



# Chlorophyll *a* fluorescence of safflower affected by salt stress and hormonal treatments

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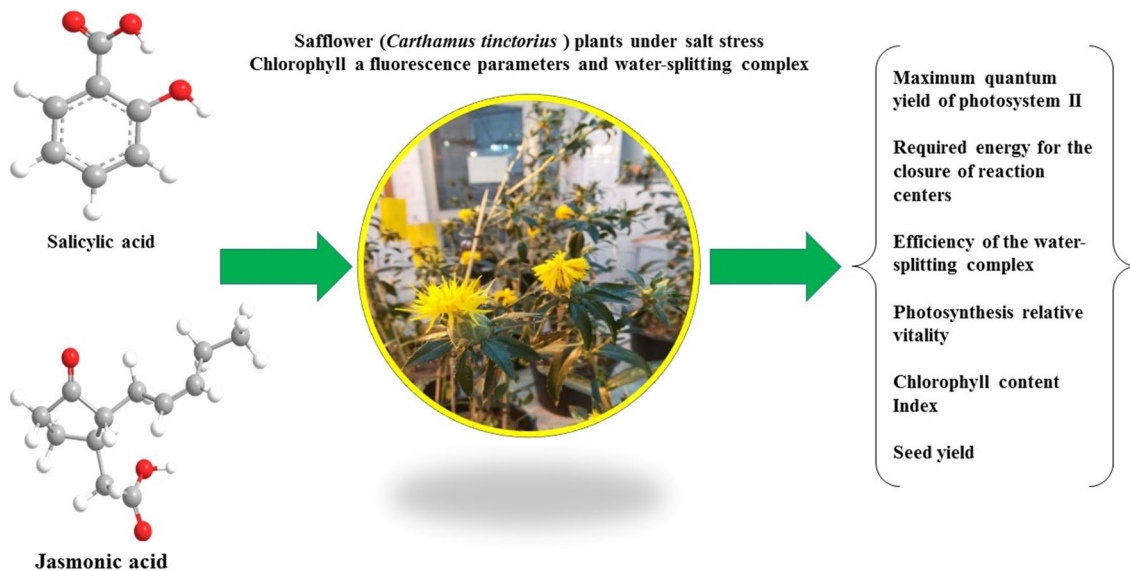
## Abstract

Salicylic and jasmonic acids are classified as stress hormones, which can affect numerous physiological characteristics of plants such as electron transporting systems in thylakoid membrane under normal and stressful conditions. A greenhouse experiment was conducted with factorial arrangement based on a randomized complete block design with three replications to assess the possible effects of salicylic acid (1 mM) and jasmonic acid (0.5 mM) on different parameters of chlorophyll *a* fluorescence in safflower (*Carthamus tinctorius* L. cv. Goldasht) under salt stress [0, 4, 8, and 12 dS m<sup>-1</sup> NaCl (about 0, 40, 80 and 120 mM NaCl, respectively)]. Leaf chlorophyll content index, relative water content, leaf area and seed yield were decreased with increasing salinity. Salinity caused a significant decrease in the variable fluorescence, the maximum quantum yield of photosystem II, efficiency of water-splitting complex on the donor side of the photosystem II and total performance index (PI<sub>total</sub>). The highest time needed to reach maximum fluorescence was recorded at 12 dS m<sup>-1</sup>. Maximum fluorescence and PI<sub>total</sub> were increased, but initial fluorescence and maximum fluorescence were significantly decreased by salicylic acid and jasmonic acid treatments under saline conditions. Salicylic acid and jasmonic acid considerably improved the variable fluorescence, maximum quantum yield of photosystem II, the efficiency of water-splitting complex, PI<sub>total</sub>, physiological parameters and seed yield under salinity. In this way, foliar application of salicylic acid and jasmonic acid could play a key role in salt stress tolerance of safflower plants.

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## Graphic abstract



**Keywords** Chlorophyll · Fluorescence · Jasmonic acid · Safflower · Salicylic acid · Salt stress

## 1 Introduction

The chlorophyll fluorescence and its characters are very sensitive to changes in photosynthesis, which can be recorded with great accuracy. The captured solar energy in the form of excited electrons of pigment molecules can be transported from energy antennae to photosynthetic reaction centers, where they activate biochemical pathways [1]. Chlorophyll fluorescence is an interesting instrument that can manifest information on plant photosynthetic performance and defensive responses via fast, non-intrusive measurements [2]. A strong parameter achieved from chlorophyll fluorescence measurement is the photochemical potential of photosystem II reaction centers (such as maximum quantum yield of photosystem II), either in dark and/or light situations [3, 4]. The water-splitting complex, placed on the inner side of the thylakoid membranes, and has a very critical role in photosystem II performance. This complex is made from four manganese atoms and low eight protein components. During water-splitting, electrons are split off (four electron) from the manganese complex and transferred to P680 reaction center. Different environmental stresses such as drought and salinity can disorder water spelling complex and reduce electron transporting efficiency in plants [5]. In crops (thylakoid cell membranes) active in photosynthesis, quantum energy of light is absorbed by chlorophyll. Activated chlorophyll pigments can resuscitate from its activated form to the

non-activated form by releasing heat [6, 7]. Single parts of chlorophyll *a* placed in the active center of the photosystem I and II are involved in energy transportation in thylakoid cell membranes [8, 9]. Photosystem II is a worthwhile parameter to examine the effects of adverse environmental conditions on crop photosynthetic performance, since photosynthetic activities are often decreased under stresses such as salinity [10].

Salt toxicity of soil has been a major limiting factor in food production. According to the Munns and Tester [11] approximately 50% of farmlands and 20% of agricultural lands in the world is salt-affected. Salinity inhibits the crop growth and productivity via limiting photosynthesis and energy conservation imbalance [12]. An increase in photosystem I activity and a decrease in photosystem II mediated oxygen evolution activity as a result of salt stress can cause some modifications in the thylakoid membrane proteins, leading to a decline in electron transfer from light harvesting antenna to photosystem II [13]. The restrictions to carbon assimilation enforced by stomatal termination can result in an imbalance between the electron requirement for photosynthetic movements and photochemical activities at photosystem II, which may lead to photo-inhibitory destruction of photosystem II reaction centers. The main defense mechanism involved in photo-inhibitory effects in plant cells is probably the increase in non-photochemical quenching energy dissipation [14]. Lee et al. [15] reported that maximum photochemical efficiency of

photosystem II ( $F_v/F_m$ , where  $F_v$  is the variable fluorescence and  $F_m$  is the maximum fluorescence) is still high under tolerable salt toxicity, while plant biomass decreases under this salinity level. Salt stress delays the fluorescence and reduces the light trapping efficiency in wheat plants [16], as also reported for mung bean plants [17].

One practical strategy for reducing the adverse effects of salt stress on growth and productivity of crops is the foliar application of plant growth regulators such as salicylic acid and jasmonic acid [18, 19]. Salicylic acid is a phenolic component and acts as an important growth regulator in plant cells. Many researchers confirmed the role of salicylic acid in alleviating salt toxicity in crops. For example, this growth regulator has been found to stimulate antioxidant enzymes activities [20],  $H^+$ -ATPase activity in root tonoplast [18] and biosynthesis of chlorophylls under salinity [20]. Ghassemi-Golezani and Farhangi-Abriz [18] reported that the foliar treatment of salicylic acid increases the potassium uptake by soybean plants under salt stress. Exogenous application of salicylic acid also enhanced nitrogen and sulfur contents in soybean leaves and improved seed yield under salt stress [21]. Jasmonic acid is another growth regulator which can affect different processes in crops [22]. Jasmonic acid modifies several physiological pathways, leading to increased tolerance against salt stress [23]. Jasmonic acid treatment of the salt stressed soybean plants also reduced lipid peroxidation and enhanced the antioxidant enzymes activities and osmolytes content in plant leaves [20]. Harpreet et al. [24] stated that the jasmonic acid application increases sugar accumulation and improves salt stress tolerance in rapeseed plants.

$$RWC = [(fresh\ weight - dry\ weight) / (turgid\ weight - dry\ weight)] \times 100.$$

Safflower (*Carthamus tinctorius* L.) is an important oilseed crop used for edible oil production in the world [25]. This crop is cultivated on marginal lands that are most affected by water availability and salinity [26]. Thus, this research was aimed to investigate the possible effects of exogenous salicylic acid and jasmonic acid on important parameters of chlorophyll *a* fluorescence in safflower plants under salt stress.

## 2 Materials and methods

### 2.1 Plant materials and growth conditions

An experiment was designed as factorial with randomized complete block design and three replications to determine

the possible effects of 1 mM salicylic acid and 0.5 mM jasmonic acid spray on different parameters of chlorophyll *a* fluorescence in safflower plants under salt stress. Each plastic pot (30 × 30 cm) was filled with 1.0 kg perlite and then seeds of safflower (*C. tinctorius* L. cv. Goldasht) were sown. Subsequently, tap water (0.8 dS m<sup>-1</sup>) and saline solutions [4, 8 and 12 dS m<sup>-1</sup> (about 40, 80 and 120 mM NaCl) as mild, moderate and severe salinities, respectively] were added to achieve 100% field capacity in 36 planted and 4 unplanted pots. The salinity treatments were chosen to evaluate the range of salt tolerance in safflower plants. All pots were kept inside a glass greenhouse under 145 W m<sup>-2</sup> light intensity with 13 h photoperiod. Minimum and maximum temperatures of the greenhouse were 25 and 30 °C, respectively. During the experiment, the unplanted pots were weighed and the losses were made up with a Hoagland solution (EC = 1.3 dS m<sup>-1</sup> and pH 7) for all pots. Salicylic acid and jasmonic acid were sprayed on leaves at vegetative and flowering stages.

### 2.2 Leaf area (LA) and relative water content (RWC)

LA per plant was measured at the beginning of pod formation stage using a leaf area meter (ADC-AM 300). Relative water content (RWC) of safflower leaves was assayed according to Barr and Weatherley [27]. Initially, fresh weight of the youngest fully expanded leaf was recorded, then the turgid weight was obtained after soaking the leaf in distilled water for 24 h. In next step, leaf dry weight was determined after oven drying at 75 °C for 48 h. Relative water content of leaves was calculated as:

### 2.3 Chlorophyll content and fluorescence measurements

Chlorophyll content index (CCI) of safflower leaves was measured by a portable chlorophyll meter (CCM-200). Induction of chlorophyll *a* fluorescence was monitored by a handy-PEA portable fluorometer (Hansatech, UK) at flowering stage. Fluorescence emission was monitored from the upper surface of the leaves. Dark-adapted leaves (30 min) were initially exposed to the weak modulate measuring beam, followed by exposure to saturated white light to estimate the initial ( $F_0$ ) and maximum ( $F_m$ ) fluorescence values, respectively. This device has a software for calculation, numerical presentation and memorization of chlorophyll fluorescence parameters. Total performance index ( $PI_{total}$ ),  $T_{fm}$  (time needed to reach maximum fluorescence) and Area (the

**Table 1** Means of RWC (%), CCI, LA (cm<sup>2</sup> per plant) and parameters of chlorophyll *a* fluorescence in safflower affected by NaCl salinity and hormonal application

Treatments	RWC	CCI	LA	F <sub>m</sub>	PI <sub>total</sub>	T <sub>fm</sub>	Area	S <sub>m</sub>	S <sub>m</sub> /T <sub>fm</sub>
<i>Salinity (dS m<sup>-1</sup>)</i>									
Non-saline	83.4 a	60.9 a	148.97 a	2857.8 a	3.72 a	24,677.8 b	37,628.8 a	15.7 a	0.00064 a
4	73.3 b	57.7 a	136.73 b	2718.7 bc	3.68 a	25,255.5 b	37,311.1 a	16.7 a	0.00067 a
8	70.1 b	58.1 a	134.69 c	2798.2 ab	3.25 a	27,777.7 b	36,355.5 a	16.2 a	0.00062 a
12	69.4 b	44.7 b	132.65 d	2664.6 c	2.33 b	31,888.8 a	36,511.1 a	17.5 a	0.00056 a
<i>Hormonal applications</i>									
Control	66.2 b	51.8 a	134.69 b	2588.5 b	2.21 b	32,091.6 a	34,616.6 b	17.1 a	0.00055 a
Salicylic acid (1 mM)	76.8 a	57.8 a	140.81 a	2814.3 a	3.64 a	25,441.6 b	37,125.0 ab	16.0 a	0.00063 a
Jasmonic acid (0.5 mM)	79.2 a	56.5 a	140.81 a	2870.7 a	3.82 a	23,916.6 b	39,113.3 a	16.4 a	0.00069 a

RWC relative water content, CCI chlorophyll content index, LA leaf area, F<sub>m</sub> maximum fluorescence, PI<sub>total</sub> total performance index, T<sub>fm</sub> time needed to reach maximum fluorescence, Area the area above the chlorophyll fluorescence curve between F<sub>0</sub> and F<sub>m</sub>, S<sub>m</sub> required energy for the closure of reaction centers, S<sub>m</sub>/T<sub>fm</sub> redox state of Quinone in the time span from 0 to T<sub>FM</sub>

Different letters in each column indicate significant difference at  $p \leq 0.05$

area above the fluorescence induction curve between F<sub>0</sub> and F<sub>m</sub>) were also monitored and fluorescence parameters were calculated according to Kalaji et al. [28]:

$$F_v \text{ (Variable chlorophyll fluorescence)} = F_m - F_0$$

$$F_v/F_0 \text{ (Efficiency of the water-splitting complex)} = (F_m - F_0)/F_0$$

$$F_v/F_m \text{ (Maximum quantum yield of photosystem II)} = (F_m - F_0)/F_m$$

$$PI_{total} = PI_{ABS} \times \delta R_0 / (1 - \delta R_0); \text{ where } PI_{ABS} \text{ is performance index on absorption basis and } \delta R_0 \text{ is the probability of an electron transportation from reduced plastoquinone to electron acceptor side of PSI.}$$

$$S_m \text{ (Required energy for the closure of reaction centers)} = \text{Area} / (F_m - F_0)$$

$$S_m/T_{fm} \text{ (Redox state of Quinone in the time span from 0 to } T_{FM}) = \text{Area} / (F_m - F_0) \times T_{fm}$$

## 2.4 Seed yield

At maturity, plants from each pot were harvested. Then grains were separated from the pods and seed yield per plant was determined.

## 2.5 Statistical analysis

Analysis of variance of the data appropriate to the experimental design and comparison of means at  $p \leq 0.05$  were carried out, using MSTAT-C software. Figures and tables were prepared for the significant effects of individual factors or their interactions.

## 3 Results

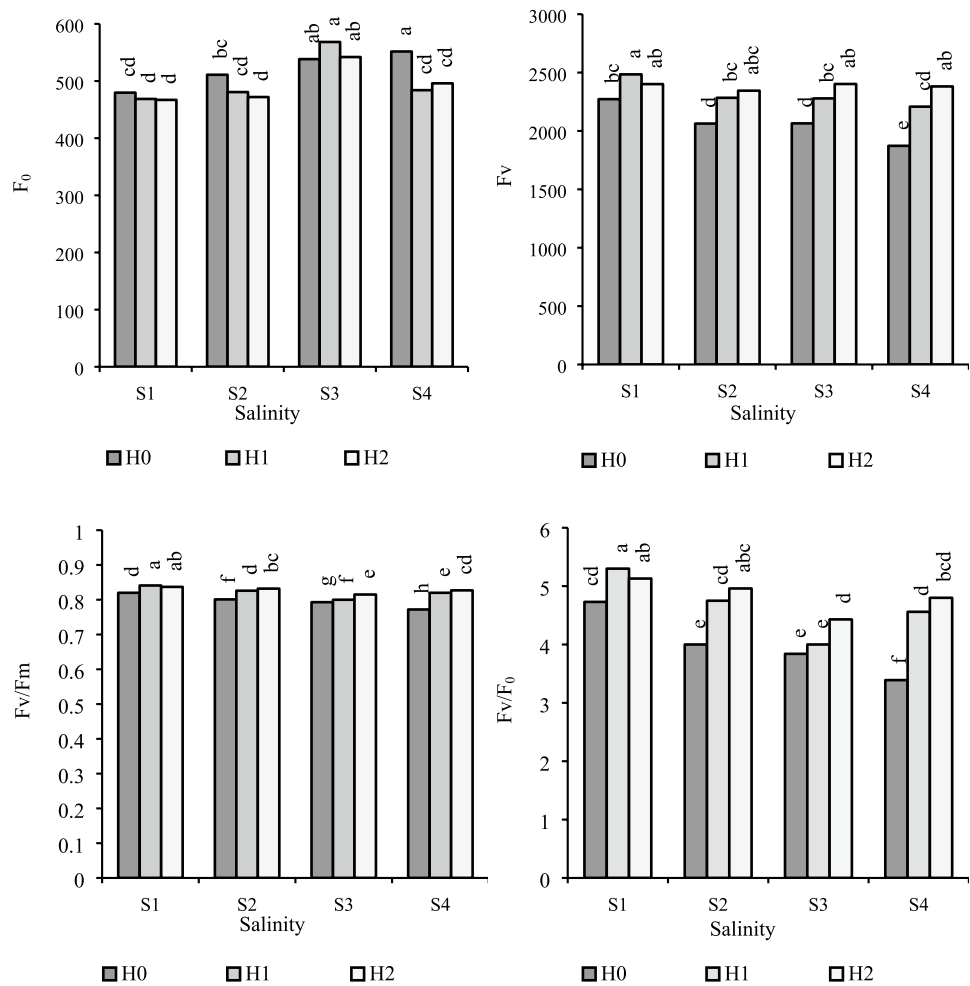
### 3.1 RWC, CCI and LA

RWC of safflower leaves was decreased by enhancing salt stress. However, there was no significant difference between plants under different levels of salinity. Foliar application of jasmonic acid and salicylic acid similarly increased RWC of safflower leaves, compared with control (Table 1). The lowest leaf CCI was recorded for plants subjected to severe salinity, but there was no significant difference in CCI of non-saline plants with mild and moderate salinities. LA was reduced by rising salt stress, but foliar application of jasmonic acid and salicylic acid increased LA under salt stress (Table 1).

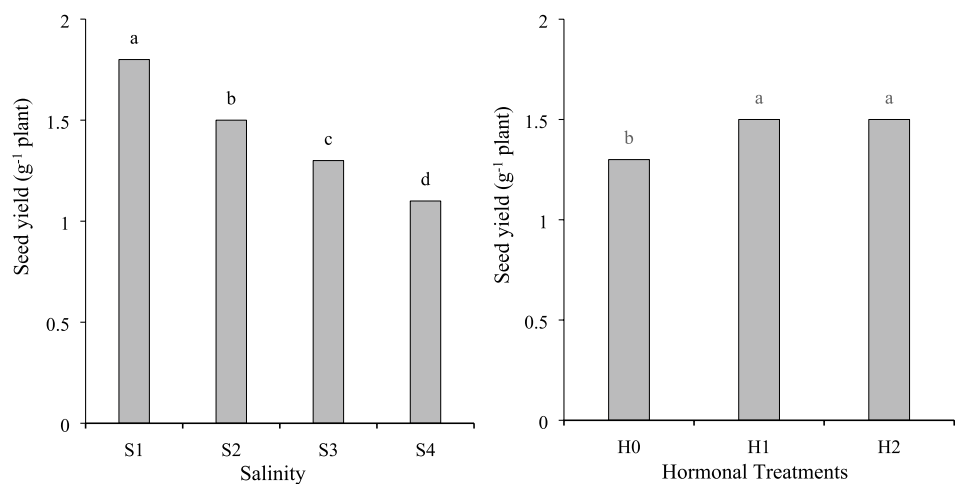
### 3.2 Maximum fluorescence, total performance index, required energy for the closure of reaction centers and time needed to reach maximum fluorescence

Salt stress caused a significant decrease in maximum fluorescence (F<sub>m</sub>) and PI<sub>total</sub>. In contrast, S<sub>m</sub> (the energy necessary for the closure of all reaction centers) increased (Insignificantly) as a result of increasing salt levels (Table 1). The highest time needed to reach F<sub>m</sub> (T<sub>fm</sub>) was recorded for severe salinity (Table 1). Application of jasmonic acid and salicylic acid significantly decreased T<sub>fm</sub> and increased the area above the chlorophyll fluorescence curve between F<sub>0</sub> and F<sub>m</sub> (Area).

**Fig. 1** Changes in minimum fluorescence ( $F_0$ ), variable fluorescence ( $F_v$ ), maximum quantum yield of photosystem II ( $F_v/F_m$ ) and water-splitting complex ( $F_v/F_0$ ) of safflower under salt stress and hormonal applications. Different letters indicate significant difference at  $p \leq 0.05$ .  $S_1, S_2, S_3, S_4$ : 0, 4, 8 and 12 dS  $m^{-1}$  NaCl salinity, respectively.  $H_0, H_1$  and  $H_2$ : Control, 1 mM salicylic acid and 0.5 mM jasmonic acid, respectively



**Fig. 2** Effects of salicylic acid and jasmonic acid treatments on safflower seed yield under different levels of salt stress. Different letters indicate significant difference at  $p \leq 0.05$ .  $S_1, S_2, S_3, S_4$ : 0, 4, 8 and 12 dS  $m^{-1}$  NaCl salinity, respectively.  $H_0, H_1$  and  $H_2$ : Control, 1 mM salicylic acid and 0.5 mM jasmonic acid, respectively



Maximum fluorescence ( $F_m$ ) and  $PI_{total}$  were increased by hormonal treatments (Table 1). Hormonal treatments did not alter the  $S_m$  and  $S_m/T_{fm}$  in safflower leaves.

### 3.3 Maximum quantum yield of photosystem II

Initial fluorescence ( $F_0$ ) was significantly decreased by the application of jasmonic acid and salicylic acid under

different salinities and non-saline condition. This deduction for plants under severe salinity was larger than that under other salinity levels (Fig. 1). Variable fluorescence ( $F_v$ ) of safflower leaves declined with increasing salt levels.  $F_v$  under both saline and non-saline conditions increased by exogenous application of jasmonic acid and salicylic acid. The beneficial effects of jasmonic acid and salicylic acid on  $F_v$  were more evident under severe salinity (Fig. 1). The maximum quantum yield of photosystem II ( $F_v/F_m$ ) diminished with increasing salt stress in both hormonal treated and untreated plants. Foliar application of jasmonic acid and salicylic acid considerably improved  $F_v/F_m$  of safflower leaves under different salinities. The highest improvement in  $F_v/F_m$  due to hormonal treatments was observed under severe salt stress (Fig. 1).

### 3.4 Water-splitting complex activity

The efficiency of the water-splitting complex on the donor side of the photosystem II ( $F_v/F_0$ ) was decreased as salt stress increased. The  $F_v/F_0$  was enhanced as a result of foliar treatments of plants with jasmonic acid and salicylic acid. Treatments with jasmonic acid and salicylic acid increased  $F_v/F_0$  of safflower leaves under different levels of salinity. This advantage of hormonal application on  $F_v/F_0$  was more pronounced under severe salinity (Fig. 1).

### 3.5 Seed yield

Seed yield was decreased with increasing salt stress. Foliar application of plants with jasmonic acid and salicylic acid significantly increased seed yield of safflower by about 15%, compared with the non-hormonal treatment (Fig. 2).

## 4 Discussion

Salt stress can damage plant cells by stimulating oxidative, osmotic and ionic stresses [29]. The increment of sodium ions in the rhizosphere can lead to a reduction in leaf water content and, therefore, may affect different physiological pathways [30]. The reduction in RWC of leaves (Table 1) could be related to sodium toxicities, cation imbalance and osmotic stress [31, 32]. The high RWC of plants treated with jasmonic acid and salicylic acid may be associated with accumulation of so-called JA and SA-induced peptides and proteins that were found in all plant species [33, 34]. Reduction in CCI under severe salinity (Table 1) can be attributed to increased chlorophyllase enzyme activity [35] and reduction in chlorophyll stability index [20].

Chlorophyll *a* fluorescence was assayed to assess the possible effects of salt toxicity on the photochemical

efficiency of photosystem II in safflower leaves. The reduction in  $F_m$  under salt toxicity (Table 1) may be caused by a reduction in electron transfer at the donor side of the photosystem II, which causes the accumulation of P680 due to a decline in the pool size of Quinones [17]. Kalaji et al. [36] stated that NaCl salinity is one of the important environmental stresses that can affect most parameters of the chlorophyll *a* fluorescence in barley plants. Faseela et al. [37] showed that the maximum quantum yield and the electron transport from the PSII donor side to the PSII reaction center was highly reduced under NaCl stress in rice seedlings. The  $PI_{total}$  is the pooled indicator of the quantity of photosynthetic reaction centers and the highest energy fluidity which spreads to the photosystem II reaction centers [16]. Deduction of  $PI_{total}$  under severe salt toxicity (Table 1) may be related with the damage of light and dark reactions in photosynthesis process. The inhibition of dark and light photosynthetic responses due to salt toxicity looks like to happen by the modifications in photo-inhibition [38]. It appears that the weakness of  $PI_{total}$  in safflower leaves to high concentration of salt ions (Table 1) may be caused by the low capacity of non-assimilatory electron pathways and a decrease in pool size of Quinones. It was shown that salinity reduces photochemical and non-photochemical quenching in photosystem complex, leading to a decline in light absorption capacity of plants [39, 40]. Non-photochemical quenching is an important mechanism used by plants to protect themselves from the harmful impacts of high light intensity [36]. Salt stress reduced photochemical quenching of tomato plants by damaging D1 protein [41]. This stress also lowered the electron transporting rate in the photosynthetic process by damaging the photosystems (especially PSII) [41, 42].

The higher value of  $S_m$  under severe salt stress (Table 1) implies that the heterogeneity of plastoquinone enhances the electron donation capacity and Quinone reduction in the photosystem II acceptor side. Decreasing the total energy receptor capacity of leaves under salinity, as indicated by high  $S_m$  (Table 1), shows the pool of electron transporters between photosystem II and the acceptor side of photosystem I [43]. If the electron transfer to Quinone pool from reaction center is blocked, the area over the fluorescence induction curve between initial ( $F_0$ ) and maximum ( $F_m$ ) fluorescence values will be reduced. However, the decline of the area over the fluorescence curve between the salinity levels and non-saline condition was not significant (Table 1).

Enhancing initial fluorescence value under salt toxicity (Fig. 1) may be related to the early destruction occurring in photosystem II, due to ion toxicity. This increment in initial fluorescence under salt toxicity is dependent on fundamental properties affecting the possibility of the electron transference between the photosynthetic pigments

[17]. The low  $F_v$  and  $F_v/F_m$  values under saline conditions (Fig. 1) may be associated with the damage happening in photosystem II. This decline in  $F_v/F_m$  under salt toxicity of soil is dependent on reducing electron transport capacity in photosystem II and damage to the reaction centers [44, 45]. The efficiency of the water-splitting complex on the donor side of photosystem II is the most sensitive part of the photosynthetic electron transport chain. According to Fricke and Peters [46], a reduction of osmotically driven uptake of water is observed under salt toxicity. This can explain the lower values of water-splitting complex in safflower leaves under different levels of salt stress (Fig. 1). Water-splitting complex is a sensitive parameter that is related to the photosynthetic electron flow. Decrement of this parameter is an indication of electron transport inhibition and photophosphorylation [47]. Khatri and Rathore [48] stated that the lower activity of water-splitting complex on the donor side of the PSII under salt stress is attributed to impairment in photosynthetic electron transport. In this study, lower values of water-splitting complex in salt stressed plants were related with the osmotic stress caused by salinity.

Foliar application of jasmonic acid and salicylic acid considerably increased chlorophyll *a* fluorescence of safflower by reducing  $T_{fm}$  (Table 1), initial fluorescence (Fig. 1) and increasing maximum fluorescence,  $PI_{total}$  and area (Table 1). Increasing maximum fluorescence by application of salicylic acid and jasmonic acid (Table 1) could be resulted from the rising photosystem II activity due to conformational modifications in the D1 protein [49], affecting changes in the properties of photosystem II electron acceptors. The increment in maximum fluorescence by jasmonic acid and salicylic acid may be also caused by the reduction in electron donation from water to photosystem II due to an increase in manganese content and extrinsic proteins from the oxygen evolution complex [50]. The enhancement of variable fluorescence ( $F_v$ ) by application of jasmonic acid and salicylic acid (Fig. 1) is supported by a decrease in initial fluorescence (Table 1), which is a characteristic of simulation of the acceptor side. Increasing  $PI_{total}$  (Table 1) may be related to the effects of salicylic acid and jasmonic acid on the density of reaction centers per photosystem II antenna, and also with the high quantum yield for electron transport.

Application of salicylic acid and jasmonic acid significantly improved chlorophyll fluorescence of safflower by increasing photosystem II efficiency (Fig. 1). Reduction of time to reach  $F_m$  ( $T_{fm}$ ) and minimum fluorescence ( $F_0$ ) by salicylic acid and jasmonic acid was led to enhance the average redox state of primary Quinone in the time span from 0 to  $T_{fm}$  ( $S_m/T_{fm}$ ) (Table 1) and efficiency of the water-splitting complex on the donor side of photosystem II ( $F_v/F_0$ ) (Fig. 1). Increasing the efficiency of the water-splitting

complex as a result of salicylic acid and jasmonic acid applications could be attributed to the improvement of photosynthetic electron transport.

Song et al. [51] showed that salicylic acid enhances malt-ing barley tolerance to heavy metal stress by increasing the antioxidative activities. Antioxidative activities have an important role in decreasing salinity depended oxidative stress in plants [52]. Exogenous SA can protect photosynthetic pigments from oxidative damage that may help to maintain normal photosynthesis of rice plants under drought [53]. Reduction of seed yield under salt toxicity (Fig. 2) is most likely caused by the inhibition of leaf area, CCI, RWC, fluorescence parameters and water-splitting complex efficiency of safflower plants (Table 1; Fig. 1) involved in both growth and photosynthetic activities. In a recent study, Sharma et al. [54] found that salicylic acid can preserve water content of plant cells by stimulating biosynthesis of osmolytes such as proline, glycine betaine, soluble sugars, polyamines and polyphenols. Farhangi-Abriz et al. [55] showed that foliar applications of salicylic acid and jasmonic acid elevate the endogenous content of these growth regulators in rapeseed plants under salt stress. Increasing endogenous content of these growth regulators in plant cells noticeably mitigates the salinity dependent oxidative and osmotic stresses that improve rapeseed growth. Increasing seed yield of safflower by salicylic acid and jasmonic acid treatments was the consequence of improvements of leaf area, CCI, leaf water content and photosystem II and water-splitting complex efficiencies of safflower leaves under salt stress, Therefore, stimulating photosystem II and water-splitting complex efficiencies by hormonal treatments, can more likely improve safflower performance and productivity under salt toxicity.

## 5 Conclusions and future perspectives

Salt stress reduced the efficiency of photosystem II, performance index for energy conservation from exciton to the reduction of PSI end acceptors and efficiency of the water-splitting complex in safflower leaves. The CCI, RWC, LA and seed yield of safflower were reduced as a consequence of salt toxicity. Foliar application of salicylic acid and jasmonic acid improved the variable chlorophyll fluorescence, efficiency of photosystem II, performance index for energy conservation from exciton to the reduction of PSI end acceptors and efficiency of the water-splitting complex by rising water content and energy required for the closure of reaction centers, redox state of primary Quinone in the time span from initial to maximum fluorescence. Salicylic acid and jasmonic acid increased the Quinone pool size of safflower leaves and enhanced the electron fluidity to the

photosystem II reaction centers. These improvements in the efficiency of photosystem II by salicylic acid and jasmonic acid treatments were consequently upgraded the physiological performance and seed yield of safflower under salt stress. Future studies could be focused on possible effects of other growth regulators on improving the efficiency of photosystem II and I under salt stress. Similar studies under other environmental stresses such as heavy metal toxicities can improve our knowledge about this subject.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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