Ameliorating Drought Stress Effects on Soybean Physiology and Yield by Hydrogen Peroxide

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Summary

Soybean is considered as an important legume because of its high content of protein and oil. However, it is sensitive to drought stress that was increasingly recorded recently. Plants respond to drought by several changes on the physiological and molecular levels and by endogenously changing the concentrations of certain substances, such as reactive oxygen species (ROS). An experiment was conducted in 2018 and 2019 to investigate the effects of drought stress and the possible effects of exogenously sprayed hydrogen peroxide ($H_2O_2$) at R1 stage on two soybean cultivars. Significant decreases in all studied traits were recorded as a result of drought stress. Noticeable enhancements in stomatal conductance, relative chlorophyll content, relative water content, leaf area index, plant height and the final seed yield of both cultivars when treated with $H_2O_2$ were also recorded. It could be concluded that $H_2O_2$ spraying can be a good strategy to alleviate presumable negative influence of drought.

Key words

g<sub>s</sub>, height, LAI, RWC, SPAD, yield
Introduction
Among seed legumes, soybean (Glycine max (L.) Merrill) has the greatest global area harvested representing the main source of relatively-cheap protein and vegetable oil (Mutava et al., 2015). Soybean is highly affected by many abiotic stresses, majorly drought stress (Fan et al., 2013) that intensively increased over the past decades, affecting the world’s food security (Vurukonda et al., 2016). Soybean is considered highly-sensitive to drought stress compared to other crops (Maleki et al., 2013) especially during certain periods of plant lifecycle (Liu et al., 2004). Drought stress decreases stomatal conductance, biomass, grain yield and its components (Ruppenthal et al., 2016). Drought also affects chlorophyll pigments and photosynthetic electron transport system. As such, production of reactive oxygen species (ROS) is induced (Zgalai et al., 2005) in higher concentrations (Shigeoka et al., 2002) resulting in cellular damage as a result of gene alteration, protein degradation and enzyme inactivation (Mahajan and Tuteja, 2005). High concentrations of ROS cause damages to the cells, yet low concentrations play the role of signaling molecules that can ease several processes like germination and growth (Dowling and Simmons, 2009). For example, it was reported that ROS play noticeable role in regulating stomatal closure in order to optimize water use efficiency (Wang and Song, 2008; Huang et al., 2009). Hydrogen peroxide (H$_2$O$_2$) is a compound that belongs to non-radical ROS (Matilla-Vázquez and Matilla, 2012). It regulates many physiological mechanisms, such as growth and development, under both normal and stressed conditions, playing a major role in activating various signal molecules in plants leading to induction of different mechanisms of tolerance (Wendehenne et al., 2004; Bright et al., 2006; Foyer and Noctor, 2009). Many reports have demonstrated that treating plants with suitable concentrations of H$_2$O$_2$ increases tolerance to abiotic stresses (Chao et al., 2009; He et al., 2009; Xu et al., 2010; Gondim et al., 2013; Hossain and Fujita, 2013). It was previously reported that treating seeds before sowing with H$_2$O$_2$ or applying it as a foliar spray can enhance abiotic stress tolerance in plants. For example, a stimulation in the germination was reported when seeds of Pseudotsuga menziesii, Sorghum nutans, Andropogon garudii, Panicum virgatum (Sarath et al., 2007) and Zinnia elegans (Ogawa and Iwabuchi, 2001) were pre-treated with H$_2$O$_2$. Similarly, enhanced germination rates were recorded in maize seeds pre-soaked in 140 mM of H$_2$O$_2$ (Ashraf et al., 2015), Jubany-Mari et al. (2009) reported that H$_2$O$_2$ is involved in the acclimation of Cistus albidus to summer drought. Ishibashi et al. (2011) concluded that spraying soybean plants with H$_2$O$_2$ resulted in better net photosynthesis ($P_{n}$) and that this application made the plants more tolerant to drought stress. Similar conclusion was also reported for melon plants (Ozaki et al., 2009) and for cucumber seedlings (Sun et al., 2016). Liu et al. (2010) reported improved osmotic stress resistance when two cucumber varieties were pre-treated with H$_2$O$_2$ as a result of the activation of antioxidant system. It was suggested that the mechanism by which plants exogenously-sprayed with H$_2$O$_2$ better tolerate stress could be by ROS-detoxification modification or by regulation of multi-pathways that respond to stress (Terzi et al., 2014; Hossain et al., 2015). Other authors reported that H$_2$O$_2$ alleviated the negative stress effects by either a regulated stomatal closure (Kolla et al., 2007; Quan et al., 2008; Wang and Song, 2008) or by promoting the biosynthesis of the oligosaccharide and, accordingly, maintaining the leaf water content (Ishibashi et al., 2011). Many efforts were made to exploit this characteristic in enhancing stress tolerance in plants (Jubany-Mari et al., 2009; Liu et al., 2010).

Although some experiments were conducted to investigate the effects of early exogenous H$_2$O$_2$ spraying on some physiological and molecular traits of some plant species, yet, to our knowledge, no report was introduced on the influence of the application of H$_2$O$_2$ at reproductive stages on soybean physiology and yield, especially in the study area where the soybean production is newly introduced. Therefore, our study aimed at revealing the probable positive effects of exogenously spraying H$_2$O$_2$ at R1 stage on both the physiology and the seed yield of two soybean cultivars.

Materials and Methods

Two soybean cultivars, 'Pannonia Kincse' and 'Boglár', were sown in Debrecen University’s experimental site (Látókép) (N, latitude 47° 33’, E, longitude 21° 27’) on April 23rd and 26th and were harvested on September 15th and 16th in 2018 and 2019, respectively. The soil type is calcareous chernozem. The precipitation and the average temperature during the vegetative period of the soybean plants are presented in Figure 1. The experimental design was split-plot with cultivars representing the main plots and irrigation treatments being the sub-plots. Three treatments were applied in three replications: fully-irrigated (FI) treatment, where irrigation was conveniently applied (100 mm in total) to reach water demands as recommended by the experimental site’s management (taking into account the precipitation amounts which were recorded as 271.2 mm and 275.9 mm in 2018 and 2019, respectively); drought-stressed treatment (counting only on precipitation) with the application of 1 mM of hydrogen peroxide (H$_2$O$_2$) as a foliar spray at R1 stage (Fehr and Caviness, 1977) (HP) and drought-stressed treatment with distilled water foliar spray at R1 stage (DW). Hydrogen peroxide and DW treatments received 1.5 liters of H$_2$O$_2$ and distilled water per plot, respectively, ensuring that the whole plant parts were completely covered by the sprayed liquid. The final number of plots was 18 (2 cultivars * 3 treatments * 3 replications), with a plot area of 9 m$^2$ (3 * 3 m). Each plot consisted of six rows.

The relative chlorophyll content (SPAD) was measured using SPAD-502Plus (Konica Minolta, Japan).

Figure 1. Precipitation (mm) and average temperature (°C) during the vegetative period of the soybean plants in 2018 and 2019.

The stomatal conductance (g) was measured using AP4 porometer (Delta- T Devices, UK). Leaf area index (LAI) values were recorded using SS1 – SunScan canopy analysis system (Delta-
To calculate the relative water content (RWC), ten fully-matured leaves (homogenous in size) were collected at 6.30 am and fresh weight (FW) of the leaf was measured immediately. Dry weight (DW) was determined via drying the sample at 80°C to constant weight (after 48 h), and turgid weight (TW) was obtained after floating the leaf in distilled water in a tray at 4°C for 48 h. RWC was calculated as \( \text{RWC}(\%) = (\text{FW} - \text{DW})/(\text{TW} - \text{DW}) \times 100\% \) (Weatherley, 1950). All traits were measured at R2 stage (1 - 2 weeks after \( \text{H}_2\text{O}_2 \) application).

Yield was estimated by manually harvesting the middle two rows of every plot at full maturity (R8) stage. The analysis of variance (ANOVA) was conducted to compare the means and to indicate the effect size of each treatment, and then Tukey post-hoc test was conducted to indicate the statistically-different means (IBM SPSS ver.25, USA Software).

### Results

#### Stomatal Conductance (g\(_s\))

In both cultivars, g\(_s\) was significantly higher when irrigation (FI) was applied. However, \( \text{H}_2\text{O}_2 \)-sprayed plots were significantly higher than drought-stressed treatments in terms of g\(_s\) value. Drought application reduced g\(_s\) by 51.6 and 47.7% compared to irrigated counterparts, whereas \( \text{H}_2\text{O}_2 \) spraying decreased the reduction ratio to 21.6 and 19.5% in ‘Boglár’ and ‘Pannonia Kincse’, respectively (Table 1). Correlation between g\(_s\) and irrigation treatment was highly significant (< 0.01) (Table 3), and the effect size of g\(_s\) changes in ‘Boglár’ and ‘Pannonia Kincse’, respectively. In other words, \( \text{H}_2\text{O}_2 \) application was responsible for 81.6 and 90.5% of g\(_s\) changes in ‘Boglár’ and ‘Pannonia Kincse’, respectively.

#### Relative Chlorophyll Content (SPAD)

In ‘Boglár’, drought significantly decreased SPAD value by 26.7% compared to the irrigated counterpart, whereas \( \text{H}_2\text{O}_2 \) spraying resulted in better SPAD than both FI and DW counterparts. In ‘Pannonia Kincse’, on the other hand, irrigation resulted in the highest SPAD value; it was significantly higher (by 22.4%) than drought-stressed counterpart. However, HP treatment enhanced this value (by 13.1%) compared to DW, without reaching the same level of FI treatment as in ‘Boglár’ (Table 1). The correlation with irrigation was significant (< 0.05) and highly significant (< 0.01) in ‘Boglár’ and ‘Pannonia Kincse’ cultivars, respectively (Table 3), and the effect size of \( \text{H}_2\text{O}_2 \) application was noticeably higher (85.7%) in ‘Boglár’ compared to ‘Pannonia Kincse’ (59.1%).

#### Relative Water Content (RWC)

In ‘Boglár’, drought significantly decreased RWC by 21.2% compared to the irrigated counterpart. However, \( \text{H}_2\text{O}_2 \)-sprayed treatment significantly increased RWC (by 17.3%) compared to drought-stressed treatment and had very close value to FI treatment. In ‘Pannonia Kincse’, applying \( \text{H}_2\text{O}_2 \) significantly increased RWC by 29.2% compared to the drought-stressed treatment; however, irrigation treatment had significantly higher RWC (by 8.3 and 39.9%) compared to HP and DW treatments, respectively (Table 1).

Application of \( \text{H}_2\text{O}_2 \) had a significant effect on RWC (by 95.9 and 97.3% in ‘Boglár’ and ‘Pannonia Kincse’, respectively) with a highly significant correlation coefficient (Table 3).

#### Leaf Area Index (LAI)

Both cultivars followed the same trend; LAI was significantly lower in DW treatment (by 13.0 and 17.5% in ‘Boglár’ and ‘Pannonia Kincse’, respectively) compared to FI counterpart. Hydrogen peroxide treatment resulted in the highest LAI in both cultivars; LAI was 21.3 and 28.8% higher compared to DW counterparts in ‘Boglár’ and ‘Pannonia Kincse’, respectively (Table 2).

Significant correlation was recorded between irrigation and LAI (Table 3). The effect of \( \text{H}_2\text{O}_2 \) application was also significant in both cultivars as well (with ratios of 92.8 and 95.1% in ‘Boglár’ and ‘Pannonia Kincse’, respectively).

#### Plant Height

Drought significantly reduced plant height in both cultivars compared to irrigated counterpart; the reduction ratio was 13.2 and 7.1% in ‘Boglár’ and ‘Pannonia Kincse’, respectively. Applying \( \text{H}_2\text{O}_2 \) significantly increased plant height in both cultivars; plant height was 3.6% less in ‘Boglár’, whereas it was only 0.2% less in ‘Pannonia Kincse’ compared to irrigated counterparts (Table 2).

Application of \( \text{H}_2\text{O}_2 \) had an effect size of 84.2 and 82.8% in ‘Boglár’ and ‘Pannonia Kincse’, respectively.

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**Table 1.** Stomatal conductance (g\(_s\)), relative chlorophyll content (SPAD) and relative water content (RWC) of soybean cultivars ‘Boglár’ and ‘Pannonia Kincse’ under three irrigation treatments; fully-irrigated (FI), drought-stressed with \( \text{H}_2\text{O}_2 \)-foliar spray (HP) and drought-stressed (DW) treatments.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Treatment</th>
<th>‘Boglár’</th>
<th>‘Pannonia Kincse’</th>
</tr>
</thead>
<tbody>
<tr>
<td>g(_s) (mmol m(^{-2})s(^{-1}))</td>
<td>DW</td>
<td>190.0(^a)</td>
<td>218.3(^a)</td>
</tr>
<tr>
<td>SPAD</td>
<td>HP</td>
<td>307.7(^b)</td>
<td>336.3(^b)</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td>392.7(^c)</td>
<td>417.7(^c)</td>
</tr>
<tr>
<td></td>
<td>DW</td>
<td>26.4(^a)</td>
<td>33.6(^a)</td>
</tr>
<tr>
<td>RWC (%)</td>
<td>HP</td>
<td>37.2(^a)</td>
<td>38.0(^a)</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td>36.0(^a)</td>
<td>43.3(^a)</td>
</tr>
<tr>
<td></td>
<td>DW</td>
<td>57.33(^b)</td>
<td>61.713(^b)</td>
</tr>
</tbody>
</table>

In each trait, the same letter indicates no significant differences at \( p \leq 0.05 \) level among the treatments within the same cultivar.
Table 2. Leaf area index (LAI), plant height and yield of soybean cultivars 'Boglár' and 'Pannonia Kincse' under three irrigation treatments: fully-irrigated (FI), drought-stressed with H₂O₂ foliar spray (HP) and drought-stressed (DW)  

<table>
<thead>
<tr>
<th>Trait</th>
<th>Treatment</th>
<th>Boglár</th>
<th>Pannonia Kincse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Height (cm)</td>
<td>DW</td>
<td>86.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>HP</td>
<td>100.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>101.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td>96.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>101.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>DW</td>
<td>3.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.7&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Yield (t ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>HP</td>
<td>4.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

In each trait, the same letter indicates no significant differences at p ≤ 0.05 level among the treatments within the same cultivar.

Yield

Irrigation resulted in the best yield in both cultivars; the yield significantly increased by 27.3 and 24.3% in irrigated treatment compared to drought-stressed counterpart in 'Boglár' and 'Pannonia Kincse', respectively. Spraying with H₂O₂ also increased the yield of both cultivars compared to drought-stressed treatment; the increase ratio was 21.2 and 13.5% in 'Boglár' and 'Pannonia Kincse', respectively (Table 2). The effect of H₂O₂ application was bigger (78.9%) in 'Pannonia Kincse' compared to 'Boglár' (72.1%). Correlation of irrigation with yield was highly significant in both cultivars (Table 3).

Table 3. Correlation coefficient of irrigation treatments with the studied traits

<table>
<thead>
<tr>
<th>Trait</th>
<th>Boglár</th>
<th>Pannonia Kincse</th>
</tr>
</thead>
<tbody>
<tr>
<td>gs</td>
<td>.959**</td>
<td>.975**</td>
</tr>
<tr>
<td>SPAD</td>
<td>.758*</td>
<td>.926**</td>
</tr>
<tr>
<td>RWC</td>
<td>.929**</td>
<td>.948**</td>
</tr>
<tr>
<td>LAI</td>
<td>.668*</td>
<td>.720*</td>
</tr>
<tr>
<td>Plant Height</td>
<td>.908**</td>
<td>.755*</td>
</tr>
<tr>
<td>Yield</td>
<td>.861**</td>
<td>.912**</td>
</tr>
</tbody>
</table>

* Correlation is significant at p ≤ 0.05 level (2-tailed).
** Correlation is significant at p ≤ 0.01 level (2-tailed).

Discussion

Drought reduced gs in both cultivars as compared to irrigated counterparts, whereas H₂O₂ application could measurably alleviate gs. Drought stress induces stomatal closure, limits gas exchange and photosynthesis (Yordanov et al., 2000). Ohashi et al. (2006) reported that stomatal conductance of soybean plants significantly decreased under drought stress conditions; similar result was reported by Zhang et al. (2016); a 98.8% decrease in gs under drought. They concluded that this reduction in gs was a result of the reduced ratio of open stomata and stomatal aperture size in the plants subjected to drought stress. Hao et al. (2013) reported a significant reduction in stomatal conductance from 0.25 to 0.10 mol H₂O m<sup>-2</sup> s<sup>-1</sup> as a result of drought applied on soybean plants. Mathobo et al. (2017) justified the reduction in gs in their experiment on dry beans (Phaseolus vulgaris) by the prevention of CO₂ from entering the leaf by stomatal closure. Similarly, Rosales et al. (2012) reported a 70% reduction of gs after 22 days of drought stress application. Tang et al. (2017) concluded that polyethylene glycol (PEG) induced water stress on soybean significantly reduced gs by 73%. Ishibashi et al. (2011) compared gs of two groups of soybean seedlings under drought stress conditions. One group was sprayed with H₂O₂ and the other group with distilled water (DW). They reported that gs was significantly higher in H₂O₂-treated plants than in DW-treated plants. After two days of spraying, gs levels in H₂O₂-treated and DW-treated plants were 508 and 323 mmol m<sup>-2</sup> s<sup>-1</sup>, respectively. They concluded that H₂O₂ spraying reduced stomatal closure caused by drought stress; i.e. H₂O₂ treatment reduced soybean sensitivity to drought stress. In experiment of Terzi et al. (2014) maize leaves pretreated with 10 mM H₂O₂ significantly enhanced gs (by approximately 50%) as compared to drought-stressed leaves. They concluded that spraying leaves with H₂O₂ can reduce water loss under drought stress conditions by increasing the concentrations of metabolites that are involved in osmotic adjustment (such as proline, polyamines and soluble sugars). Other ROS species were also reported to have a role in alleviating drought stress. Razmi et al. (2017) reported that water stress reduced stomatal conductance of three soybean leaves compared to well-watered counterparts, and foliar spray of 0.4 mM salicylic acid (SA) significantly reversed drought induced stomatal closure and increased it.

Drought resulted in lower SPAD values compared to irrigated counterparts of both cultivars, whereas H₂O₂ application enhanced this value; it even increased SPAD to a level more than did irrigation in 'Boglár', but not in 'Pannonia Kincse'. Similarly, Ergo et al. (2018) reported that SPAD values significantly decreased from 35.5 to 22.4 under drought stress applied 30 days after R5.5 stage. Chlorophylls are the main pigments of absorbing, transporting and converting light energy, and their content is a major parameter that indicates photosynthetic performance (Liu et al., 2007). Subjecting plants to drought stress resulted in a significant decline in chl<sub>a+b</sub> (from 19.5 to 13.0 mg g<sup>-1</sup> DW), indicating a reduced capacity of absorbing and converting light energy (Tang et al., 2017). Similarly, Dong et al. (2015) concluded that light absorption was reduced by drought stress that resulted in changing both leaf area index and leaf chlorophyll content. Both chlorophylls a and b were reduced under drought stress (Faroog et al., 2010). Other papers also reported that chlorophyll content was decreased because of drought in soybean (Makbul et
Drought decreased plant height in both cultivars, and 
\( \text{H}_2\text{O}_2 \) application could ameliorate drought's effects and result in enhanced plant height, reaching a very close level of irrigated counterparts, especially in 'Pannonia Kincse' cultivar. Many previous papers reported a reduction in plant height under drought stress conditions (e.g. Atti et al., 2004; Demirtas et al., 2010; Hao et al., 2013; Mak et al., 2014). Moreover, Garcia et al. (2010) reported a significant difference in plant height of drought-stressed soybean genotypes compared to control counterparts. They also reported the different examined genotypes to be significantly different in plant height, which was demonstrated later by Hossain et al. (2014) who studied the effect of drought stress on the plant height of three soybean genotypes, one drought-susceptible and two drought-tolerant genotypes; they reported plant height to be shortened as a result of drought stress for the three genotypes. However, the drought-susceptible genotype had a 44.3% of height of the control plants, whereas it was 56.7% and 59.1% for the two drought-tolerant genotypes. The authors attributed this reduction to a drought tolerance mechanism, as cell swells, cell wall and synthesis enzymes reduces, consequently, growth and plant height decreases (Levitt, 1980; Austin, 1989).

An evaluation of the effects of 
\( \text{H}_2\text{O}_2 \) on leaf chlorophyll content during adventitious rooting under drought conditions showed that drought stress resulted in a decline in chlorophyll content after 72 h of its application, producing a 39.1% decrease in the chlorophyll \( a \) content compared to control. However, applying exogenous \( \text{H}_2\text{O}_2 \) retarded chlorophyll degradation, especially chlorophyll \( a \) (Liao et al., 2012). Maize leaves had higher levels of both chlorophylls \( a \) and \( b \) when seeds were soaked in 140 mM \( \text{H}_2\text{O}_2 \) before sowing (Ashraf et al., 2015). Enhanced chlorophyll levels induced by hydrogen peroxide treatment were justified by \( \text{H}_2\text{O}_2 \)-stimulated antioxidant enzyme activities (Azevedo Neto et al., 2005; Gao et al., 2010). Razmi et al. (2017) reported that drought significantly reduced both chlorophyll \( a \) and \( b \) contents in soybean leaves. However, significant increases (by 15% in chlorophyll \( a \) and 19% in chlorophyll \( b \)) resulted from foliar application of 0.4 mM of salicylic acid (\( \text{SA} \)) compared to control treatment (no \( \text{SA} \)).

Application of \( \text{H}_2\text{O}_2 \) significantly increased RWC in both cultivars compared to drought-stressed counterparts, and irrigation further enhanced this trait. It was previously reported that drought stress reduced RWC of soybean leaves (Razmi et al., 2017). Ishibashi et al. (2011) reported that RWC in \( \text{H}_2\text{O}_2 \)-treated and DW-treated (control, treated with distilled water only) plants was 60 and 40%, respectively after four days of drought stress application, and RWC was also higher in \( \text{H}_2\text{O}_2 \)-treated plants than in DW-treated plants after six days of drought stress imposition. Authors concluded that \( \text{H}_2\text{O}_2 \) spraying enabled the leaves to maintain high levels of RWC by regulating the osmolality in the leaves, consequently ameliorating the negative effects of drought stress. Similar results on cucumber seedlings were reported later by Sun et al. (2016). Application of \( \text{SA} \) on common bean improved RWC under drought stress conditions (Sadeghipour and Aghaei, 2012).

Irrigation significantly increased LAI in both cultivars compared to drought-stressed counterparts. Furthermore, \( \text{H}_2\text{O}_2 \) application could further increase LAI in both cultivars, drought stress decreases LAI (Liu et al., 2008). Ashraf et al. (2015) reported that seeds soaked in 20, 80, 100 and 140 mM of \( \text{H}_2\text{O}_2 \) later formed plants with higher leaf area under drought stress conditions compared to non-treated seeds. Using (\( \text{SA} \)), other authors concluded that treatments with \( \text{SA} \) could improve LAI in different plants including soybean (Kuchlan et al., 2017; Razmi et al., 2017), strawberry (Ghaderi et al., 2015) and lemongrass (Idrees et al., 2010). This was attributed to increased accumulation of certain proteins (such as proline) and soluble sugars that, in part, enhances cell turgor pressure (Razmi et al., 2017).

Yield was significantly reduced by drought in both cultivars, whereas \( \text{H}_2\text{O}_2 \) application measurably recovered yield. The recovery was significant in 'Boglár' cultivar. Soybean seed yield decreases under drought stress conditions (Karam et al., 2005; Dogan et al., 2007; Bajaj et al., 2008; Sincik et al., 2008; Gurcek et al., 2009; Sadeghipour and Abbasi, 2012; Li et al., 2013). It was also reported that genotypes significantly differ in yield production under drought stress conditions (Bellaloui and Mengistu, 2008; Maleki et al., 2013; He et al., 2017). Explanations for under drought stress conditions were that drought stress shortens the seed-filling period what explains yield decrease (Smiciklas et al., 1992). Other authors suggested that it is due to the reduction of seeds number (Dornbos et al., 1989), seeds weight (Samarah et al., 2006; Demirtas et al., 2010) and pod number per plant (Atti et al., 2004; Khatun et al., 2016). However, exogenous application of \( \text{H}_2\text{O}_2 \) improved plant biomass in wheat under drought stress (He et al., 2009), and \( \text{SA} \) application improved the grain yield of common bean under drought stress conditions (Sadeghipour and Aghaei, 2012). Horvath et al. (2007) reported that \( \text{SA} \) can enhance metabolite stream to the developing grains which reduces the abortion rate that, in part, can significantly increase pod number per plant and seed number pod \(^{-1} \) in soybean (Khatun et al., 2016). Not only yield, but also yield components (number of grains m\(^{-2} \), pods plant \(^{-1} \)) were enhanced with the application of \( \text{SA} \) on soybean leaves under drought stress conditions (Razmi et al., 2017). The authors attributed the increase of grain yield due to \( \text{SA} \) application, improved RWC, reduced restrictions of stomatal conductance and the enhanced biosynthesis of photosynthetic pigments in the leaves.
Conclusions

Drought stress negatively affects soybean morphology, physiology and, consequently, the final seed yield; it resulted in significant reductions in all studied traits. Treating drought-stressed soybean plants with 1 mM of H$_2$O$_2$ could alleviate that negative influence and enhance all studied traits. Its effect was more noticeable on the leaf area index LAI as H$_2$O$_2$-sprayed plants had higher LAI values than both drought-stressed and fully-irrigated counterparts. The effect was also noticeable on the relative water content RWC of both cultivars. The correlation of irrigation with the studied traits was also significant.

Acknowledgments

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References

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