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Synthesis and characterization of naphthalene-sulfonate hybrid structures and their effects on abiotic stress indicators in maize

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Research Article

ABSTRACT

As a result of global warming and environmental pollution resulting from human activities such as industrialization, CO_2 emissions, and mining, plants are exposed to more and more abiotic stress types day by day. As a natural consequence of this situation, yield losses and economic problems occur in agricultural plants. To contribute to the solution of these problems, firstly, ıt was present a simple synthetic strategy involving naphthalene-sulfonate hybrid derivatives mediated by triethylamine. It successfully obtained a sequence of four designed molecules. Biologıcal evaluation of hydrogen peroxide (H_2O_2) and thiobarbituric acid-reactive substances (TBARS) levels were measured in maize seedlings under abiotic stress for naphthalene-sulfonate hybrid constructions. It was observed that the **3a**, **3b**, **3c**, and **3d** derivatives reached the lowest H_2O_2 content at 0.5 mM, 0.75 mM, 0.25, and 0.25 mM concentrations, respectively. For all 3a, 3b, 3c, and 3d derivatives, the TBARS content was the lowest at concentrations between 0.25 mM and 0.5 mM, and there was no statistical difference between the two pre-treatments. In light of the findings, it was observed that all of the **3a**, **3b**, **3c,** and **3d** derivatives were effective at different levels in alleviating the adverse effects of abiotic stresses on plants. However, 0.25 mM concentration of the **3c** derivative was determined to be the most effective in reducing both H_2O_2 and TBARS levels in maize seedlings under stress.

Key Words: Oxidative stress, naphthalene derivatives, sulfonate derivatives, H_2O_2, TBARS

Naftalin-sülfonat hibrit yapılarının sentezi, karakterizasyonu ve mısırda abiyotik stres göstergelerine etkileri

ÖZ

Küresel ısınma ve sanayileşme, CO_2 emisyonları, madencilik gibi insan faaliyetlerinden kaynaklanan çevre kirliliği sonucunda bitkiler her geçen gün daha fazla abiyotik stres türlerine maruz kalmaktadır. Bu durumun doğal bir sonucu olarak da tarımsal bitkilerde verim kayıpları ve ekonomik sorunlar ortaya çıkmaktadır. Bu problemlerin çözümüne katkı sağlamak için öncelikle trietilamin aracılı naftalin-sülfonat hibrit türevlerini içeren basit bir sentez stratejisi sunulmuştur. Başarıyla tasarlanmış dört molekül dizisi elde edildi. Naftalin-sülfonat hibrit yapıları için abiyotik stres altındaki mısır fidelerinde hidrojen peroksit (H_2O_2) ve tiyobarbitürik asit-reaktif maddesinin (TBARS) düzeyleri ölçülmüştür. **3a, 3b, 3c** ve **3d** türevlerinin sırasıyla 0,5 mM, 0,75 mM, 0,25 ve 0,25 mM konsantrasyonlarında en düşük H_2O_2 içeriğine ulaştığı gözlendi. **3a, 3b, 3c** ve **3d** türevleri için TBARS içeriği, 0,25 mM ile 0,5 mM arasındaki konsantrasyonlarda en düşük seviyedeydi ve iki uygulama arasında istatistiksel bir fark yoktu. Elde edilen bulgular ışığında **3a, 3b, 3c** ve **3d** türevlerinin tamamının bitkiler üzerindeki abiyotik streslerin olumsuz etkilerini azaltmada farklı düzeylerde etkili olduğu görülmüştür. Ancak stres altındaki mısır fidelerinde hem H_2O_2 hem de TBARS düzeylerini düşürmede **3c** türevinin 0,25 mM konsantrasyonunun en etkili olduğu belirlenmiştir.

Anahtar Kelimeler: Oksidatif stres, naftalin türevleri, sülfonat türevleri, H_2O_2, TBARS

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1. Introduction

Plants grown in their natural ecosystems can be exposed to a single stress or different stress combinations from germination to death (Hussain et al., 2019; Handayani and Watanabe, 2020). There are many studies aiming to increase the tolerance of plants against the adverse effects of abiotic stresses that cause yield losses by exogenous applications of naturally synthesized substances such as ascorbate (El-Beltagi et al., 2022), proline (Ghosh et al., 2022), hydrogen peroxide and salicylate (Sohag et al., 2020), nitric oxide (Liu et al., 2015), gallic acid (Yetişsin and Kurt, 2020), glutathione (Cai et al., 2011), α-tocopherol (Shah et al., 2021), melatonin (Li et al., 2016), and ABA (Guo et al., 2012), which have important functions in the metabolism of living things. However, the possibilities of use of newly synthesized derivatives in many areas related to humans, from cancer (Nagaraju et al. 2019) to enzyme inhibition (Anwar et al., 2020), from antibiotics (Singh et al., 2019) to antioxidants (Shirinzadeh et al., 2020), are being investigated, studies to increase the tolerance of these derivatives to abiotic stresses of plants are limited. The exogenous application of various stimulating metabolites that increase stress tolerance to plants under abiotic stresses is preferred as an efficient, effective, and inexpensive method (He et al., 2009; Shaddad, 2010).

Also, naphthalene derivatives are an aromatic conjugated system that has been extensively investigated for various applications such as anticancer, antiviral, antituberculosis, antidiabetic, and anti-neurodegenerative (Makar et al., 2019). Because of these pharmacological properties, studies on synthesizing modified naphthalene-based derivatives have become the focus of attention. within the scope of these studies, the anticancer properties of the chalcone derivatives containing naphthaldehyde were studied by Lim et al. (2020). In particular, it has been shown that substituents such as hydroxyl, methoxy, prenyl and chloro in the structure can increase the anticancer activity (Lim et al., 2020). Antimicrobial activities of the containing naphthalene structure were investigated by various studies (Sivasankari, 2018; Eltayeb et al., 2020; Evren et al., 2020).

In addition, studies with sulfonate derivatives have attracted attention recently (Korkmaz et al., 2022[a]; Korkmaz, 2022; Korkmaz and Bursal, 2022[a]; Korkmaz and Bursal 2022[b]; Korkmaz and Bursal 2022[c]). Recently, enzyme inhibition of compounds containing the naphthalene-sulfonate structure has been studied (Korkmaz et al., 2022[b]). In this study, naphthalene-sulfonate structures (**3a**, **3b**, **3c**, and **3d**) were synthesized and it was evaluated whether these synthesized derivatives have tolerance-increasing potential in plants under abiotic stress.

2. Material and Methods

2.1 Equipment and tools

N, N-Dimethylformamide (DMF) was purified in a vacuum on 4A molecular sieves. Reagents and solvents were purchased from Sigma-Aldrich and used without purification. ^{1}H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded on a Bruker DRX-400 high performance digital FT-NMR spectrometer. The melting points of the compounds were determined with the ELECTRO THERMAL-IA 9100 instrument. The seeds of 523 varieties of maize (*Zea mays* L.) were provided by Sakarya Maize Research Institute. Seeds were grown in soil-filled pots in a plant growth chamber at 25 °C, 65% RH, 8/16 h dark/light and a photon intensity of 400 µmol m^{-2} s^{-1}. Polyethylene Glycol (PEG_{6000}) was used to induce stress in maize seedlings. Determination of H_2O_2 and TBARS amounts in leaves was made with a UV-Vis spectrophotometer (Thermo Scientific).

2.2 Synthesis of the naphthalen-sülfonate hybrid

In a 100 mL flask, 1-hydroxy-1-naphthaldehyde (1.0 mmol) was dissolved with 2.5 mL of DMF. Triethylamine (TEA) (1.3 mmol) was added to the flask. The reaction vessel was immersed in an ice bath. The corresponding sulfonyl chloride (1.0 mmol) was added slowly over 1 min. The reaction was controlled by Thin Layer Chromatography (TLC). After 75 minutes, the reaction vessel was poured into 15 mL of water. The resulting solid was filtered off with vacuum suction. The product was dried in a desiccator. Crystallization was carried out in a mixture of benzene:n-hexane (1:4).

2.2.1 Naphthalen-1-yl 4-bromobenzenesulfonate (3a)

m.p 103-105 °C; Mol. wt: 361.96; Cream powder (benzene-hexane (1:4); (Yield 51 %); ^{1}H NMR (400 MHz, $CDCl_3$), (ppm): 7.96-7.73 (m, 5H, Ar H), 7.71-7.61 (m, 2H, Ar H), 7.58-7.37 (m, 3H, Ar H), 7.32-7.20 (m, 1H, Ar H); ^{13}C NMR (100 MHz, $CDCl_3$), (ppm): 145.5 (Ar-**C)**, 134.7 (Ar-**C)**, 132.5 (2 units of Ar-**C**), 129.9 (2 units of Ar-**C**), 129.8 (Ar-**C)**, 127.4 (Ar-**C)**, 127.4 (Ar-**C)**, 127.07 (Ar-**C)**, 127.03 (Ar-**C)**, 126.9 (Ar-**C)**, 126.8 (Ar-**C)**, 125.1 (Ar-**C)**, 121.5 (Ar-**C)**, 118.4 (Ar-**C)**; HRMS (ESI) m/z: calculated for $C_{16}H_{11}BrO_3S$ $[M+Na]^+$= 384.96123 found 384.9508.

2.2.2 Naphthalen-1-yl 2,5-dichlorobenzenesulfonate (3b)

m.p 82-84 °C; Mol. wt: 351.97; Cream powder (benzene-hexane (1:4); (Yield 50 %); ^{1}H NMR (400 MHz, $CDCl_3$), (ppm): 8.22-8.12 (d, J=8.9 Hz, 1H, Ar H), 8.06-7.99 (s, 1H, Ar H), 7.92-7.85 (m, 1H, Ar H), 7.83-7.77 (d, J=8.2 Hz, 1H, Ar H), 7.64-7.52 (dd, J=11.2, 7.6 Hz, 4H, Ar H), 7.43-7.35, (t, J=7.9 Hz, 1H, Ar H), 7.24-7.17 (d, J=7.6 Hz, 1H, Ar H); ^{13}C NMR (100 MHz, $CDCl_3$), (ppm): 145.5 (Ar-**C)**, 135.5 (Ar-**C)**, 135.0 (Ar-**C)**, 134.8 (Ar-**C)**, 133.3 (Ar-**C)**, 131.8 (Ar-**C)**, 131.7 (Ar-**C)**, 127.8 (Ar-**C)**, 127.6 (Ar-**C)**, 127.2 (Ar-**C)**, 127.1 (Ar-**C)**, 127.0 (Ar-**C)**, 125.0 (2 units of Ar-**C**), 121.7 (Ar-**C)**, 117.9 (Ar-**C)**; HRMS (ESI) m/z: calculated for $C_{16}H_{10}Cl_2O_3S$ $[M+Na]^+$= 374.97277 found 374.9619.

2.2.3 Naphthalen-1-yl 2,4,6-trimethylbenzenesulfonate (3c)

m.p 109-110 °C; Mol. wt: 326.09; Cream powder (benzene-hexane (1:4); (Yield 54 %); ^{1}H NMR (400 MHz, $CDCl_3$), (ppm): 8.20-8.12 (m, 1H, Ar H), 7.89-7.83 (m, 1H, Ar H), 7.79-7.72 (d, J=8.2 Hz, 1H, Ar H), 7.59-7.52 (m, 2H, Ar H), 7.34-7.27 (m, 1H, Ar H), 7.09-7.01 (s, 2H, Ar H), 6.90-6.84 (d, J=7.6 Hz, 1H, Ar H), 2.62 (s, 6H, 2 units of Ar-C**H**$_3$), 2.37 (s, 3H, Ar-C**H**$_3$); ^{13}C NMR (100 MHz, $CDCl_3$), (ppm): 145.9 (Ar-**C)**, 143.9 (Ar-**C)**,

140.37 (Ar-**C**), 134.8 (Ar-**C**), 131.9 (2 units of Ar-**C**), 131.4 (Ar-**C**), 127.87 (Ar-**C**), 127.85 (Ar-**C**), 127.6 (Ar-**C**), 126.9 (Ar-**C**), 126.8 (2 units of Ar-**C**), 125.0 (Ar-**C**), 122.2 (Ar-**C**), 117.4 (Ar-**C**), 22.8, (2 units of Ar-**C**H_3), 21.1 (Ar-**C**H_3); HRMS (ESI) m/z: calculated for $C_{19}H_{18}O_3S$ $[M+Na]^+$= 349.09767 found 349.0869.

2.2.4 Naphthalen-1-yl naphthalene-2-sulfonate (3d)

m.p 101-103 °C; Mol. wt: 334.06; Cream powder (benzene-hexane (1:4); (Yield 56 %); ^{1}H NMR (400 MHz, $CDCl_3$), (ppm): 8.54-8.46 (s, 1H, Ar H), 8.03-7.90 (m, 5H, Ar H), 7.85-7.80 (d, J=8.1 Hz, 1H, Ar H), 7.77-7.60 (m, 3H, Ar H), 7.50-7.31 (m, 3H, Ar H), 7.23-7.17 (d, J=7.6 Hz, 1H, Ar H); ^{13}C NMR (100 MHz, $CDCl_3$), (ppm): 145.8 (Ar-**C**), 135.4 (Ar-**C**), 134.7 (Ar-**C**), 132.6 (Ar-**C**), 131.8 (Ar-**C**), 130.4 (Ar-**C**), 129.6 (2 units of Ar-**C**), 129.4 (Ar-**C**), 128.0 (Ar-**C**), 127.8 (Ar-**C**), 127.7 (Ar-**C**), 127.3 (Ar-**C**), 127.2 (Ar-**C**), 126.7 (2 units of Ar-**C**), 125.1 (Ar-**C**), 122.9 (Ar-**C**), 121.7 (Ar-**C**), 118.3 (Ar-**C**); HRMS (ESI) m/z: calculated for $C_{20}H_{14}O_3S$ $[M+Na]^+$= 357.06637 found 357.0557.

2.3 Experimental design

The seeds grown in soil-filled pots were grown to the four-leaf stage for approximately 28 days in the plant growth chamber and irrigated with 200 mL of tap water three times a week. After cutting all shoots, they were kept in tubes containing distilled water for 1 hour. There were eight different treatment groups for each Naftalene-Sulfonate Hybrid Structure (**3a, 3b, 3c,** and **3d**) synthesized in the experiment: (1) Control, 6-h pre-treatment with DW, followed by 12-h treatment with 5% PEG (m/v) (2) 6-h pre-treatment with 0.01 mM (m/v), followed by 12-h treatment with 5% PEG (m/v) (3) 6-h pre-treatment with 0.1 mM (m/v), followed by 12-h treatment with 5% PEG (m/v), (4) 6-h pre-treatment with 0.25 mM (m/v), followed by 12-h treatment with 5% PEG (m/v), (5) 6-h pre-treatment with 0.5 mM (m/v), followed by 12-h treatment with 5% PEG (m/v), (6) 6-h pre-treatment with 0.75 mM (m/v), followed by 12-h treatment with 5% PEG (m/v), (7) 6-h pre-treatment with 0.1 mM (m/v), followed by 12-h treatment with 5% PEG (m/v), (8) 6-h pre-treatment with 5 mM (m/v), followed by 12-h treatment with 5% PEG (m/v). After 18 hours, the samples were run through liquid nitrogen and stored at -20 °C for analysis of H_2O_2 and TBARS contents in the leaves of maize seedlings. All experiments were performed in triplicate.

2.4 Determination of hydrogen peroxide content

Velikova et al. (2000) H_2O_2 levels were determined by the measurements made. The homogenate prepared with 0.1 g leaf was homogenized with 0.01 g activated charcoal and 1.8 mL 0.1% TCA with a Qiagen tissue shredder. Then it was centrifuged for 15 minutes in a device set at +4°C, 15,000 g. After adding 1 M KI (1500 µL) and phosphate buffer (10mM, pH 7.0) in the supernatant, the absorbance reading of the mixture was taken at 390 nm.

2.5 Determination of thiobarbituric acid-reactive substances content

To determine the amount of TBARS according to Heath and Packer's (1968) method, 0.1 g maize leaves and 1.8 mL of 0.1% (m/v) trichloroacetic acid were homogenized together with a qiagen tissue lyser. The resulting homogenate was centrifuged at +4°C, 15,000 g for 5 minutes. Next, 1 mL of the supernatant was added to 4 mL of the filtered reaction solution containing 20% TCA and 0.5% thiobarbituric acid. The solution was left in an incubator set at 95°C for 30 minutes for the reaction to occur. The TBARS level was recorded with a UV-visible spectrophotometer (Thermo Scientific) making use of the difference in absorbance at 532 and 600 nm.

2.6 Statistical analysis

Numerical data were analyzed with the help of SPSS (v.17, SPSS Inc., USA). Statistical significance was expressed using Duncan's multiple range test. Statistical significance was stated as $P < 0.05$ in all analyzes.

3. Results

3.1 Synthesis and characterization

At the beginning of our study, 2-naphthyl, 2,5-dichlorophenyl, 2,4,6-trimethylphenyl, and 4-bromophenyl sulfonate derivatives with a naphthalene scaffold motif were modeled. Their backbones are decorated with electron-withdrawing and electron-releasing substituents. Similar synthetic protocols (Korkmaz and Bursal, 2022[a]) have been applied by our group before. 1-Naphthalene-sulfonate derivatives were applied at 1.3 TEA/substrate ratio, 75 minutes, and 0-5 °C (Figure 1).

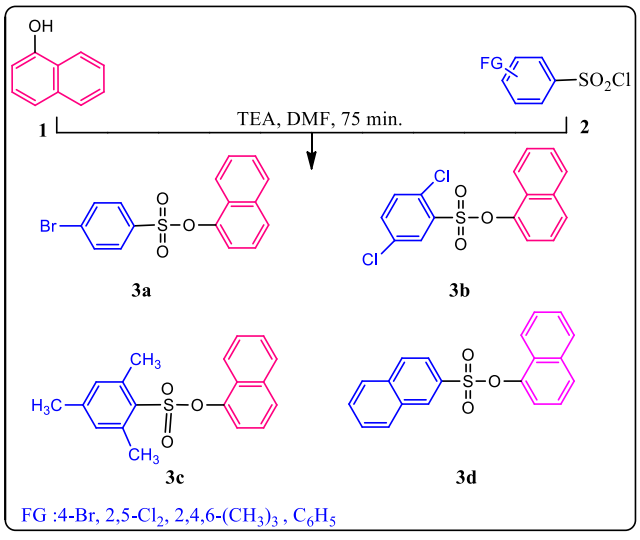

Fig. 1. The synthesis of the naphthalene-sulfonate hybrid structure

Naphthalene-sulfonate hybrid structures were purified and characterized using ^{1}H NMR, ^{13}C NMR, and HRMS spectroscopic methods. The observed proton number of compound 3d, 14 aromatics, is consistent with the expected

number of protons in the 1H NMR spectrum. Compound 3a has 7.77-7.60 (m, 3H, ArH), 7.50-7.31 (m, 3H, ArH), and 8.03-7.90 (m, 5H, ArH), centered three multiplets (Table 1). Additionally, doublet signals at 7.85-7.80 (d, J=8.1 Hz, 1H, ArH) and 7.23-7.17 (d, J=7.6 Hz, 1H, ArH) were observed. Also observed as a single signal at 8.54-8.46 ppm (s, 1H, ArH) of compound 3d.

Table 1. ^{1}H NMR spectra data of compounds 3a-d

Compounds	Chemical shift δ (ppm)	Peak types	J (Hertz)	Number of hydrogen	Types of the proton
3a	7.96-7.73	Multiplet	-	5H	Ar-**H**
	7.71-7.61	Multiplet	-	2H	Ar-**H**
	7.58-7.37	Multiplet	-	3H	Ar-**H**
	7.32-7.20	Multiplet	-	1H	Ar-**H**
3b	8.22-8.12	Doublet	8.9 Hz	1H	Ar-**H**
	8.06-7.99	Singlet	-	1H	Ar-**H**
	7.92-7.85	Multiplet	-	1H	Ar-**H**
	7.83-7.77	Doublet	8.2 Hz	1H	Ar-**H**
	7.64-7.52	Doublet of doublet	11.2 Hz, 7.6 Hz	4H	Ar-**H**
	7.43-7.35	Triplet	7.9 Hz	1H	Ar-**H**
	7.24-7.17	Doublet	7.6 Hz	1H	Ar-**H**
3c	8.20-8.12	Multiplet	-	1H	Ar-**H**
	7.89-7.83	Multiplet	-	1H	Ar-**H**
	7.79-7.72	Doublet	8.2 Hz	1H	Ar-**H**
	7.59-7.52	Multiplet	-	2H	Ar-**H**
	7.34-7.27	Multiplet	-	1H	Ar-**H**
	7.09-7.01	Singlet	-	2H	Ar-**H**
	6.90-6.84	Doublet	7.6 Hz	1H	Ar-**H**
	2.62	Singlet	-	6H	2 units of Ar-**H$_3$**
	2.37	Singlet	-	3H	Ar-**H$_3$**
3d	8.54-8.46	Singlet	-	1H	Ar-**H**
	8.03-7.90	Multiplet	-	5H	Ar-**H**
	7.85-7.80	Doublet	8.1 Hz	1H	Ar-**H**
	7.77-7.60	Multiplet	-	3H	Ar-**H**
	7.50-7.31	Multiplet	-	3H	Ar-**H**
	7.23-7.17	Doublet	7.6 Hz	1H	Ar-**H**

=coupling constant in hertz.

Similarly, proton signals of compound 3b in the aromatic region were observed at 8.22-8.12 (d, J=8.9 Hz, 1H, ArH), 8.06-7.99 (s, 1H, ArH), 7.92-7 .85 (m, 1H, ArH), 7.83-7.77 (d, J=8.2 Hz, 1H, ArH), 7.64-7.52 (dd, J=11.2, 7, 6 Hz, 4H, ArH), 7.43-7.35, (t, J=7.9) Hz, 1H, ArH), and 7.24-7.17 (d, J=7.6 Hz, 1H, ArH).

It was observed that the aromatic expected proton numbers of compound 3c were similarly consistent with the observed proton numbers (8.20-8.12 (m, 1H, Ar H), 7.89-7.83 (m, 1H, Ar H), 7.79-7.72 (d, J= 8.2 Hz, 1H, Ar H), 7.59-7.52 (m, 2H, Ar H), 7.34-7.27 (m, 1H, Ar H), 7.09-7.01 (s, 2H, Ar H), 6.90-6.84 (d , J=7.6 Hz, 1H, Ar H)). In addition, 2.62 (s, 6H, 2 units of Ar-CH3), and 2.37 (s, 3H, Ar-CH3) of the aliphatic proton peaks were observed to be compatible with the structure. In the other compound 3a, the proton peaks were observed to be congruent as expected (see supplemental data). All ^{13}C NMR signals of Compounds 3a-d were correctly determined as peaks concordant (see supplementary data). In addition, expected molecular peaks of Compounds as 3a-d HRMS masses [M+Na] values were observed. As a result, it was observed that pure-form 3a-d compounds were obtained according to spectrum analyzes (Figure 2).

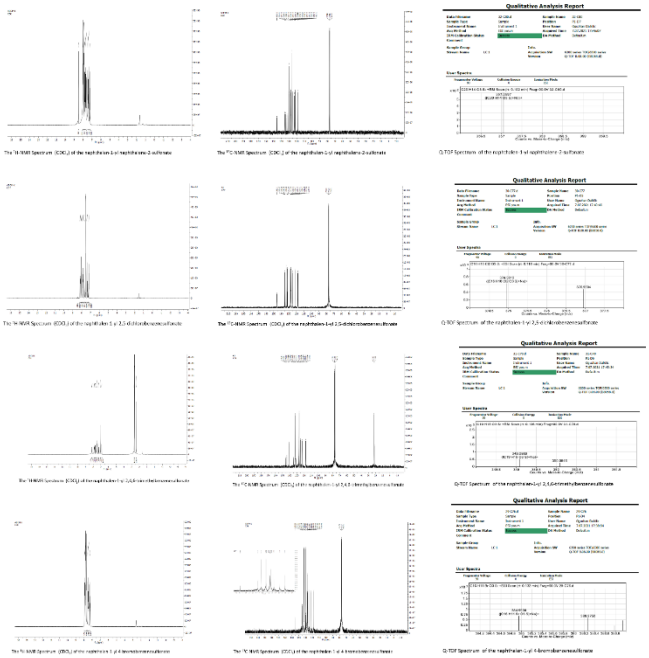

Fig. 2. The spectra of the naphthalene-sulfonate hybrid structure

3.2 Hydrogen peroxide and TBARS content

H_2O_2 levels, which have a critical importance in cell metabolism, were measured in maize seedlings under abiotic stress of different concentrations of **3a, 3b, 3c,** and **3d** derivatives synthesized in the present study. It was observed that the **3a, 3b, 3c,** and **3d** derivatives reached the lowest H_2O_2 content at 0.5 mM, 0.75 mM, 0.25, and 0.25 mM concentrations, respectively (Figure 3**)**.

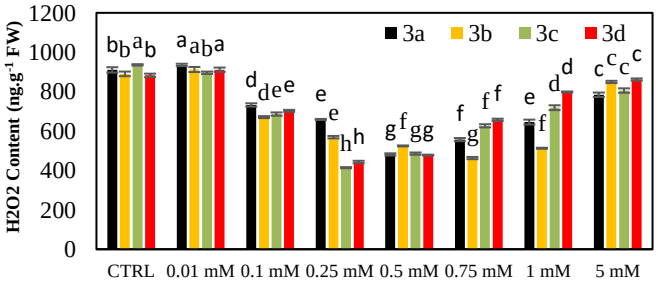

Fig. 3. Effect of pre-treatment of **3a, 3b, 3c,** and **3d** derivatives on H_2O_2 content in maize seedlings under abiotic stress

TBARS levels were measured in stressed maize seedlings of different concentrations of **3a, 3b, 3c,** and **3d** derivatives synthesized in this study (Figure 4**)**. For all **3a, 3b, 3c,** and **3d** derivatives, the TBARS content was the lowest at concentrations between 0.25 mM and 0.5 mM, and there was no statistical difference between the two pre-treatments. However, it was concluded that substance **3c** was the most effective of the four derivatives in reducing the level of TBARS.

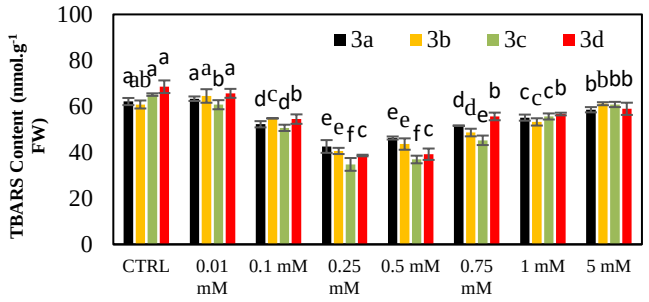

Fig. 4. Effect of pre-treatment of 3a, 3b, 3c, and 3d derivatives on TBARS content in maize seedlings under abiotic stress

4. Discussion

There are many sources that cause the formation of reactive oxygen species (ROS) in plants. The main production sites of ROS are the PSI and PSII reaction centers in chloroplast thylakoids. Apart from that, ROS formation occurs during mitochondrial respiration. In addition, peroxisomes and glycosomes participate in the generation of ROS during photorespiration and fatty acid oxidation (Gechev et al., 2006). On the other hand, it has been determined that NADPH oxidases, amine oxidases, and cell wall-associated peroxidases also contribute to the formation of ROS (Mittler, 2002). When plants are exposed to various abiotic stresses, the rate of formation of some ROS such as superoxide, hydrogen peroxide, hydroxyl radicals, and singlet oxygen increases. ROS production results in lipid peroxidation, which is the most important harmful effect of oxidative stress (Kadıoğlu et al., 2011). Superoxide is not very reactive on its own, it is effective by forming H_2O_2 and hydroxyl (•OH) radicals (Halliwell and Gutteridge, 1989). During the reaction of superoxide and hydrogen peroxide to form the hydroxyl radical (Haber-Weiss reaction), increased iron or other transition metals such as copper can further increase oxidative damage by accelerating these reactions (Fenton reaction) (Smirnoff, 1993). H_2O_2, which does not have radical properties since it does not contain unshared electrons in its structure, is accepted as a signal that activates plant defence mechanisms under biotic and abiotic stress (Prasad et al., 1994; Foyer et al., 1997). It was concluded that the 3c substance was the most effective among the four derivatives in reducing the H_2O_2 level. Pre-application of a sulfonate derivative oxime to maize seedlings under cadmium stress significantly reduced H_2O_2 content compared to cadmium application (Demiralay, 2022), alleviated the adverse effects of copper stress and decreased H_2O_2 level compared to copper application (Yetişsin and Kardeş, 2022).

Free radicals formed by the effect of abiotic stresses can initiate lipid peroxidation in plants (Thompson et al., 1987). Lipid peroxidation is determined by looking at the malondialdehyde (MDA) content formed as a result of oxidative stress (Irigoyen et al., 1992). The oxidation of lipids can increase two or three times under abiotic stresses (Pastori and Trippi, 1992). It is known that H_2O_2 causes lipid peroxidation and damage to cell membranes at high concentrations (Munne-Bosch et al., 2001). In a study, it was reported that lipid peroxidation caused by Cd in rice seedlings exposed to cadmium stress was eliminated by pre-application of glutathione or salicylic acid (Cao et al., 2013). In a study conducted by Demiralay (2022), a sulfonate-derived oxime pre-treatment under cadmium stress significantly reduced the TBARS content of maize seedlings compared to cadmium application. In another study, a sulfonate derivative alleviated the negative effects of copper stress and decreased MDA levels compared to copper application (Yetişsin and Kardeş, 2022).

5. Conclusion

As a result of global warming and environmental pollution resulting from human activities such as industrialization, CO_2 emissions, and mining, plants are exposed to more and more abiotic stress types day by day. As a natural consequence of this situation, yield losses and economic problems occur in agricultural plants. In the current study to perform the synthesis, characterization, and biological evaluation of naphthalene-sulfonate hybrid constructions, H_2O_2 and TBARS levels were measured in maize seedlings under abiotic stress after synthesis of sulfonate derivatives **3a**, **3b**, **3c,** and **3d**. In light of the findings, it was observed that all of the **3a**, **3b**, **3c,** and **3d** derivatives were effective at different levels in alleviating the adverse effects of abiotic stresses on plants. However, 0.25 mM concentration of the **3c** derivative was determined to be the most effective in reducing both H_2O_2 and TBARS levels in maize seedlings under stress. We recommend that the effects of the four derivatives synthesized in the present study, as well as the effects on plants, phytoremediation, phytomining, as well as the treatment of diseases, enzyme inhibition, and antibiotic effects should be investigated with more detailed studies.

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Declaration of Competing Interest

The authors declare no conflicts of interest.

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