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Assessment of some chlorophyll *a* fluorescence parameters of different corn cultivars in response to clodinafop-propagrgyl herbicide and salicylic acid

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Abstract
Nowadays, the use of chlorophyll *a* fluorescence has become a simple and nondestructive method for detecting plant's photosynthetic response to different kinds of stress. The aim of this research was to evaluate the effects of different concentrations of clodinafop-propagrgyl (TOPIK®) herbicide on some chlorophyll *a* fluorescence parameters of different corn cultivars (SC260, SC400, SC704) in response to salicylic acid (SA) application (control, seed priming, spraying on plants three days before herbicide treatment, concurrent with herbicide application) in greenhouse of University of Tabriz in 2017, using a factorial arrangement of treatments based on randomized complete block design with three replicates. Results showed that by increasing of TOPIK levels in the absence of SA, the maximum fluorescence (F_m), variable fluorescence (F_v), efficiency and/or activity of water-splitting complex at donor side of photosystem II (F_v/F_0) and maximum photochemical efficiency of photosystem II (F_v/F_m) decreased but minimum fluorescence (F_0) increased. However, application of SA improved several parameters of chlorophyll *a* fluorescence in some corn cultivars. Application of SA as seed priming and spraying on plants three days before TOPIK treatment had higher effect on the studied cultivars than SA spraying concurrent with herbicide application. Correlation between the F_0 and F_v/F_0 was significant and negative. Also shoot dry weight (SDW) taken at 28 days after herbicide application had significant and positive relationship with F_v/F_m taken at 7 days after herbicide application. The findings of this research demonstrates that chlorophyll *a* fluorescence parameters and especially F_v/F_m are fast and reliable criteria for determining the effects of herbicides, such as TOPIK, and/or plants growth regulators, such as salicylic acid, shortly after treatment as compared to classical methods.

Keywords: Chlorophyll *a* fluorescence; Clodinafop-propagrgyl; Corn; Salicylic acid

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Introduction

Herbicides are used widely in agriculture, industry and urban areas. However, injuries of cell organelles and alteration in physiological activities of crop plants have been raising due to application of herbicides (Fayez and Kristen 1996; Fayez 2000). These components modify the cell cycle, plastid metabolism, or they act as endogenous growth regulators, but they usually affect the photosynthetic carbon fixation reaction or photo-induced electron transport (electron transport inhibitors, artificial acceptors, inhibitors of ATP synthesis) (Grumbach 1982). A cardinal site of inhibition of the photosynthetic electron transport is the donor side of PSII. The mechanism of inhibition stands on a competitive binding of the herbicide to the Q_B^- site on D1 protein in the reaction center of PSII (Govindjee *et al*. 1992; Ikeda *et al*., 2003) thus preventing Q_A^- to reduce Q_B.

The main mode of action of clodinafop-propargyl (TOPIK®) active ingredient is to inhibit the biosynthesis of lipids which leads to the cessation of growth and destruction of weed grasses. TOPIK also induces oxidative stress in cereals. Lukatkin *et al.* (2013) indicated that application of TOPIK on cereal crops predominantly increases the lipid peroxidation intensity, superoxide anion generation, total antioxidant activity and catalase and ascorbate peroxidase activity.

Photosynthetically active radiation energy absorption by photosynthetic pigment molecules occurs in the antenna complexes located in the thylakoid membranes (Kalaji *et al.* 2012). The absorbed energy is then transferred as excitation energy to photosystem I (PSI) and photosystem II (PSII) reaction centers, where it is used to initiate photochemical reactions. A part of this energy is lost as heat and chlorophyll *a* fluorescence. The chlorophyll *a* fluorescence process can provide information on the functioning and structure of the photosynthetic apparatus (Kalaji and Loboda 2007; Goltsev *et al.* 2009; Kalaji *et al.* 2016). Moreover, methods based on records of chlorophyll *a* fluorescence are reliable, non-invasive, powerful and simple tools for assessment of photosynthetic electron transport (Živčák *et al*. 2013) and related photosynthetic processes and allow for detection of stress in plants (Baker and Rosenqvist 2004; Borawska-Jarmułowicz *et al.* 2014). Fast chlorophyll *a* fluorescence kinetics data are derived from the time dependent increase in fluorescence intensity achieved upon application of continuous bright light to a previously dark adapted sample. The result is called the Kautsky curve or chlorophyll *a* fluorescence transient (Force *et al*. 2003).

Salicylic acid (SA) is an important signaling molecule in plants that induces tolerance of plants to various biotic and abiotic stresses (Ghassemi-Golezani and Lotfi 2015). The majority of SA as phytohormone regulated abiotic stresses in plants is involved in antioxidant responses. This indicates that protection of plants from oxidative damage by SA is associated with an enhanced antioxidant system and induction of biotic stress tolerance (Dat *et al.* 1998; Kogel and Langen 2005). Thus, the main aim of this research was to evaluate whether application of SA on corn plants can eliminate the negative effects of TOPIK as non-recommenced herbicide for this crop.

Materials and Methods

A pot experiment was carried out in a greenhouse of University of Tabriz in 2017. The factorial set of treatments was arranged using randomized complete block design with three replications. The factors were corn cultivars (SC260, SC400, SC704) and methods of 1 mM salicylic acid application (no SA as control, seed priming with SA, spraying SA on plants three days before TOPIK treatment, spraying SA concurrent with the application of herbicide) and TOPIK application (0, 50, 75 and 100% of recommendation dose, 800 ml ha^{1}). Herbicide treatment was applied at V5-V6 growth stage (appearance of 5-6 corn leaves with collars). The size of each pot was 20 cm × 20 cm with 25 cm depth, containing 1.0 kg of perlite. Ten seeds of each corn cultivar were sown at the depth of 3 cm and then tap water (0.8 dS m^{-1}) was added to achieve 100% field capacity. All pots kept inside a glass greenhouse under natural light. Minimum and maximum temperatures of greenhouse were 25 and 30 °C, respectively. After germination, plants were thinned to 5 plants per pot. During the growth period, the pots were weighed and the losses were made up with Hoagland solution (electrical conductivity= 1.3 dS m^{-1} and pH= 6.5-7). Perlites within the pots were washed every 25 days in order to prevent further increase in electrical conductivity, due to adding the Hoagland solution.

Induction of chlorophyll *a* fluorescence was monitored with a handy-PEA portable fluorometer (Hansatech, UK). Before measuring the experimental signals, plants were kept in dark at least for 30 min and then exposed to saturated white light to estimate the minimum (F_0) and maximum (F_m) fluorescence. Measurements were carried out on the upper surface of fully developed leaves seven days after the herbicide application on plants. Other chlorophyll *a* fluorescence parameters were as follows:

F_v (variable fluorescence) = $F_m - F_0$

F_v/F_0 (the efficiency and/or activity of water-splitting complex at donor side of photosystem II) = $(F_m-F_0)/F_0$

F_v/F_m (the maximum photochemical efficiency of photosystem II) = $(F_m-F_0)/F_m$

The root dry weight (RDW) and shoot dry weight (SDW) of plants were determined after four weeks from herbicide application.

The means were compared according to Duncan's multiple range test at p≤ 0.05. The data were analyzed by SPSS 16 software.

Results

The effects of different corn cultivars, SA applications and TOPIK treatments and also all possible interactions between them were significant on F_0, F_m, F_v, Fv/Fm and F_v/F_0 (Table 1).

Table 1. Analysis of variance of the corn cultivars in response to salicylic acid (SA) and TOPIK application

Source	df	F_0	F_m	F_v	F_v/F_m	F_v/F_0	RDW	SDW
Replication	2	45.04	590	353	0.001	0.01	5.08**	7.72**
Cultivars (C)	2	649**	60205**	60633**	3865**	2.1**	42.5**	2.74**
SA	3	1943**	30236**	35935**	3834**	3.5**	0.45**	1.30**
C *SA	6	2588**	24009**	21204**	3834**	1.3**	3.05**	2.73**
TOPIK (T)	3	1946**	3922**	4420**	3839**	0.9**	24**	12.00**
C*T	6	2279**	23379**	19051**	3811**	1.2**	0.39**	0.15*
SA*T	9	538**	26379**	24069**	3839**	0.4**	0.48**	0.28**
C*SA*T	18	2006**	17559**	18026**	3830**	1.3**	0.55**	0.32**
Error	94	77.3	633	719	0.01	0.09	0.10	0.05

ns: non-significant; *: significant at p≤ 0.05; **: significant at p≤ 0.01.
F_0: minimum fluorescence; F_m: maximum fluorescence; F_v: variable fluorescence; Fv/Fm: maximum photochemical efficiency of PSII; F_v/F_0: activity of water split complex on donor side of PSII; RDW: root dry weight; SDW: shoot dry weight.

Corn cultivars showed different response to various concentrations of TOPIK herbicide. F_0 significantly increased with increasing TOPIK in SC260 and SC400, but decreased at all levels in SC704. When SA sprayed on plants three days before herbicide application, F_0 increased at all TOPIK levels in SC260 and SC704, but decreased at all levels of this herbicide in SC400. Spraying of SA concurrent with herbicide application increased F_0 in all cultivars under all TOPIK levels (Table 2).

All concentration of TOPIK herbicide in non-SA treatments, significantly decreased F_m in all corn cultivars. In SC260, seed priming with SA improved F_m in comparison with non SA treatment. Treating corn plants with SA three days before TOPIK application or concurrent with this herbicide, decreased F_m under increasing herbicide levels in all cultivars (Table 2).

In the control plants (without SA treatment), application of TOPIK decreased variable fluorescence (Fv) in all cultivars. Seed priming with SA decreased the F_v in comparison with non-SA treatment in all cultivars. Lowest F_v was obtained for SC704 at 100% herbicide level. Treating plants with SA three days before herbicide application or concurrent with that decreased the F_v in SC400, although the F_v was lower in 100% than 75% and 50% recommended herbicide dose (RHD) (Table 3).

Table 2. Changes in the minimum (F0) and maximum (Fm) fluorescence of corn cultivars in response to salicylic acid (SA) and TOPIK application

Salicylic acid	TOPIK	F0			Fm		
		SC260	SC400	SC704	SC260	SC400	SC704
No SA	0	147	150	160	759	841	784
	50%	154	155	150	660	799	630
	75%	163	167	146	655	749	620
	100%	236	170	130	572	661	540
SA-seed priming	0	162	176	131	812	832	651
	50%	171	164	137	739	755	630
	75%	174	163	151	732	725	571
	100%	212	155	174	606	710	530
SA-3 days before herbicide treatment	0	150	179	112	766	830	781
	50%	159	171	170	753	777	766
	75%	160	169	184	737	739	743
	100%	167	161	193	709	685	624
SA-concurrent with herbicide treatment	0	159	143	167	808	773	778
	50%	167	145	180	720	699	749
	75%	184	167	191	661	638	699
	100%	199	179	212	443	610	619
LSD (5%) for the treatment combinations of SA × Cultivar × TOPIK		14.28			40.88		

Application of different TOPIK levels decreased the activity of water splitting complex at donor side of PSII (F_v/F_0) in all cultivars under no application of SA. Priming seeds with SA improved the F_v/F_0 in SC260 under 50, 75 and 100% RHD of TOPIK in comparison with non-SA treatment. The F_v/F_0 increased as result of SA application at three days before TOPIK treatment in SC704, especially under 0 (control) and 50% RHD of TOPIK. Spraying plants with SA as concurrent with TOPIK application decreased F_v/F_0 in almost all cultivars (Table 3).

Treating corn cultivars with different TOPIK levels decreased maximum photochemical efficiency of PSII (F_v/F_m) under control conditions (without SA application). Improved F_v/F_m was observed for seed priming with SA in SC704 under 50% RHD of TOPIK and in SC400 and SC260 at 100% TOPIK. Spraying of plants with SA three days before herbicide application also improved F_v/F_m in SC704 under 0 and 50% TOPIK and in SC260 at 50%. 75% and 100% of TOPIK. Spraying plants with SA as concurrent with herbicide significantly decreased F_v/F_m of SC260 under 75% and 100% RHD of TOPIK (Table 3).

Root dry weight (RDW) decreased with increasing TOPIK concentrations under 0 SA and application of SA with different methods in all corn cultivars. The lowest amount of RDW was recorded under highest concentration of herbicide (100% RHD). Treating plants with SA under non-application of TOPIK increased the RDW of plants in SC260 and SC704 (Table 4). Treated plants with different concentrations of TOPIK strongly decreased shoot dry weight (SDW) in all cultivars under application and non-application of

Table 3. Changes in variable fluorescence (F_v), activity of water splitting complex at donor side of PSII (F_v/F_0) and maximum photochemical efficiency of photosystem II (F_v/F_m) of corn cultivars in response to salicylic acid (SA) and TOPIK application

Salicylic acid	TOPIK	F_v			F_v/F_0			F_v/F_m		
		SC260	SC400	SC704	SC260	SC400	SC704	SC260	SC400	SC704
No SA	0	612	691	624	4.16	4.61	3.90	0.81	0.82	0.80
	50%	506	650	480	3.29	4.19	3.20	0.77	0.81	0.76
	75%	492	582	474	3.02	3.49	3.25	0.75	0.78	0.76
	100%	336	491	410	1.42	2.89	3.15	0.59	0.74	0.76
SA-seed priming	0	560	656	520	4.01	3.73	3.97	0.80	0.79	0.80
	50%	568	591	493	3.32	3.60	3.26	0.77	0.78	0.78
	75%	558	562	420	3.21	3.45	2.41	0.76	0.78	0.74
	100%	394	555	356	1.86	3.58	2.60	0.65	0.78	0.67
SA-3 days before herbicide treatment	0	616	651	669	4.11	3.64	5.97	0.80	0.78	0.86
	50%	594	606	596	3.74	3.54	3.51	0.79	0.78	0.78
	75%	577	570	559	3.61	3.37	3.04	0.78	0.77	0.75
	100%	542	524	431	3.25	3.25	2.23	0.76	0.76	0.69
SA-concurrent with herbicide treatment	0	649	630	611	4.08	4.4	3.66	0.8	0.82	0.79
	50%	553	554	569	3.31	3.82	3.16	0.77	0.79	0.76
	75%	477	471	508	2.59	2.82	2.66	0.72	0.74	0.73
	100%	244	431	407	1.23	2.41	1.92	0.55	0.71	0.66
LSD (5%) for the treatment combinations of SA × Cultivar × TOPIK			43.57			0.49			0.162	

Table 4. Changes in root dry weight (RDW) and shoot dry weight (SDW) of the corn cultivars in response to salicylic acid (SA) and TOPIK applications (four weeks after herbicide application)

Salicylic acid	TOPIK	RDW			SDW		
		SC260	SC400	SC704	SC260	SC400	SC704
No SA	0	3.70	3.75	0.68	2.16	2.63	1.64
	50%	3.26	2.76	0.52	1.30	1.86	0.81
	75%	2.26	2.03	0.37	0.56	0.96	0.66
	100%	1.83	1.08	0.26	0.34	0.68	0.63
SA-seed priming	0	3.80	1.91	2.88	1.40	2.63	2.14
	50%	3.33	1.55	0.98	0.92	1.72	1.25
	75%	3.06	0.56	0.89	0.83	0.88	0.96
	100%	2.84	0.38	0.77	0.64	0.18	0.72
SA-3 days before herbicide treatment	0	4.60	3.67	2.44	2.45	2.34	1.50
	50%	3.36	1.58	1.80	1.35	1.40	1.09
	75%	2.36	1.18	1.30	1.06	1.28	0.53
	100%	1.88	1.02	0.37	0.91	1.10	0.47
SA-concurrent with herbicide treatment	0	3.83	2.83	2.52	3.26	1.33	1.41
	50%	3.23	2.74	1.23	2.84	1.29	1.29
	75%	2.49	0.97	0.61	2.52	0.98	0.89
	100%	2.08	0.86	0.55	1.46	1.10	0.71

SA (Table 4).

RDW had positive and significant correlation with SDW. Correlation coefficient of F_0 with F_v/F_0 was negative and significant. A strong positive correlation was found between F_v and F_m. SDW (taken at 4 weeks after herbicide application) had also a positive correlation with $F_v/F_{m,}$ taken one week after herbicide application, but its coefficient of determination (0.058) was low (Table 5).

Discussion

Records of chlorophyll *a* fluorescence parameters in dark adapted samples represent an efficient tool for assessment of many external or intrinsic adverse effects on PSII photochemistry (Strasser *et al*. 2004). Our result indicated that corn cultivars (SC260, SC400, SC704) have different response to application of TOPIK and salicylic acid. F_0 represents the fluorescence level when the PQ electron acceptor pool is fully oxidized, and it may change when exposed to unfavorable conditions (Fracheboud *et al.* 2004). An increase in F_0 in SC260 and SC400 under herbicide application (Table 2) can be interpreted as a reduction in the rate constant of energy trapping by the PSII centers, which could be the result of a physical dissociation of the light harvesting complex from the PSII core observed in several plant species under environmental stress (Armond *et al.* 1980). Furthermore, the increase in F_0 could also be the result of release of light harvesting complex from PSII, the inactivation of the PSII photochemical reaction, or an inhibition of

Table 5. Interrelationships of root dry weight (RDW), shoot dry weight (SDW) and chlorophyll *a* fluorescence parameters of the corn cultivars under study

Trait	RDW	SDW	F_0	F_m	F_v	F_v/F_0	F_v/F_m
RDW	1						
SDW	0.64**	1					
F_0	0.07	0.05	1				
F_m	0.09	0.06	0.19*	1			
F_v	0.07	0.04	-0.09	0.95**	1		
F_v/F_0	0.04	-0.08	-0.69**	0.53**	0.74**	1	
F_v/F_m	-0.09	0.24**	0.02	0.21**	0.21**	0.13	1

* and **: significant at p ≤0.05 and p ≤0.01, respectively.
F_0: minimum fluorescence; F_m: maximum fluorescence; F_v: variable fluorescence; F_v/F_0: activity of water split complex on donor side of PSII; Fv/Fm maximum photochemical efficiency of PSII.

electron flow due to the reduced transfer of Q_A to Q_B (Mathur *et al.* 2011). The reduction in F_m under herbicide application (Table 2) may have been caused by inhibition of electron transport at the donor side of PSII or may be related to denaturation of chlorophyll proteins (Yamane *et al.* 1997). Rising of F_0 and decreasing of F_m indicate a block in the electron transport to Q_A^- (Krause and Weis 1991).

Efficiency of the water-splitting complex on the donor side of PSII (F_v/F_0) is the most sensitive component in the photosynthetic electron transport chain. A decrease in this ratio as a consequence of herbicide application (Table 3), results from photosynthetic electron transport destruction, which affects the average redox state of Q_A in the time span from 0 to T_{fm} (S_m/T_{fm}) in plants (Ghassemi-Golezani and Lotfi 2015). Similar result was also shown by Moustaka and Moustakas (2014) on *Arabidopsis* plant under application of paraquat.

In our research, application of TOPIK destructed the reaction centers of PSII in most treated plants (photochemically active), thus electron transport capacity in PSII and the number of quanta absorbed per unit of time decreased. Herbicide treatment could not only decrease protein kinase activity, but also destructed D_1 protein level and corresponding F_v/F_m (Table 3). The ratio of F_v/F_m is often used as a stress indicator and describes the potential yield of photochemical reaction. Chlorophyll *a* fluorescence allows us to study different functional levels of photosynthesis indirectly (processes at the pigment level, primary light reactions, thylakoid electron transport reactions, carbon fixation – enzymatic reactions, slow regulatory processes) (Goedheer 1964; Govindjee 1995). Wang *et al.* (2016) also reported similar results. They indicated that one day after ACCase inhibitor herbicide application, F_v/F_m values of *Alopecurus myosuroides* plants decreased and were significantly lower than F_v/F_m values of the control group.

The interactions between TOPIK and SA treatments indicated that in some cases SA improved the electron transport between two photosystems and growth parameters of corn cultivars under TOPIK application. But the effect of this phytohormone was dependent on the TOPIK concentration dose. Vercampt *et al.* (2016) reported that chlorophyll *a* fluorescence parameters unaffected at metalachlor doses up to 0.75 kg ha^{-1} but at concentration of 1.0 $kgha^{-1}$, negative effect was observed on all chlorophyll *a* fluorescence parameters. SA regulates plant response to organic contaminants and provides a basis to control herbicide contamination in crop production. SA mediates paraquat tolerance in *Hordeum vulgare* seedling (Ananieva *et al.* 2002) by enhancing chlorophyll and carotenoid content and leaf total protein. In addition, SA significantly reduced free proline, lipid peroxidation and CAT activity in paraquat stressed *Zea mays* seedlings (Shahrtash *et al.* 2011). It improved growth of napropamide treated *Brassica napus* and reduced napropamide levels in plants. Its application also decreased the abundance of O_2- and H_2O_2 as well as activity of SOD, CAT, APX and increased activities of POD, guaiacol peroxidase (GPX) and GST at 8 mg L^{-1} napropamide-exposed plants (Cui *et al.* 2010). The use of plant growth regulators may result in the development of resistance against herbicides through activation of defense mechanisms, such as controlling ROS production, enhancing osmolytes biosynthesis and nutrients homeostasis and activation of antioxidant system resulting in the protection from cell damage. These effects ensured higher photosynthesis, growth and yield. In this research, SDW had a positive correlation with F_v/F_m. In other investigations, positive relationship was observed between some fluorescence parameters such as F_v/F_m and dry weight of plants treated with bentazone (Christensen *et al.* 2003), metamitron and terbuthylazine (Abbaspoor *et al.* 2006), clodinafop (Abbaspoor and Streibig 2005), desmedipham and phenmedipham (Abbaspoor and Streibig 2007).

Conclusion

The use of herbicides has become a potential tool in modern agriculture to control weeds, but unknowingly the indiscriminate application of herbicides has resulted in adverse effects on the morphological, physiological and biochemical characteristics of crop plants. Our research was aimed to investigate that whether application of salicylic acid on corn plants can eliminate the negative effects of TOPIK as non-recommended herbicide for this crop. We clearly showed that with increasing TOPIK concentration on corn cultivars F_m, F_v, F_v/F_0 and F_v/F_m decreased but F_0 increased. However, application of SA improved these chlorophyll *a* fluorescence parameters in some cases. Corn cultivars differently responded to SA, while in most cases, the response of all cultivars to SA and TOPIK was similar. Application of SA as seed priming and spraying on plants three days before of TOPIK treatment had larger effect than SA spraying as concurrent with this herbicide application in most cases. SDW taken at 28 days after herbicide application had a positive correlation with the F_v/F_m taken at 7 days after herbicide application. According to our results and some other investigations, classical screening methods (such as shoot and root dry weight) can be replaced by chlorophyll *a* fluorescence as simple and non-destructive methods. We can conclude from the results of this research that F_v/F_m is a proper parameter for evaluating the effect of TOPIK herbicide shortly after application. Evaluating chlorophyll *a* fluorescence parameters, such as F_v/F_m, 4 weeks before shoot and root dry weight measurement can save the time and aware about the physiological stresses caused by herbicides.

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ارزیابی برخی از پارامترهای فلورسانس کلروفیل *a* ارقام مختلف ذرت در پاسخ به علفکش کلودینافوپ-پروپارژیل و سالیسیلیک اسید

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چکیده

امروزه استفاده از فلورسانس کلروفیل *a* به عنوان روشی ساده و غیرتخریبی برای تشخیص پاسخ فتوسنتزی گیاهان به انواع تنش‌ها مطرح است. هدف این آزمایش ارزیابی اثر غلظت‌های مختلف علفکش کلودینافوپ-پروپارژیل (تاپیک) روی برخی پارامترهای فلورسانس کلروفیل *a* در ارقام مختلف ذرت (SC260، SC400، SC704) در پاسخ به کاربرد اسید سالیسیلیک (شاهد، پرایمینگ بذر، محلول‌پاشی گیاهان سه روز قبل از تیمار علفکش، محلول‌پاشی هم‌زمان با علفکش) بود که در قالب یک آزمایش فاکتوریل بر پایه طرح بلوک‌های کامل تصادفی در سه تکرار در گلخانه دانشگاه تبریز در سال ۱۳۹۶ انجام شد. نتایج نشان داد که با افزایش سطوح تاپیک، در غیاب اسید سالیسیلیک ، حداکثر فلورسانس (F_m)، فلورسانس متغیر (F_v)، کارایی و یا فعالیت کمپلکس تجزیه کننده آب در بخش دهنده الکترون فتوسیستم دو (F_v/F_0) و حداکثر کارایی فتوشیمیایی فتوسیستم دو (F_v/F_m) کاهش یافت، ولی حداقل فلورسانس (F_0) افزایش نشان داد. از طرف دیگر کاربرد اسید سالیسیلیک سبب بهبود تعدادی از پارامترهای فلورسانس کلروفیل *a* در برخی از ارقام ذرت شد. کاربرد اسید سالیسیلیک ، به صورت آماده‌سازی بذر و محلول پاشی روی گیاهان، سه روز قبل از سمپاشی تاپیک، تأثیر بیشتری نسبت به محلول‌پاشی هم‌زمان اسید سالیسیلیک با علفکش روی ارقام مورد مطالعه داشت. همبستگی بین F_0 و F_v/F_0 معنی‌دار و منفی بود. همچنین بین وزن خشک اندام هوایی در ۲۸ روز بعد از سمپاشی و F_v/F_m در ۷ روز بعد از سمپاشی، رابطه مثبت و معنی‌داری وجود داشت. یافته‌های آزمایش نشان داد که از پارامترهای مرتبط با فلورسانس کلروفیل *a* به ویژه F_v/F_m می‌توان به عنوان معیارهای سریع و قابل اطمینان به جای روش‌های کلاسیک، برای ارزیابی اثرعلفکش‌هایی مانند تاپیک و تنظیم‌کننده‌های رشد گیاهی مانند اسید سالیسیلیک، مدتی بعد از اعمال تیمار استفاده کرد.

واژه‌های کلیدی: ذرت، اسید سالیسیلیک، فلورسانس کلروفیل *a*، کلودینافوپ - پروپارژیل