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Effect of salicylic acid foliar application on growth, glandular hairs and essential oil yield in *Salvia officinalis* L. grown under zinc stress

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Abstract

Background: Generally, zinc (Zn) is an essential element and acts as a plant nutrient, but at higher concentrations, it is toxic. Higher uptake and translocation of Zn into plant tissues can cause serious physiological and biochemical alterations. However, salicylic acid (SA) is an endogenous regulator of growth and signaling molecule responsible for inducing environmental stress tolerance in plants. Therefore, spray application of SA could provide protection against several types of stresses such as Zn toxicity. In this context, the ameliorative effect of SA (0.5 and 1 mM) on *Salvia officinalis* L. under Zn stress (40 mM) was studied.

Results: Zn stress decreased growth, chlorophyll content, essential oil yield and peltate glandular trichome density. This toxicity can be linked to a strong accumulation of Zn in the various parts of the plant. In addition, Zn stress disturbed nutrients assimilation (K, P and Ca). However, spray of SA, particularly at 0.5 mM improved all parameters studied under both Zn and normal conditions. The positive effects of SA under Zn stress condition may be due to the decrease of Zn accumulation in different parts of the plant. This decrease was accompanied by an increase in K, P and Ca content. In addition, the histological study of *S. officinalis* leaves showed the presence of two types of glandular hairs, the peltate and capitate glands. In the leaves of stressed plants, we noticed the presence of glands with deformations in the form of pockets in the number of one or more as well as the glands with an oval form. On the other hand, all these abnormalities glands were not detected in stressed plants that were sprayed with SA. Therefore, the absence of these anomalies under the effect of SA showed the remedial effect of this growth regulator.

Conclusion: The findings of the present work suggest that spraying SA maybe useful for improving the plant growth in Zn-contaminated areas.

Keywords: *Salvia officinalis*, Zinc, Stress, Salicylic acid, Glandular hairs

Background

The essential oil of *S. officinalis* presented high industrial and medicinal application. According to a previous study of Es-sbihi et al. [1] and Hazzoumi et al. [6], the main components of *S. officinalis* essential oils was cis-thujone, trans-thujone, camphor, 1,8-cineole. In the fruits of *S. officinalis*, Taarit et al. [2] showed that viridiflorol,

1,8-cineole, thujone, camphor, borneol, caryophyllene, manool, thujone, pinene, linalool and caryophyllene oxide were the main compounds. The accumulation of essential oil is limited to specialized secretory structures, namely, glandular trichomes. Özkan [3], Werker et al. [4], Bisio et al. [5] and Hazzoumi et al. [6] subdivided these glands into peltate hairs and capitate hairs, based on morphological criteria, the secretory material, the mode and the moment of secretion.

However, the metallic elements nature and their concentrations in the soil have a strong impact on plant growth. Depending on their concentrations,

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these elements can play the benefic or toxic role. The toxicity is manifested by growth inhibition [7], nutritional imbalance [8] as well as by inactivation of biomolecules by blocking functional groups or by exchange of vital ions [9]. It can also lead to variations in the yield and composition of essential oil [9–11]. Chaney [12] and Marschner [13] reported that symptoms of zinc toxicity become visible at concentrations above 300 mg kg⁻¹ dry matter (DM), although some cultures exhibit symptoms of toxicity at concentrations below 100 mg kg⁻¹ DM. Macfarlane and Burchett [14] showed that Zn at 125 µg g⁻¹ in soil stimulated the growth parameters of *Avicennia marina* while it becomes toxic from 500 µg g⁻¹ in soil. On certain aromatic and medicinal plants, Macnicol and Beckett [15] have shown that doses of Zn between 200 and 400 µg g⁻¹ of soil had a harmful effect. Thus, Misra [8] showed a decrease in the menthol contents when the Zn concentration increased in the mint leaves. Exogenous applications of growth regulators have been shown to be effective in improving plant growth and yield production under Zn stress. Among these regulators, SA is an endogenous growth regulator [16] naturally found in plants in very small quantities. It is considered as a chemical messenger that plays an important role in biotic and abiotic stress tolerance. SA plays a role in the regulation of various physiological processes [17–19]. It also plays a role in seeds germination [20], fruit yield, glycolysis, flowering in thermogenic plants [21], ion capture and transport [22]. Under abiotic stress conditions, the remedial effect of SA on growth is linked to its role on the physiological parameters of the plant such as water content, nutrients assimilation, chlorophyll pigments biosynthesis, growth, regulation stomatal, inhibition of ethylene biosynthesis, regulation of hormonal profile and synthesis of protein kinase [23–26]. Our previous works [1] have shown the positive effect of SA on growth and on the accumulation of certain minerals (Ca, K and P) in *S. officinalis* grown under copper stress. Additionally, several studies showed that exogenous SA contributes to the regulation of the metabolic and physiological pathways of plants grown under heavy metals such as copper, cadmium, chromium and lead on plants [27–31]. On the other hand, the effect of SA on the toxicity of Zn was not studied. It is therefore relevant to examine the influence of SA on the regulation of various physiological and biochemical activities of *S. officinalis* L. grown under Zn stress.

In this context, we investigated the influence of SA on the toxic effects of Zn stress on *S. officinalis* L. on plant

growth, mineral uptake, essential oil yield and secretory glands.

Materials and methods

Plant material and growth conditions

Salvia officinalis L. cuttings were taken from the botanical garden of the Faculty of Science and Technology, Fez. Each cutting included at least two nodes. Culturing was carried out in plastic pots (3 kg capacity) containing 5 plants per pot and grown in a greenhouse.

Zn and SA treatments

After 30 days of plants transplantation (DAT), they were watered with 40 mM solution of ZnSO₄. This Zn dose was chosen because a preliminary experiment showed that from 40 mM Zn induced growth inhibition of *S. officinalis*. Zn was applied weekly over a 5-week period (200 ml per pot). SA (0.5 and 1 mM) was applied by foliar spray at 60 DAT (these SA concentrations were chosen based on a preliminary screening experience). Three SA sprays were performed at a weekly interval using a hand sprayer (100 ml per pot).

This experiment includes total six treatments: control, 0.5 mM salicylic acid (SA 0.5 mM), 1 mM salicylic acid (SA 1 mM), 40 mM ZnSO₄ (Zn), 40 mM ZnSO₄ + 0.5 mM salicylic acid (Zn + SA 0.5 mM) and 40 mM ZnSO₄ + 1 mM salicylic acid (Zn + SA 1 mM). The experiment was performed in five replicates and sampling was done at 100 DAT.

Dosage of chlorophyll total

Fragments of leaves (1 g) were ground in a mortar previously placed in ice with a pinch of magnesium carbonate and 5 g of anhydrous sodium sulfate. Then, 10 ml of 80% acetone was poured into the ground material, which was filtered on a Buchner, the residue was recovered in essays tubes. Further extractions were carried out with acetone to obtain a colorless filtrate (devoid of all traces of chlorophyll pigments) for which the final volume was specified. OD measurements were made with a spectrophotometer at wavelengths of around 663 nm to 645 nm for chlorophyll (a) and chlorophyll (b).

McKinney [32] established systems of equations that calculate the concentrations (g l⁻¹) chlorophyll from absorbance at 663 and 645 nm of an extract of 80% acetone are:

1. Chlorophyll a = (0.0127 OD₆₆₃) – (0.00269 OD₆₄₅),
2. Chlorophyll b = (0.0229 OD₆₄₅) – (663 0.00468 OD),

3. Total chlorophyll = (0.0202 OD 645) + (0.00802 OD 663).

Zn and nutrients (K, P and Ca) content

Content of Zn and minerals (K, P and Ca) was determined according to Cottenie et al. [33]. The root and shoot samples of *S. officinalis* were dried at 100 °C for 48 h. 100 mg of dried plant was calcined at 450 °C for 12 h in a muffle furnace. The ash obtained was dissolved in 3 ml of nitric acid (0.1 N) and then filtered through Whatman filter paper 540 hardened ashless. The volume was adjusted to 20 ml with distilled water. Based on this solution, the assay was performed by inductively coupled plasma emission spectrometry (ICP-AES) to determine the content of Zn and minerals (K, P and Ca).

Environmental scanning electron microscope

Microscopic observations of the fresh leaves were made using an environmental scanning electron microscope (Quanta 200, FEI Company). The microscope was equipped with a tungsten electron gun. Analyses were carried out under partial pressure of water vapor.

Count of peltate glandular trichome

Peltate glands counting was performed on the ventral side of the fresh leaves on a 1 mm² area, taking into consideration the basal (near the petiole), central and apical areas of the leaf. For each treatment, the glands number represents the average of glands of five plants and three leaves per plant [34].

Essential oil extraction

Essential oil extraction was carried out by hydrodistillation (Clevenger apparatus) of 100 g of parts aerial of *S. officinalis* dried in the free area. The extraction was carried out in 2 L of distilled water for 180 min. The essential oil was collected, dehydrated with sodium sulfate and stored at 4 °C. Essential oil yield was calculated by the following formula [35]:

$$\text{YEO (ml/100 g DM)} = (V/\text{DM} \times 100).$$

YEO is the essential oil yield of DM, V is the volume of essential oil collected (ml), and DM is the dry plant weight (g).

Statistical analysis

One-way analysis of variance was carried out for each parameter studied. Tukey's post hoc multiple mean comparison test was used to test for significant differences between treatments ($P \leq 0.05$). Univariate analysis was used to test significant differences in treatments,

and their interaction for an individual parameter. All statistical analyses were performed with IBM SPSS statistics, Version 22. The results of each experiment (biochemical assays) were repeated three times (20 times for morphological assays).

Results

Plant growth

In the case of non-stress, the plants sprayed with SA at 0.5 mM showed an increase of the growth by 44% and 56% of the stem and root parts, respectively, compared to the control (Fig. 1). At a higher concentration (1 mM), no significant differences were observed. In addition, in the absence of SA, Zn reduced stem and root growth, since a decrease in length can be observed which can reach 44%.

However, spraying of SA on the stressed plants increased the length of the aerial and root at the two concentrations 1 and 0.5 mM. Moreover, 0.5 mM presents the most pronounced results with an increase which can reach 50% for the aerial part.

Total chlorophyll content

In non-stress condition, SA at 0.5 mM increased the chlorophyll content in *S. officinalis* with 79% (Fig. 2). Zn stress significantly reduced total chlorophyll content (with 52% compared to the control). However, foliar spraying of SA, particularly at 0.5 mM improved chlorophyll synthesis, this increase was estimated by 501% compared to stressed plants untreated with SA.

Zn accumulation and mineral elements in plant

Table 1 shows the accumulation of Zn, Ca, K and P according to the different culture conditions. In non-stress conditions, the SA generally increased mineral element (Ca, K and P) contents compared to the control. At the leaf, whatever the concentration of SA used, there was a slight increase in the Ca contents, but a significant accumulation of K and Zn. In non-stress conditions, the SA generally increased mineral elements contents compared to the control. Under stress conditions, Zn was accumulated significantly at the roots (compared to the control) and can even be translocated to the leaves where its contents reach high values (3.31 mg g⁻¹ MS against 0.48 mg g⁻¹ MS for the control). This accumulation of Zn in the plant was accompanied by a decrease in the Ca, K and P contents. Spraying SA significantly decreased Zn accumulation in roots and its translocation to shoots. These decreases were more pronounced at 0.5 mM with 74% and 87%, respectively, in the leaves and roots compared to stressed plants untreated with SA. This concentration of SA (0.5 mM) promotes the increased absorption of mineral elements in both parts of

the plant (leaves and roots), which can reach 58% for Ca, 198% for K, 131% for P at the leaf level, and 44.54% for Ca, 303% for K and 59% for P at the root level, compared to stressed plants not treated with SA.

Essential oil yield

In non-stressed plants, SA is involved in essential oil synthesis (Table 2). This increase in essential oil contents was proportional to the concentration of SA; it can reach 25% for the SA at 0.5 mM and 50% for SA at 1 mM compared to control. On the other hand, Zn stress significantly decrease essential oil synthesis, which pass from 1.2% to 0.4% (reduction of 67% compared to control). Nevertheless, foliar spraying of SA on stressed remedy the negative effect of Zn by increasing the essential oil yield. This increase was estimated by 425% at 0.5 mM and by 250% at 1 mM compared to stressed plants not treated with SA.

Peltate glandular trichome density

Microscopic observations made on the leaves of *S. officinalis*, showed a difference in peltate glands abundance along the leaf, since they were concentrated at the basal part more than the central and apical part, this gradient (basal > central > apical) remains the same whatever the treatment. Moreover, the number of glands varies according to the treatment applied (Zn, SA) (Figs. 3 and 4). Zn stress decreased peltate glands density (Fig. 4b) in the different areas of the leaf (Fig. 3). Compared to the control (Fig. 4a), this decrease estimated by 40% at the basal, 38% central levels and 47% at the apical level (Fig. 3). On the other hand, spray of SA increased the density of the glands in the different zones of the leaf (Fig. 3). This increase was more pronounced at 0.5 mM (Fig. 4c) and can reach 177% in the basal area, 215% in the central area and 222% in the apical area (Fig. 3) compared to stressed plants untreated with SA.

Histological study of glandular trichomes

Microscopic observations in control plants showed the existence of the protective hairs (non-glandular hairs) and two types of secretory glands: peltate and capitate (Fig. 5a). The peltate and capitate glands differ in the size of the head, the length of the stem, mode and the period of secretions. The peltate glands are formed by a basal cell, a short, unicellular stem and head wide and round. The capitate glands consist of a base including epidermal cells, a longer (multicellular) stem and a smaller head than that of the capitate glands.

In addition to these common forms of the glands, the treatment with Zn revealed structures characterized by atypical morphology, presenting deformations in the

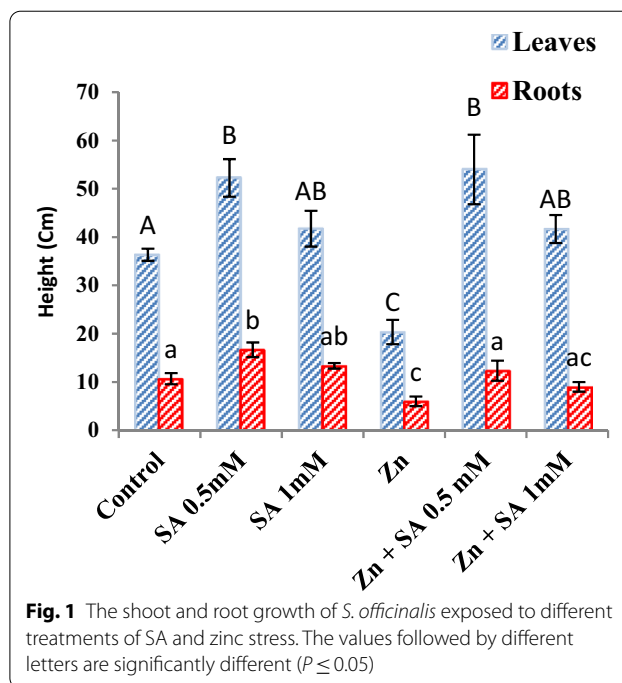


Fig. 1 The shoot and root growth of *S. officinalis* exposed to different treatments of SA and zinc stress. The values followed by different letters are significantly different ($P \leq 0.05$)

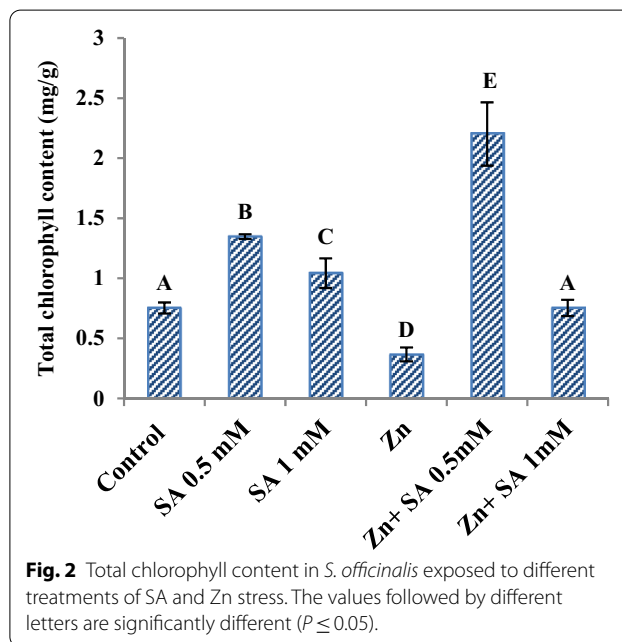


Fig. 2 Total chlorophyll content in *S. officinalis* exposed to different treatments of SA and Zn stress. The values followed by different letters are significantly different ($P \leq 0.05$).

form of pockets on their surface (Figs. 5b and 6). These pockets, generally spherical, can be either unique or numerous on the same gland. In addition, another form of deformation may appear, it was the oval form (Fig. 7) instead of the usually spherical shape of the glands.

In addition, in plants treated with SA (0.5 and 1 mM) these deformed structures were not detected, which does encourage us to suggest that the toxicity of Zn caused

Table 1 Content of Zn and mineral nutrients (P, K and Ca) in *S. officinalis* exposed to different treatments of SA and Zn stress

	Zn (mg/g DM)	Ca (mg/g DM)	K (mg/g DM)	P (mg/g DM)
Leaves				
Control	0.48 ± 0.03A	12.56 ± 0.09a	11.41 ± 0.94A*	2.47 ± 0.11a*
SA (0.5 mM)	0.83 ± 0.07B	13.86 ± 0.02b	19.27 ± 1.10B*	2.66 ± 0.05a*
SA (1 mM)	0.92 ± 0.01C	13.19 ± 0.41b	15.03 ± 0.37C*	2.47 ± 0.11a*
Zn	3.31 ± 0.18D	9.74 ± 0.36c	9.41 ± 0.21D*	0.72 ± 0.10b*
Zn + SA (0.5 mM)	0.87 ± 0.01B	15.37 ± 0.12d	28.07 ± 0.29E*	1.67 ± 0.11c*
Zn + SA (1 mM)	1.06 ± 0.05E	12.55 ± 0.21a	26.62 ± 0.17F*	1.68 ± 0.21c*
Roots				
Control	0.50 ± 0.01a	8.41 ± 0.07A	6.42 ± 0.05a*	1.01 ± 0.01A*
SA (0.5 mM)	0.51 ± 0.00a	16.11 ± 0.10B	12.84 ± 0.02b*	3.85 ± 0.01B*
SA (1 mM)	0.90 ± 0.08b	15.03 ± 0.37C	8.87 ± 0.02c*	1.13 ± 0.01A*
Zn	6.89 ± 0.66c	6.87 ± 0.19D	4.05 ± 0.04d*	0.54 ± 0.12C*
Zn + SA (0.5 mM)	0.89 ± 0.00b	9.93 ± 0.11E	16.33 ± 0.29e*	0.86 ± 0.12D*
Zn + SA (1 mM)	1.16 ± 0.00d	8.78 ± 0.02F	18.26 ± 0.11f*	0.69 ± 0.10D*

The values within vertical lines followed by different letters are significantly different ($P \leq 0.05$)

Table 2 Yield of essential oil (%) in *S. officinalis* exposed to different treatments of SA and Zn stress

Control	SA 0.5 mM	SA 1 mM	Zn	Zn + SA 0.5 mM	Zn + SA 1 mM
1.2 ± 0.01a	1.5 ± 0.05 b	1.8 ± 0.01c	0.4 ± 0.1d	2.1 ± 0.02 e	1.4 ± 0.01 f

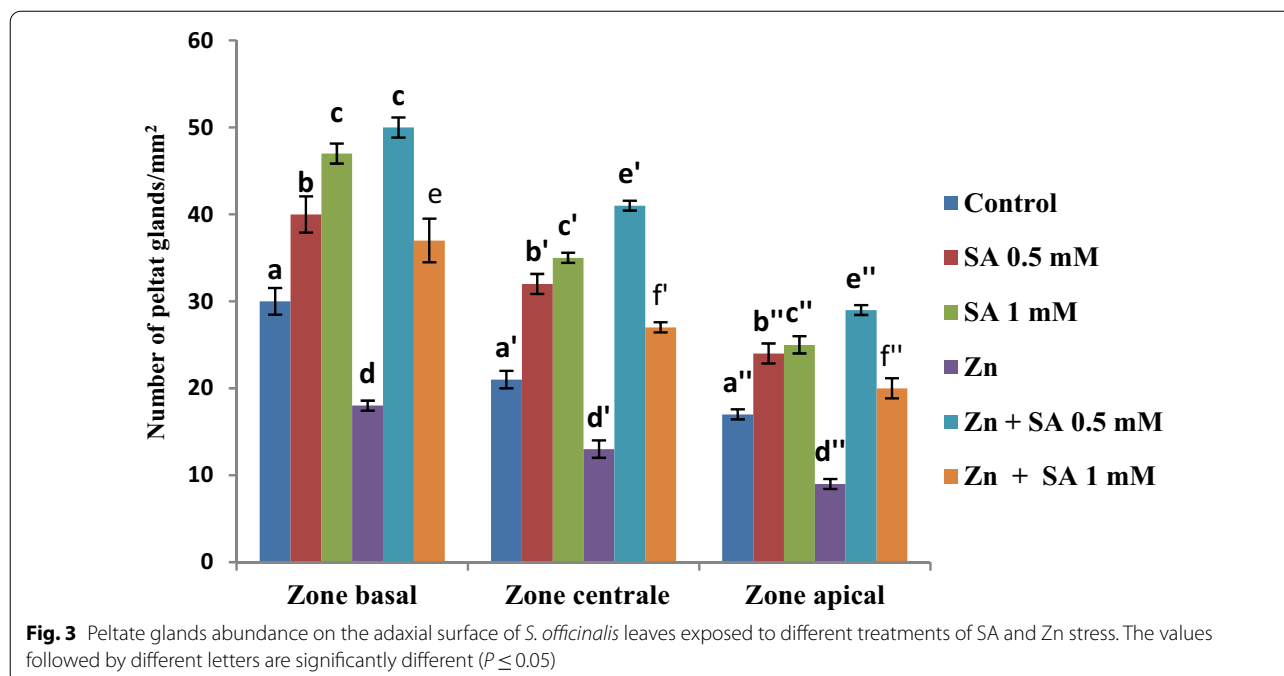
The values followed by different letters are significantly different ($P \leq 0.05$)

this structural anomaly, and SA treatment corrects the negative effects of Zn stress.

Discussion

The present study indicated that Zn stress inhibits stem and root growth of *S. officinalis*, which is in agreement with previous works [7, 36]. In addition, Sagardoy et al. [37] reported in *Beta vulgaris* L. that increasing Zn concentrations leads to a decrease in the dry weight, with the appearance of chlorosis symptoms. Furthermore, applying 40 mM Zn to the growth media significantly elevated the Zn concentrations in various parts of sage plants with a maximum accumulation in the roots. Macfarlane and Burchett [14], Frey et al. [38] reported that Zn accumulated in the vacuoles of epidermis cells and leaf mesophylls. In addition, Turner and Marshall [39] indicated that the exclusion of metals in the roots maybe a mechanism of tolerance since metals bind to the cell walls of the roots and the extent of this bond is proportional to the degree of tolerance to heavy metal. Some authors reported that symptoms of toxicity become visible at concentrations above 300 mg kg⁻¹ of DM, although some cultures exhibit symptoms of

toxicity at concentrations below 100 mg kg⁻¹ DM [12, 13]. These high concentrations caused a nutritional imbalance, which results in growth retardation [8, 40]. Other researchers reported the same effect after accumulation of other metals such as copper [1, 41, 42] and cadmium [3, 43]. In this perspective, our results showed that the mineral content in root and shoot was also significantly decreased by Zn stress. These results are confirmed by Sagardoy et al. [37] who showed that increasing of Zn concentrations decreases the concentrations of several nutrients in *Beta vulgaris* L. such as K, Mg, Mn, P, Ca and Fe. In addition, Ambler et al. [44] reported an inhibition of iron translocation from the root to the leaves which caused chlorosis. Furthermore, the essential oil production was strongly inhibited by Zn stress confirming the results of Misra and Sharma [9] and Misra et al. [8] who showed disturbances in essential oil contents in *Mentha arvensis* at higher Zn concentrations (at 25 µg g⁻¹ DM). Copetta et al. [34] and Hashmi et al. [45] demonstrated the importance of mineral nutrition on essential oil yield. In this sense, we can link this negative effect of Zn on essential oil to the nutritional imbalance under Zn toxicity. In addition, the Zn stress application impact negatively the chlorophyll levels. The biosynthesis of essential oil as a secondary metabolite was linked to photosynthetic activity [46] and that metals caused disturbances of chlorophylls synthesis, following the synthesis of free radicals [8, 47]. In this study, it has been found that essential oil of *S. officinalis* L. was strongly correlated with secretory glands density. Same observation was made by others authors [46, 48].



The observations made by environmental scanning electron microscopy of *S. officinalis* leaves showed the presence of peltate, capitate glands and non-glandular trichomes (protective hairs). Hazzoumi et al. [6] noted in *S. officinalis* also the presence of peltate glands with a unicellular stem and a large round head, and of capitate glands with a longer stem and a smaller head than that in peltate glands. These same structures have also been encountered in the leaves of plants grown under Zn stress. However, in these stressed plants, we highlighted the presence of some anomalies never observed in the control plants and in plants treated with SA. These anomalies consist of glandular structures with deformations in the form of pockets located on the head. The number of these pockets can be variable (in number of 1 or more).

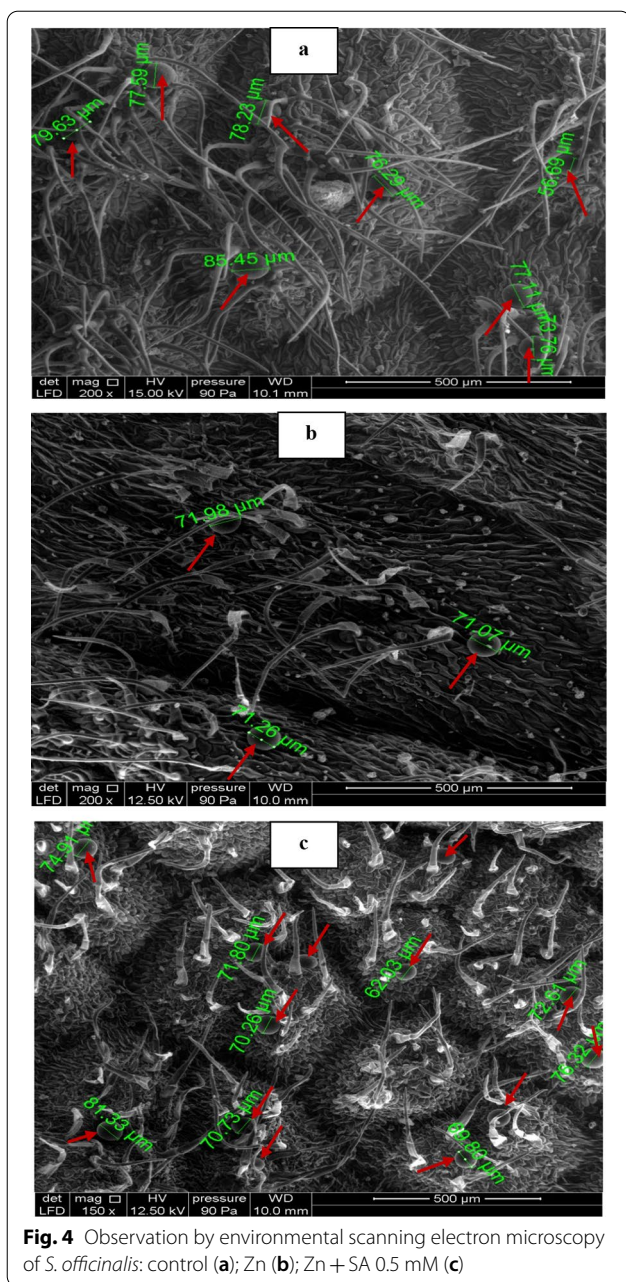
These pockets can be either a drop of secretion or abnormalities caused by Zn toxicity. The latter hypothesis seems to be as possible as these structures only appear in plants treated with Zn. Indeed, we have never been able to meet such structures in control plants and in plants sprayed with SA. In this sense, the hypothesis of an excretion oil was excluded because:

The peltate glands release their contents to outside by bursting of the cuticle. Chez genus *Salvia*, Corsi and Bottega [49]; Serrato-Valenti et al. [50]; Bisio et al. [5] and Janošević et al. [51] stated that at the time of secretion, a large space in which materials accumulate has developed through the elevation of the cuticle and the outermost layer of the walls of the secretory cells.

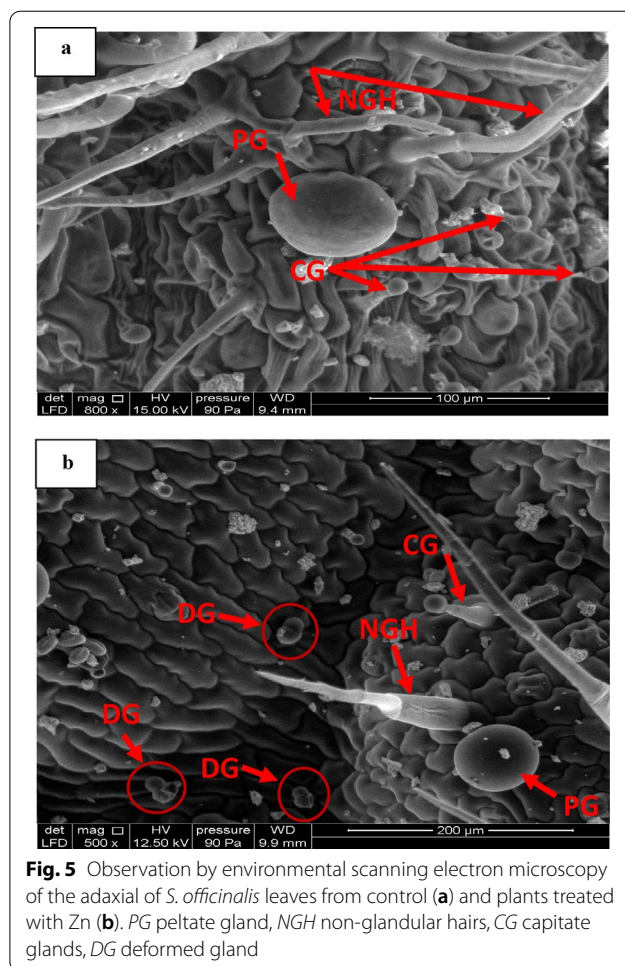
A line of equatorial weakness became visible around the head; the rupture of the cuticle along this line and the subsequent detachment of the cuticular cap lead to the release of exudate. These same authors showed that matter is not released until the cuticle is broken by mechanical events or at the end of the gland's life.

The capitate glands release their contents through a single pore. But, in our case on the same glands several pockets were observed (in number of 1 or more). In this sense, Bisio et al. [5] reported in the genus *Salvia* two potential mechanisms for the release of secreted material for the capitate glands: (1) the passage of a droplet through the intact cuticle; or (2) early cuticle (single pore) rupture.

In addition, our observations showed also in stress case, the presence of the glands characterized by an oval morphology which were not encountered in the control and in the plants treated with SA. Therefore, it can be deduced that all these glandular structures observed can be considered as anomalies caused by the Zn toxicity. Several authors have used exogenous SA against certain biotic stresses [52, 53] and abiotic such as saline stress [54, 55], water stress [56]; heat stress [57], cadmic stress [58]. On the other hand, on the toxicity of Zn, the effect of SA was not studied. On Zn toxicity, this work showed the positive effect of SA, particularly at 0.5 mM, on the stem and root growth. The stimulation of growth by SA can be linked to the mineral nutrition, the hormonal profile, and photosynthesis. Several authors linked the positive effect of SA on growth to its positive effect on



hormonal balance disturbed by metallic stress. Shakirova et al. [59] showed in wheat treated with SA increased ABA content, which plays a role in regulating the movements of the stomata [60], in the regulation of genes and the activity of antioxidant enzymes [61]. Shakirova et al. [62] concluded that endogenous ABA is a hormonal intermediary to trigger defense reactions under the influence of SA. These results are confirmed by the results of Guo et al. [63] on cadmium, and de Gunes et al. [64] on copper. In addition, we showed the positive effect of SA on the synthesis of chlorophyll pigments confirming



the results of Tahjib et al. [65] in corn and Faghilic et al. [66] in strawberry plant under saline stress. The improvement of photosynthesis under the influence of SA can be attributed to its stimulating effects on the activity of RuBisCO, PEP carboxylase and carbonic anhydrase [67]. Others attributed the positive effect of SA on chlorophyll content to the stimulation of mineral assimilation and to the effectiveness of PSII [68], to the mobilization of internal tissue nitrate or to the chlorophyll biosynthesis [69]. Spraying of SA, particularly at 0.5 mM, increased the essential oil content in stressed plants. In stress condition, Khanam and Mohammad [70] on *Mentha piperita* L. and Es-sbihi et al. [1] on *S. officinalis* L. showed also an increase in essential oil content under the effect of SA. These authors linked this increased in essential oil content under SA in stress condition, to the improvement of growth, photosynthesis, nutrient assimilation and peltate glands density. Others also demonstrated also that spraying of SA increased peltate glands density [71, 72]. In this sense, this study showed an increase in peltate glands density in *S. officinalis* grown under Zn stress and

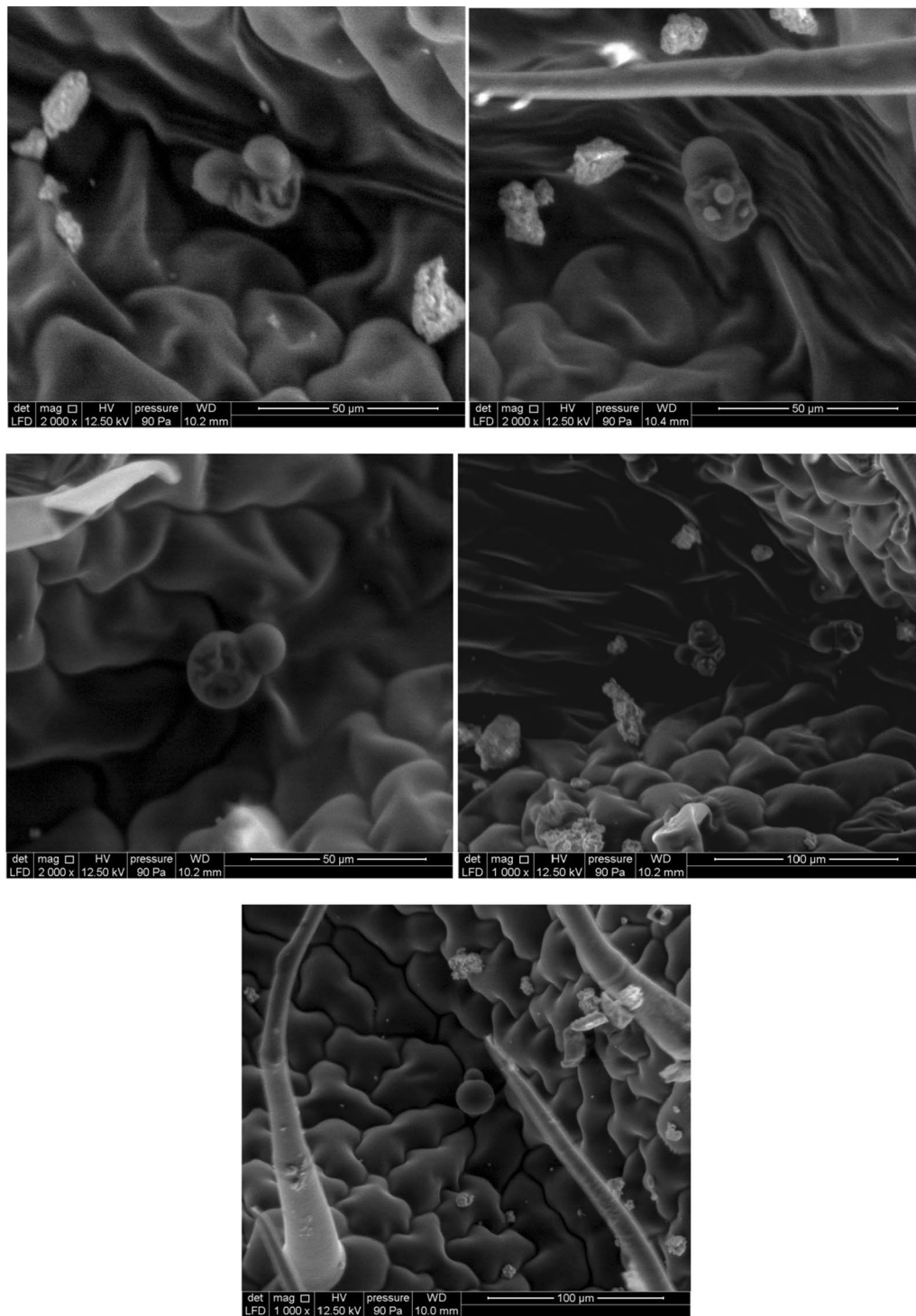


Fig. 6 Observation by environmental scanning electron microscopy of the adaxial of *S. officinalis* leaves shows deformed glands under the effect of zinc

sprayed with SA (especially at 0.5 Mm). Some authors attributed this positive effect of SA to improvement of the hormonal profile [34, 35] like auxins and gibberellins [45, 73]. In *Zea mays* exposed to cadmic stress, Szalai

et al. [58] found that the application of SA at 0.5 mM increased the levels of phytochelatin, responsible for the tolerance of plants to metal ions. In our study, this positive effect of SA on growth, chlorophyll and essential oil

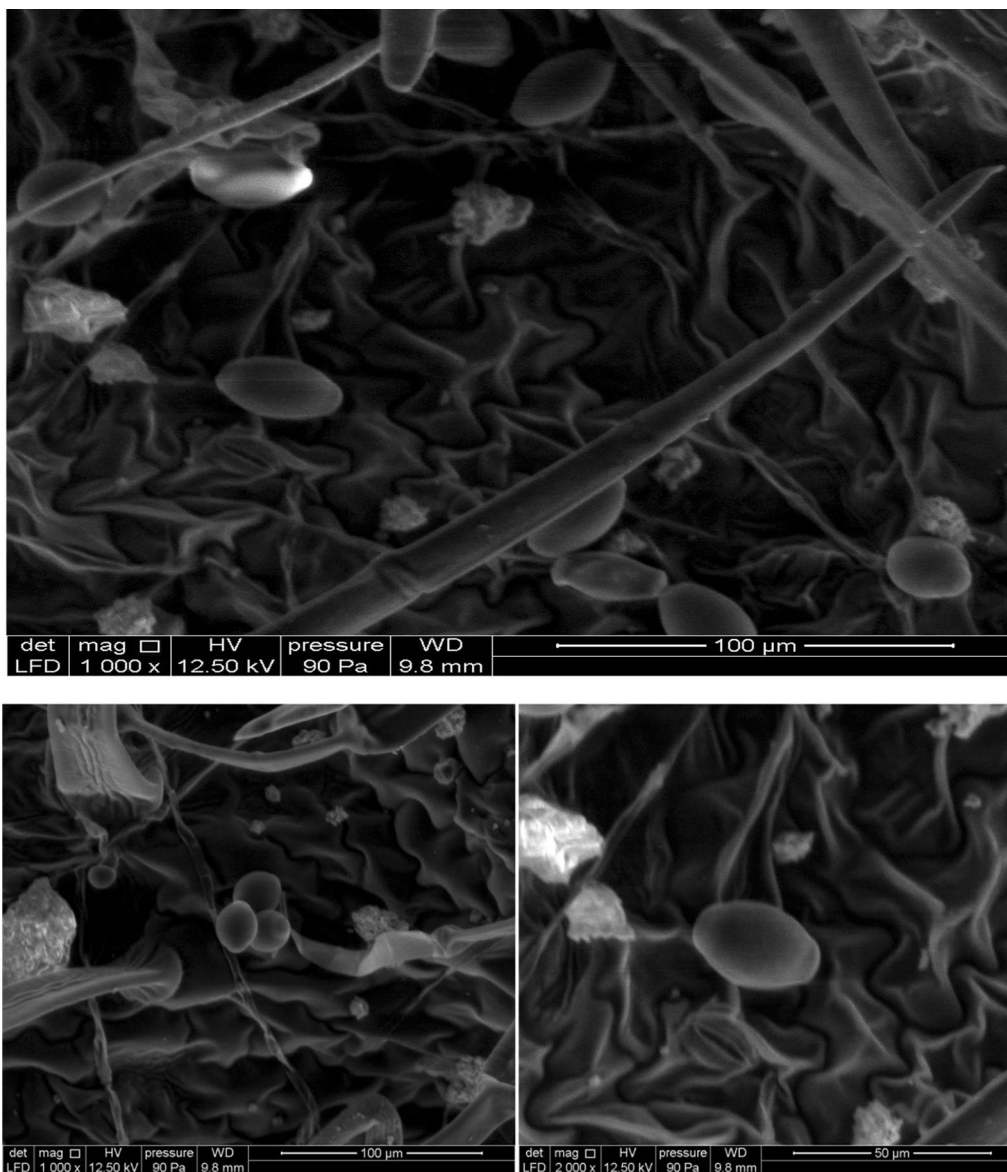


Fig. 7 Observation by environmental scanning electron microscopy of the adaxial of *S. officinalis* leaves from plants treated with Zn

biosynthesis under Zn stress could be related with limiting Zn uptake and translocation in leaves under stressful environment and to the improvement of the nutritional balance disturbed by Zn accumulation.

However, histological study of the leaves of stressed plants sprayed with SA showed the presence of similar peltate and capitate glands observed in the control. On the other hand, in these plants we never detected the structures discovered in stressed plants untreated with SA. This finding confirms the hypothesis which stipulates that these deformations are anomalies that appear under

the effect of toxic concentrations of Zn. Spraying SA decreased Zn uptake which explains the disappearance of these structures discovered in stressed plants.

Conclusion

Zn stress inhibited growth and the synthesis of chlorophyll and essential oil. However, spraying of SA (particularly at 0.5 mM) reduced Zn content and promoting nutrients content, growth, chlorophyll, essential oil and peltate glandular in *S. officinalis* grown under Zn stress.

The histological study of the leaves of plants cultivated under Zn stress showed the presence of the glands with deformations in the form of pockets located on the surface of the head and glands characterized by an oval morphology not detected in plant control. However, sprayed with SA (0.5 and 1 mM) we noticed the absence of these glandular anomalies which showed the remedial effect of SA under Zn stress.

Abbreviations

SA: Salicylic acid; Zn: Zinc; DM: Dry matter; DAT: Days of plants transplantation.

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Authors' contributions

All authors of this research paper have directly participated in planning, execution and analysis of the study. All authors read and approved the final manuscript.

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Availability of data and materials

Additional data may be availed on request to the authors through the corresponding author. We take legal responsibility for information, used procedures, data and results.

Ethics approval and consent to participate

This research work meets all the ethical guidelines, adhering to the legal requirements of my country.

Consent for publication

The authors confirm that there is no conflict of interest and agree with submission of the manuscript to your journal.

Competing interests

The authors declare that they have no competing interests.

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