 50, 75 and 100 days after sowing (DAS) by irrigating pots to saturation level with the solution of the same concentration of fluoride. Plants were sampled at phenophases and harvest stages for quantifying various parameters.

Phenological parameters: Phenophases viz., days to 50% spike emergence, days to 50% anthesis and days to 50% physiological maturity were recorded visually when there was ear emergence, anthesis and maturity respectively, in 50% plants in treatment. Stage at which flag leaves of 50% plants in a treatment turned yellow and grains become hard was considered as plants have attained 50% physiological maturity. Durations of respective phenophases were counted from the sowing date.

Yield and yield attributes: At harvest number of ear bearing (effective) culms $plant^{-1}$, spike length, spikelets ear^{-1}, grains ear^{-1}, and grain yield $plant^{-1}$ were analysed. Pooled values (2016-2017 and 2017-18) for yield and yield attributes were calculated and presented.

Harvest index (%): Harvest index was calculated (Donald, 1962).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Statistical analysis: Data were statistically analysis by Complete Randomized Design (CRD). Critical differences were calculated at 5% level of significance.

RESULTS AND DISCUSSION

Phenological development: Significant differences were recorded between treatments with respect to days to 50% ear emergence, 50% anthesis and 50% physiological maturity from sowing (Table 1). 50% ear emergence was recorded at 65.50 days after sowing (DAS) in T_1. However, under T_2, T_3, T_4, T_5 and T_6 treatments this duration increased by 66.67, 69.50, 70.67, 71.00 and 72.17 days, respectively. Days to 50% anthesis, which was 73.67 days in plants under T_1 treatment increased to 74.33, 76.33, 77.17, 78.67 and 79.67 days in plants under T_2, T_3, T_4, T_5 and T_6 treatments, respectively (Table1), while days required for physiological maturity, which was 120.50 days in plants under T_1 treatment declined to 118.00, 115.50, 115.70, 112.83 and 111.00 days, respectively, in plants under T_2, T_3, T_4, T_5 and T_6 treatments. Though duration between 50% ear emergence to 50% anthesis increased marginally but grain growth duration, i. e.,

Table 1. Pooled values (2016-17 and 2017-18) for the effect of different concentrations of fluoride on 50% ear emergence, days to 50% anthesis, and days to physiological maturity in wheat genotype HUW-234. T_1, T_2, T_3, T_4, T_5 and T_6 represent 0, 50, 100, 200, 250 and 300 mg fluoride kg^{-1} soil, respectively.

Sl. No.	Treatment	Pooled values* for days to			Duration (days) between		Reduction in crop growth duration (days)
		50% ear emergence (a)	50% anthesis (b)	Physiological maturity (c)	a to b	b to c	
1	T_1	65.50	73.67	120.50	8.17	46.83	-
2	T_2	66.67	74.33	118.00	7.66	43.67	1.50
3	T_3	69.50	76.33	115.50	6.83	39.17	5.00
4	T_4	70.67	77.11	115.17	6.44	38.06	5.33
5	T_5	71.00	78.67	112.83	7.67	34.16	7.72
6	T_6	72.17	79.67	111.00	7.50	31.33	9.50
	SEm±	0.88	0.59	0.43			
	CD (5%)	2.56	1.72	1.26			

duration between 50% anthesis and 50% physiological maturity, declined as the concentration of fluoride increased. Increased fluoride level in soil affected wheat phenology. Days to 50% ear emergence and 50% anthesis increased and days for 50% physiological maturity (crop duration) decreased with increased fluoride concentrations (Table 1). Therefore, it is concluded that fluoride toxicity, like other stresses, also affects crop phenology. Days to emergence and anthesis are extended while crop growth period (days to 50% physiological maturity) is reduced under fluoride toxicity. Grain growth period, i. e., duration between anthesis and physiological maturity is reduced markedly under fluoride toxicity. No literature is available to indicate the effect of fluoride toxicity on phenology of wheat but present investigation clearly indicated that fluoride toxicity causes derangement in crop phenology.

Yield and yield attributes: Number of ears $plant^{-1}$ decreased under fluoride toxicity (Table 2). As compared to T_1 (control) treatment there was 60% reduction in ears $plants^{-1}$ in plants grown under T_6 treatment during both years. Ear length, spikelets ear^{-1} and grains ear^{-1} also decreased under fluoride toxicity (Table 2). Plants grown under T_1 (control) treatment spike length was 10.42 cm which under T_2, T_3, T_4, T_5 and T_6 treatments decreased by 12.48, 21.02, 31.09, 35.70 and 39.73 %, respectively. As the level of fluoride in root zone increased spikelets ear^{-1} decreased. Under T_1 (control) number of spikelets ear^{-1} were 17 while in T_2, T_3, T_4, T_5 and T_6 treatments as compared to T_1, number of spikelets ear^{-1} decreased by 5.88, 7.82, 17.65, 25.47 and 35.29%, respectively. Grains ear^{-1} were 38.50 in plants grown under T_1 (control) treatment there was 49 % reduction in grains ear^{-1} in plants grown under T_6 treatment. It is documented that fluoride toxicity

Table 2. Pooled values* (2016-17 and 2017-18) for ears $plant^{-1}$, ear length (cm), spikelets ear^{-1} and grains ear^{-1} in wheat genotype HUW-234. T_1, T_2, T_3, T_4, T_5 and T_6 represent 0, 50, 100, 200, 250 and 300 mg fluoride kg^{-1} soil, respectively. Values in parentheses indicate % reduction over control (T_1).

Sl. No.	Treatment	Pooled values* for							
		Ears $plant^{-1}$		Ear length (cm)		Spikelets ear^{-1}		Grains ea^{-1}	
1	T_1	1.67		10.42		17.00		38.50	
2	T_2	1.50	(10.17)	9.12	(12.48)	16.00	(5.88)	34.50	(10.39)
3	T_3	1.00	(40.12)	8.23	(21.02)	15.67	(7.82)	28.67	(25.53)
4	T_4	1.00	(40.12)	7.18	(31.09)	14.00	(17.65)	24.50	(36.36)
5	T_5	1.00	(40.12)	6.70	(35.70)	12.67	(25.47)	22.00	(42.86)
6	T_6	0.67	(59.88)	6.28	(39.73)	11.00	(35.29)	19.50	(49.35)
	SEm±	0.17		0.16		0.54		0.52	
	CD (5%)	0.49		0.45		1.59		1.51	

Table 3. Pooled values* (2016-17 and 2017-18) for test weight (100 grain weight), grain weight (g plant^{-1}), total dry matter (g plant^{-1}) and harvest index (%) in wheat genotype HUW-234. T_1, T_2, T_3, T_4, T_5 and T_6 represent 0, 50, 100, 200, 250 and 300 mg fluoride kg^{-1} soil, respectively. Values in parentheses indicate % reduction over control (T_1).

Sl. No.	Treatment	Pooled values* for 1000 grain weight (g)		Grain weight (g plant^{-1})		Total dry matter (g plant^{-1})		Harvest index (%)
1	T_1	40.00		1.58		3.74		40.40
2	T_2	38.58	(3.55)	1.37	(13.39)	3.37	(9.89)	39.54
3	T_3	37.17	(7.08)	1.06	(32.91)	2.70	(27.81)	38.72
` 4	T_4	36.67	(8.33)	0.91	(42.41)	2.48	(33.69)	37.89
5	T_5	35.67	(10.83)	0.78	(50.63)	2.19	(41.44)	36.61
6	T_6	33.00	(17.50)	0.61	(61.39)	1.74	(53.47)	36.05
SEm±		0.36		0.03		0.08		0.56
CD (5%)		1.05		0.08		0.30		1.66

causes reduction in ear plan^{-1}, seed weight plant-1 and test weight in wheat and 10 ppm NaF is reported to be the threshold level (Singh *et al.* 2014). Others reported 100-200 ppm NaF levels to be deleterious to yield and yield attributes in wheat (Choudhary *et al*. 2008, Kumar *et al.* 2013 and Singh 2013). In other crops viz. pea and barley (Kumar 2000) and urdbean (Malik and Arya 2008) harmful effects of NaF on yield and yield attributes have also been reported. In wheat tillers plant^{-1}, spikelets ear^{-1}, grains ear^{-1}, and grain size are determined between 10 - 55 DAS (tillering phase), 25 - 55 DAS (spikelet differentiation phase), 90 - 100 DAS (pollination stage) and 100 - physiological maturity (grain growth period), respectively, under normal sown condition in Indo-Gangetic plain of India (Srivastava 2003). However, tillers developed during early phase of growth have more chances to be productive (ear bearing). Any stress during tillering, spikelet differentiation, pollination and grain growth period leads to reduction in ear plant^{-1}, spikelet ear^{-1},grains ear^{-1} and test weight, respectively. In this study F was applied to pots at pre-sowing stage and at 25, 50, 75 and 100 DAS, therefore, plants under different fluoride levels experienced ionic as well as osmotic stress throughout growth period resulting in reduction in ears plant^{-1}, spikelets ear^{-1}, grains ear^{-1} and test weight (Tables 2, 3).

Test weight was the maximum (40.00 g per 1000 grains) in plants under T_1 (control) treatment. As compared to control reductions in test weight under T_2, T_3, T_4, T_5 and T_6 treatments were 3.55, 7.08, 8.33, 10.83 and 17.50 %, respectively (Table 3). Fluoride toxicity caused reduction in total dry matter production and grain yield. As compare to T_1 total dry matter and grain yield plan^{t-1} under T_6 treatment reduced to 53.47 and 61.39%, respectively (Table 3). Fluoride stress caused reduction in harvest index. It was around 40% in control (T_1) plants, which reduced to around 34% in plants under T_6 treatment (Table 3). Per cent reduction in test weight was much higher than reduction in grain number ear^{-1} under all treatments. It is therefore, inferred that fluoride toxicity affects pollination as well as test weight but the effect is more pronounced on test weight. Harvest index (HI) is also termed as migration coefficient. It indicates the extent of appotioning of photoassimilates to the economic part, i. e., grains as compared to total photoassimilates (harvestable dry matter) (Srivastava *et al.* 2009). We observed 40.40% HI in plants under T_1 which decreased progressively with increased fluoride concentration in soil and reached to 36.05% in plants under T_6 treatment (Table 3). It indicated fluoride toxicity also hampers the translocation of photoassimilates to grains in wheat. Reduction in test weight (grain size) and grain weight ear^{-1} is attributed mainly due to shortening of grain growth period, i. e., the duration between 50% anthesis to physiological maturity (Table 1), as well as decreased translocation of photoassimilates from vegetative parts to grains.

Increasing fluoride concentration reduced all the studied yield attributes in wheat but the reductions were of higher magnitude on grain weight plant^{-1}, ear plant^{-1}, dry matter plant^{-1}, grains ear^{-1}, ear length, spikelets ear^{-1} and harvest index. Fluoride toxicity effects on yield attributes were evident at 50 mg fluoride kg^{-1} soil which further intensified as the level of fluoride increased in soil.

CONCLUSION

It is concluded that fluoride toxicity, leads to extension in days to 50% ear emergence and 50% anthesis but reduces grain growth period and crop growth duration. Decrease in ears plant^{-1}, spikelets ear^{-1}, grains ear^{-1}, test weight and harvest index are the major effects of fluoride toxicity on yield attributes of wheat. It is to be investigated that which of the processes, i. e., pollen viability, stigma receptivity or both, are affected by fluoride toxicity leading to reduced grains ear^{-1}. Examining the mechanism by which fluoride retards translocation of photoassimilates to grains shall be helpful in better understanding the fluoride toxicity effects on crop productivity.

ACKNOWLEDGEMENT

This work is a part of PhD program of first author. UGC-BHU Research Fellowship received during her study period is thankfully acknowledged.

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