Medicinal and aromatic plants production under salt stress. A review

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S u m m a r y

Salinization of soils or waters is one of the world's most serious environmental problems in agriculture. It is necessary to determine the environmental factors under which medicinal and aromatic plants give higher yields and better quality. The problem of salinity is characterized by an excess of inorganic salts and is common in the arid and semi-arid lands, where it has been naturally formed under the prevailing climatic conditions and due to higher rates of evapotranspiration and lack of leaching water. Although more frequent in arid lands, salt-affected soils are also present in areas where salinity is caused by poor quality of irrigation water. Saline soil induces physiological and metabolic disturbances in plants, affecting development, growth, yield, and quality of plants. Plants affects adversely as a result of salinity, seed germination, survival percentage, morphological characteristics, development and yield and its components. In general, salt stress decreases the photosynthesis and respiration rate of plants. Total carbohydrate, fatty acid and protein content were adversely affected due to salinity effect, but increased the level of amino acids, particularly proline. The content of some secondary plant products is significantly higher in plants grown under salt stress than in those cultivated in normal conditions. The salinity tolerance depends on the interaction between salinity and other environmental factors.

Key words: *salinity, medicinal and aromatic plants, proline, growth and development, secondary products, salt tolerance*

INTRODUCTION

Plants are usually exposed to different environmental stresses which limit their growth and productivity as well as cause considerable loss to worldwide agricultural production [1]. One of the most important factors affecting plant growth and the production of secondary metabolites is the salt stress [2].

Salinity of soil or water is one of major stress obstacles to increase production in plant growing areas throughout the world and especially in arid and semi-arid regions it can severely limit plant production [3]. According to Sreenivasulu *et al.* [4] the adverse effects of salts on plant growth may be divided into three broad categories: **(i)** a reduction in osmotic potential of the soil solution that reduces plant available water and thus creates a water stress in plants, **(ii)** a deterioration in the physical structure of the soil such that water permeability and soil aeration are diminished, and **(iii)** increase in the concentration of the certain ions that have an inhibitory effect on plant metabolism (specific ion toxicity) and mineral nutrient imbalances and deficiencies or (**iv**) a combination of these factors.

Causes of salinity

1. Primary cause

Most of the saline soils are developed due to natural geological, hydrological and pedology processes. These soils include igneous rocks, volcanic rocks, sandstones, alluviam and lagoonal deposits. In arid and semi-arid lands, evapotranspiration plays a very important role in the pedogenesis of saline soils. Other types of salinity occur in coastal areas subject to tides and the main cause of salinity is intrusion of saline water into rivers [5].

2. Secondary salinization

Secondary salt-affected soils are those that have been salinized by human, mainly as a consequence of improper methods of irrigation, and poor quality of water used for irrigation. Anthropic salinization occurs in arid and semi-arid areas due to water logging brought about by improper irrigation [6]. Secondary salt-affected soils can also be caused by human activities different from irrigation and include: **(i)** deforestation – recognized as a major cause of salinization and alkalization of soils as a result of the effects of salt migration in both the upper and lower layers; **(ii)** accumulation of air-borne from industrial emissions or water-borne salts in soils as waste water; **(iii)** salinization caused by contamination with chemicals. This kind of salinization occurs more often in modern intensive agricultural systems, particularly in greenhouses and intensive farming systems; **(iv)** overgrazing – this process occurs mainly in arid and semi-arid regions, where the natural soil cover is poor and scarcely satisfies the fodder requirement of extensive animal husbandry [5].

EFFECT OF SALT STRESS ON SEED GERMINATION, SURVIVAL, MORPHOLOGICAL CHARACTERISTICS, DEVELOPMENT AND YIELD OF PLANTS

Seed germination

Germination is one of the most salt-sensitive plant growth stages severely inhibited with increasing salinity [7]. This negative response of seed germination under salt stress was reported by many authors on *Ocimum basilicum*, *Eruca sativa*, *Petroselinum hortense*, chamomile, sweet marjoram, and *Thymus maroccanus* [8-11]. Salinity affects germination of seeds in two ways: **(i)** there may be enough salt in the medium to decrease the osmotic potential to such a point which retard or prevent the uptake of water necessary for mobilization of nutrient required for germination, **(ii)** the salt constituents or ions may be toxic to the embryo [3].

Seedling growth

Seedlings are the most vulnerable stage in the plants' life cycle. There was investigated that salinity caused a significant reduction in seedling growth of *Thymus maroccanus* [11]. Salinity affects the seedling growth by slow or less mobilization of reserve foods, suspending the cell division, enlarging and injuring hypocotyls [12]. Reduced seedling growth has also been reported on basil, chamomile and marjoram [9, 10, 13].

Survival

An excess of soluble salts in the soil leads to osmotic stress, specific ion toxicity and ionic imbalances [14] and, as a consequence, plant can go to death [15]. All seedlings of *Melissa officinalis* died at 6 dS/m [16]; the observed increasing soil salinity up to 3000 ppm resulted in complete death of sage plants [17]. In thyme, it has been also reported that survival percentage was decreased significantly under salinity conditions [18]. Similar results were obtained on *Majorana hortensis* and spearmint [19, 20].

Morphological characteristics and development

Several investigators have reported plant growth reduction as a result of salinity stress, *Foeniculum vulgare* subsp. vulgare [21]; *Majorana hortensis* [19]; peppermint, pennyroyal, and apple mint [22]; *Matricaria recutita* [23]; *Thymus* *maroccanus* [11]; geranium [24]; *Thymus vulgaris* [25]; sweet fennel [26]; sage [27]; *Mentha pulegium* [28]. On *Mentha piperita* var. officinalis and *Lipia citriodora* var. verbena significant reduction in number of leaves, leaf area and leaf biomass under salt stress were noted [29]. On milk thistle growth parameters such as plant height, number of leaves per plant, number of capitula per plant, main shoot capitulum's diameter was reduced with salinity greater than 9 dS/m were found[30]. It was also stated that plant height, number of flowers, number of branches and head diameter, flower fresh weight, flower dry weight, and peduncle length were reduced by salinity [31]. Similar decreases in growth parameters under salt stress were found in *Withania somnifera* and *Catharanthus roseus* [32, 33]; *Achillea fragratissima* [34]; *Salvia officinalis* [35]; thyme [18]; *Nigella sativa* [36]; *Chamomilla recutita* [37]; and basil [38]. In *Melissa officinalis*, root growth was reduced with each increase in irrigation water salinity [16]. Like in *Satureja hortensis*, leaf area, leaf and stem fresh weight, as well as dry weight of leaves, stems and roots were decreased in plants grown in different levels of NaCl [39].

Yield

Salinity has considerable adverse impacts on plants productivity. As it was stated, the detrimental effects of high salinity on plants can be observed at the whole-plant level as the death of plants and/or decreases the productivity [40]. In fennel, cumin and *Ammi majus* increasing salt concentrations caused a significant reduction in the number of umbels, fruit yield/plant and weight of 1000 seeds [21, 41, 42]. Similar reductions in seed yield and yield components per plant were obtained on milk thistle and *Trachyspermum ammi* [30, 43].

EFFECT OF SALT STRESS ON NUTRIENT UPTAKE

Nutrient disturbances under salinity reduce plant growth by affecting the availability, transport, and partitioning of nutrients. However, salinity can differentially affect the mineral nutrition of plants. Salinity may cause nutrient deficiencies or imbalances, due to the competition of Na^+ and Cl^- with nutrients such as K^+, Ca^{2+}, and NO_3^-. Under saline conditions, a reduced plant growth due to specific ion toxicities (*e.g.* Na^+ and Cl^-) and ionic imbalances acting on biophysical and/or metabolic components of plant growth occurs [59]. Increased NaCl concentration has been reported to induce increases in Na and Cl as well as decreases in N, P, Ca, K and Mg level in fennel [21]; *Trachyspermum ammi* [43]; peppermint and lemon verbena [29], *Matricaria recutita* [23], *Achillea fragratissima* [34].

EFFECT OF SALT STRESS ON PRIMARY PLANT PRODUCTS

Carbohydrates

In fennel, a total carbohydrate was adversely affected due to salinity effect [21]. This can be attributed to the nutritional imbalance [44] of the specific toxic effects of salinity [45], hyperosmotic stress [46] and reduced photosynthesis [47]. In contrast, total carbohydrate content was pronouncedly increased with increasing salt stress levels of *Salvia officinalis* [17] content of soluble sugars was higher in plants treated with NaCl which has been shown on *Satureja hortensis* [39].

Lipids

Oil content and fatty acid synthesis of plants are influenced by salt stress, which modifies fatty acid composition, and is considered to be important for the salt tolerance of plants [48]. Oil yield in roots was significantly lowered by salt stress in *Ricinus communis*, but increased in shoots [49]. It was also reported that the total fatty acid content of *Coriandrum sativum* leaves decreased significantly due to salinity, and the content of α-linolenic and linoleic acids was decreased significantly at raising NaCl levels [50]. This inhibition in the fixed oil content under salt stress is similar to that reported [51] on sage.

Proteins

It was observed that protein content in *Catharanthus roseus* had been significantly decreased along with NaCl concentrations [52]. The level of soluble proteins decreased in salinity stressed chamomile and sweet marjoram [10]. Also, in *Achillea fragratissima* it was indicated that salinity concentration of 4000 ppm depressed significantly crude protein [34]. However, a stimulation of protein synthesis has also been found (the stimulation, of course, depends on the salinization degree) [53]. Proteins that accumulate in plants under saline conditions may provide a storage form of nitrogen that is re-utilized later [54] and may play a role in osmotic adjustment.

Amino acids

Plants under salt stress may present increased levels of certain compounds. Amino acids (alanine, arginine, glycine, serine, leucine, and valine, together with the amino acid, proline, and the non-protein amino acids, citrulline and ornithine) and amides (such as glutamine and asparagines) have also been reported to accumulate in plants subjected to salt stress [55]. On *Catharanthus roseus* and *Matricaria chamomilla* higher total free amino acids in plants subjected to salt stress conditions were reported [52, 56]. Proline occurs widely in higher plants and accumulates in larger amounts than other amino acids [57]. According to literature, proline accumulates in leaves as a response to salt stress on *Salvia officinalis*, *Trachyspermum ammi*, spearmint, chamomile, sweet marjoram, *Catharanthus roseus, Achillea fragratissima*, *Matricaria chamomilla*, sweet fennel, and *Satureja hortensis* [10, 17, 20, 26, 34, 39, 43, 52, 56]. The increase in proline content could be attributed to a decrease in proline oxidase activity in saline conditions [58].

EFFECT OF SALT STRESS ON SECONDARY PLANT PRODUCTS

The concentrations of various secondary plant products are strongly dependent on the growing conditions, especially stress conditions.

Essential oil

There are contradictory reports in the literature concerning the response of essential oil to salt stress. Salt stress decreased essential oil yield in *Trachyspermum ammi* [43]. This negative effect of salt stress in oil yield was also reported for other medicinal plants, e.g. *Mentha piperita* [29]; peppermint, pennyroyal, and apple mint [22], *Thymus maroccanus* [11], and basil [38]. Besides, salinity decreased the essential oil yield [21] on fennel. It was also observed that anethole percentage was reduced with saline water. In marjoram the proportions of the main compounds were differently affected by salt [13]. While, in *Matricaria recutita*, the main essential oil constituents (α-bisabololoxide B, α-bisabolonoxide A, chamazulene, α-bisabolol oxide A, α-bisabolol, trans-β-farnesene) showed the increase under saline conditions [23]. Also, on *Origanum vulgare* it was found that content of the main essential oil constituent (carvacrol) decreased under salt stress, while p-cymene and γ-terpinene contents increased under non-salt stress treatments [60]. Similar results of an inhibitory effect of high level of salinity were also found on lemon balm [16]; *Majorana hortensis* [19], *Matricaria chamomile* [31], *Salvia officinalis* [51] and basil [61]. On the contrary, an increase of essential oil yield due to lower levels of salinity has been reported in other plant species, e.g. *Satureja hortensis* [62] and *Salvia officinalis* [17]. It was also shown that essential oil yield of coriander leaves was stimulated only under low and moderate stress, while it decreased at the high salinity level. At low stress, (*E*)-2-decenal, (*E*)-2-dodecenal and dodecanal contents increased [50]. On *Salvia officinalis* the main essential oil compound was viridiflorol at control and 25 mM NaCl, 1,8-cineole became the predominant compound at 50 and 75 mM and manool prevailed at 100 mM [51]. However, the major components of the essential oil of *Ocimum basilicum* var. purpurascens were eugenol and linalool. Soil salinity at 1500 and 4500 mg kg^{-1} levels increased the content of linalool and decreased eugenol content [61].

There are reports of an increase in essential oil percentage due to lower levels of salinity was also found on *Satureja hortensis* [62]; sage [17] and thyme [18]. In basil the highest oil percentage was achieved under salinity condition [38]. In contrast, other reports showed a significant reduction of essential oil percentage [16] on lemon balm and sweet marjoram *(Majorana hurtensis* L.) [19] and [39] in savory (*Satureja hortensis*). The highest amount of carvacrol and the lowest amount of γ-terpinene were obtained by increasing the salinity levels. However, essential oil yield was increased significantly with increasing NaCl concentrations of coriander roots [63] and [64]. The raising EC with NaCl increased the yield of essential oil of curly-leafed parsley. The contents of aroma constituents (β-phellandrene, myristicin, β-myrcene and apiole) of the foliar essential oil were affected by salt stress. It was also demonstrated that essential oil (%) and oil yield (ml plant^{-1}) were significantly increased by using 1500 mg kg^{-1} of soil salinity as compared to control [61]. On the contrary, there was significant decrease in this regard by using higher level of soil salinity, at 4500 mg · kg^{-1}. In contrast, it was suggested that essential oil content and yield decreased with water salinity increasing in three *Cymbopogon* species [65].

The stimulation of essential oil production under a moderate degree of salinity could be due to a higher oil gland density and an increase in the absolute number of glands produced prior to leaf emergence [66]. Salt stress may also affect the essential oil accumulation indirectly through its effects on either net assimilation or the partitioning of assimilates among growth and differentiation processes [66]. Also, the formation and accumulation of essential oil in plants was also attributable to the action of environmental factors. It might be claimed that the formation and accumulation of essential oil was directly dependent on perfect growth and development of the plants producing oils [67]. The decrease in oil production might be due to the decrease in plant anabolism. The increase in oil content in some of the salt stressed plants might be attributed to decline the primary metabolites due to the effects of salinity, causing intermediary products to become available for secondary metabolites synthesis [68]. In fact, the effect of salinity on essential oil and its constituents may be due to its effects on enzyme activity and metabolism [69].

Alkaloids

In the case of *Rauvolfia tetraphylla* [70] and *Catharanthus roseus* [71] the concentration of reserpine and vincristine, respectively, is higher in plants grown under salt stress. However, on *Ricinus communis* it was observed that th elevel of ricinine alkaloids in roots was significantly lowered by salt stress, but it was increased in shoots [49]. Also the studies published on *Solanum nigrum* (solasodine) [72], *Catharanthus roseus* (indole alkaloids) [33], and *Achillea fragratissima* [34] indicated significant increase in the alkaloid content of these plants exposed to salt stress.

Phenolic compounds

In studies on spearmint it was found that phenolic acid concentration increased in salt stressed plants [20] and on *Achillea fragratissima* indicated that th econtent of phenols increased significantly along with increasing salinity [34]. Also on *Matricaria chamomilla* it was found that accumulation of phenolic acids (protocatechuic, chlorogenic and caffeic acids) increased by salinity [56]. Other studies published on *Nigella sativa* [73] and *Mentha pulegium* [28] showed increase of phenols with saline treatment.

The content of some secondary plant products are significantly higher in plants grown under salt stress than in those cultivated under normal conditions [2]. For *Nigella sativa*, salinity enhanced the biosynthesis of some components, especially quercetin, apigenin and trans-cinnamic acid [73]. However, on *Achillea fragratissima* it was indicated that the content of tannin increased significantly along with increasing salinity [34].

Cardenolides

Total cardenolide levels observed in *Digitalis purpurea* leaves and roots of the 100 mM NaCl plants were higher than those in 200 mM NaCl and control plants [68]. They infer that moderate salinity conditions lead to raised cardenolide levels, principally in leaves of *Digitalis purpurea*, although, the reason is not clear.

EFFECT OF SALT STRESS ON PHOTOSYNTHETIC PIGMENTS

There is a strong evidence that salt affects photosynthetic enzymes, chlorophylls and carotenoids [74]. Increased salinity levels reduced chlorophyll a and b contents and total chlorophyll of centaury [75], *Teucrium polium*, *Thymus vulgaris*, *Zataria multiflora*, and *Ziziphora clinopodioides* [76] and *Satureja hortensis* [39]. The observed decrease of chlorophyll content in the plants grown under saline conditions may be attributed both to the increased degradation and the inhibited synthesis of that pigment [77]. Moreover, the reduction in photosynthetic pigments (chlorophyll a, chlorophyll b, and total carotenoids) due to salinity effect which attributed to the disturbance of ions absorption involved in chloroplast formation and protein synthesis and/or plastide breakdown [21] on fennel. However, it was observed that the degradation of chlorophyll pigments was increased as a result of exposure to NaCl [78].

SALT RESISTANCE

Plant salt stress resistance has been defined [79] as an inherent ability of plants to withstand the effects of high salt concentrations without a significant adverse effect. The authors have defined salinity tolerance as the ability of a plant to grow and complete its life cycle on a substrate that contains high concentrations of soluble salt [5].

Mechanisms of salt stress resistance

These mechanisms are characterized as avoidance and tolerance. The term "salt resistance" has been used referring to a combination of tolerance and avoidance strategies [53].

Mechanisms of salt avoidance include delayed germination or maturity until favorable conditions prevail; the exclusion of salts at the root zone or preferential root growth into non-saline areas; compartmentalization of salt into and secretion from specialized organelles such as salt glands and salt hairs; or storage in older leaves [80].

Mechanisms of salt tolerance include

1. Synthesis of compatible solutes

The presence of salt in the growth media often results in accumulation of compounds, termed compatible solutes, which do not interfere with normal biochemical reactions [81]. These compatible solutes include mainly proline [82]. The proposed functions of proline under stress conditions include osmotic adjustment, protection of enzymes and membranes as well as acting as a reservoir of energy and nitrogen for utilization during exposure to salinity [5], accumulation of nitrogen-containing compounds such as amino acids, amides, proteins, polyamines [55]. These compounds have been reported to function in osmotic adjustment, protection of cellular macromolecules, storage of nitrogen, maintenance of cellular pH, detoxification of the cells and scavenging of free radicals. Other compatible solutes that accumulate in plants under salt stress include: **(a)** carbohydrates such as sugars (glucose, fructose, sucrose, fructans) and starch. Their major functions have been reported to be osmotic adjustment, carbon storage, and radical scavenging, **(b)** polyols are reported to make up a considerable percentage of compatible solutes and serve as scavengers of stress-induced oxygen radicals. They are also involved in osmotic adjustment and osmoprotection [5].

2. Control of ion uptake by roots and transport into leaves

Plants regulate ionic balance to maintain normal metabolism. For example, uptake and translocation of toxic ions such as Na and Cl are restricted, and uptake of metabolically required ions such as K is maintained or increased. They do this by regulating the expression and activity of K and Na transporters and of H pump that generate the driving force for transport [5]. It is well documented that a greater degree of salt tolerance in plants is associated with a more efficient system for the selective uptake of K over Na [83].

Changes in photosynthetic pathway under salinity

The reduction of photosynthetic rates in plants under salt stress occurs mainly due to the reduction in water potential. The main aim of salt tolerance is, therefore, to increase water use efficiency under salinity. To obtain this effect, some plants such as the facultative halophyte *Mesembryanthemum crystallinum* shift their C3 mode of photosynthesis to CAM [84]. This change allows the plant to reduce water loss by opening stomata at night, thus decreasing transpiratory water loss. In salt-tolerant plant species, such as *Atriplex lentoformis*, there was a shift from the C3 to the C4 pathway in response to salinity [85].

Induction of antioxidative enzymes by salinity

All environmental stresses have been reported to lead to the production of reactive oxygen species (ROS) that cause oxidative damage [86]. Plants possess efficient systems for scavenging active oxygen species that protect against destructive oxidative reactions [87]. As part of this system, antioxidative enzymes are key elements of the defense mechanisms. Some of these enzymes are as catalase (CAT), glutathione reductase (GR), superoxide dismutase (SOD) and glutathione-S-transferase (GST) [5]. Superoxide dismutase, for example, metabolies oxygen (O_2) radicals to hydrogen peroxide (H_2O_2), protecting cells from damage. Catalase, ascorbate peroxidase, and a variety of peroxidases catalyze the subsequent breakdown of H_2O_2 to water and oxygen. Plants with high levels of antioxidants have been reported to have greater resistance to this oxidative damage [5]. Studies reported increased activities of the antioxidative enzymes in plants under salt stress [88]. They found a correlation between these enzyme levels and salt tolerance.

Induction of plant hormones by salinity

The levels of plant hormones such as ABA increase with high salt concentration. Abscisic acid is responsible for the alteration of salt-induced genes, and these genes are predicted to play an important role in the mechanism of salt tolerance [5]. The inhibitory effect of NaCl on photosynthesis, growth and translocation of assimilates has been found to be alleviated by ABA [5]. Increase of Ca uptake is associated with the rise of ABA under salt stress and thus contributes to membrane integrity maintenance, which enables plants to regulate uptake and transport under high levels of external salinity in the longer period. ABA has been reported to reduce ethylene release and leaf abscission under salt stress probably by decreasing the accumulation of toxic Cl ions in leaves. Other plant hormones found to accumulate in the presence of salt are jasmonates which have been reported to have important role in salt tolerance [5].

CONCLUSION

Medicinal and aromatic plants are cultivated for different plant parts and their active constituents are used in many ways, especially for drugs. Owing to their high curing value and wild occurrence in diverse environments, they have been considered to be promising plants for marginal lands, new reclaimed-soils and semi-arid regions. The high yielding genotypes of these plants are very encouraging, because a substantial number of literatures reports on the response of medicinal and aromatic plants to salinity stress. Little information is available on medicinal and aromatic plants. The general objective of the future studies is better understanding of the response of medicinal and aromatic plants to salinity stress by evaluation of the relative tolerance of different medicinal and aromatic plants and their sensitivity at different plant stages; and how different environmental conditions affect salt-stressed medicinal and aromatic plants; morphological and physiological traits that contribute to salinity tolerance in medicinal and aromatic plants; the ameliorative effects of nutrition and other treatments on growth, mineral uptake, photosynthesis and active constituents of salt-stressed plants; alleviate the mechanisms of salt resistance in medicinal and aromatic plants.

Saline lands can be converted to more productive plant lands by a number of farm management practices:

1. better farm practices, such as drip or micro-jet irrigation; cultivation of deep rooted perennial plants or trees;
2. amelioration through fertilization.

Salinity causes nutrient imbalances, mainly resulting in lower concentrations of the macro-elements (N, P, K and Ca) in plants. Hence, the most direct way to recover the normal nutrient concentrations within the plant would be by raising their concentrations in the root zone by higher fertilizer dosages.

3. leaching
   Leaching soils to remove soluble salts is the most effective method known to reclaim saline soils.
4. usage of salt stress tolerant plants
   Developing of salt-tolerant plant genotypes through the use of plant-breeding strategies involving the introgression of the genetic background from salt-tolerant wild species into cultivated plants.

REFERENCES

1. Shao HB, Chu LY Jaleel CA. Water-deficit stress-induced anatomical changes in higher plants. C R Biologies 2008; 331(3):215-25.
2. Nikolova MT, Ivancheva SV. Quantitative flavonoid variations of *Artemisia vulgaris* L. and *Veronica chamaedrys* L. in relation to altitude and polluted environment. Acta Biol Szegediensis 2005; 49:29-32.
3. Jamil M, Lee DB, Jung KY, Lee SC, Rha E.S. Effect of salt (NaCl) stress on germination and early seedling growth of four vegetables species. JCEA 2006; 7(2):273-282.
4. Sreenivasulu N, Sopory SK, Kavi Kishor PB. Deciphering the regulatory mechanisms of abiotic stress tolerance in plants by genomic approaches. Gene 2007; 388(1-2):1-13.
5. Omami EN, Hammes PS, Robbertse PJ. Differences in salinity tolerance for growth and water-use efficiency in some amaranth (*Amaranthus* spp.) genotypes. New Zeal J Crop Hort Sci 2006; 34:11-22.
6. Ponnamperuma FN. Effects of flooding on soils. In: Kozlowski TT, ed. Flooding and plant growth. New York 1984:9-45.
7. Sosa L, Llanes A, Reinoso H, Reginato M, Luna V. Osmotic and specific ion effect on the germination of *Prospis strombulifera*. Ann Bot 2005; 96:261-7.
8. Miceli A, Moncada A, D'Anna F. Effect of water salinity on seeds-germination of *Ocimum basilicum* L., *Eruca sativa* L. and *Petroselinum hortense* Hoffm. Acta Hort (ISHS) 2003; 609:365-70.
9. Ramin AA. Effects of salinity and temperature on germination and seedling establishment of sweet basil (*Ocimum basilicum* L.). J Herbs Spices Med Plants 2005; 11(4):81-90.
10. Ali RM, Abbas HM, Kamal RK. The effects of treatment with polyamines on dry matter, oil and flavonoid contents in salinity stressed chamomile and sweet marjoram. Plant Soil Environ 2007; 53:529-43.
11. Belaqziz R, Romane A, Abbad A. Salt stress effects on germination, growth and essential oil content of an endemic thyme species in Morocco (*Thymus maroccanus* Ball.). J Applied Sci Res 2009; 5(7):858-63.
12. Rahman M, Soomro U, Zahoor-Ul-Hag M, Gul Sh. Effects of NaCl salinity on wheat (*Triticum aestivum* L.) cultivars. World J Agri Sci 2008; 4(3):398-403.
13. Baatour OR, Kaddour W, Wannes A, Lachaal M, Marzouk, B. Salt effects on the growth, mineral nutrition, essential oil yield and composition of marjoram (*Origanum majorana*). Acta Physiol Plant 2010; 32:45-51.
14. Munns R. Comparative physiology of salt and water stress. Plant Cell Environ 2003; 25:239-50.
15. Rout NP, Shaw BP. Salt tolerance in aquatic macrophytes: ionic relation and interaction. Biol Plant 2001; 55:91-5.
16. Ozturk A, Unlukara A, Ipekl A, Gurbuz B. Effect of salt stress and water deficit on plant growth and essential oil content of lemon balm (*Melissa officinalis* L.). Pak J Bot 2004; 36(4):787-92.
17. Hendawy SF, Khalid KhA. Response of sage (*Salvia officinalis* L.) plants to zinc application under different salinity levels. J Appl Sci Res 2005; 1:147-55.
18. Ezz El-Din AA, Aziz EE, Hendawy SF, Omer EA. Response of *Thymus vulgaris* L. to salt stress and alar (B9) in newly reclaimed soil. J Appl Sci Res 2009; 5(12):2165-70.
19. Shalan MN, Abdel-Latif TAT, Ghadban EA E El. Effect of water salinity and some nutritional compounds of the growth and production of sweet marjoram plants (*Majorana hortensis* L.). Egypt J Agric Res 2006; 84(3):959.
20. Al-Amier H, Craker LE. In-Vitro selection for stress tolerant spearmint. Reprinted from: Issues in new crops and new uses. J. Janick and A. Whipkey (eds.). ASHS Press, Alexandria, VA. 2007:306-10.

21. Abd El-Wahab MA. The efficiency of using saline and fresh water irrigation as alternating methods of irrigation on the productivity of *Foeniculum vulgare* Mill subsp. vulgare var. vulgare under North Sinai conditions. Res J Agr Biol Sci 2006; 2(6):571-7.
22. Aziz EE, Al-Amier H, Craker LE. Influence of salt stress on growth and essential oil production in peppermint, pennyroyal, and apple mint. J Herbs Spices Med Plants 2008; 14(1 & 2):77-87.
23. Baghalian K, Haghiry A, Naghavi MR, Mohammadi A. Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.). Scientia Hort 2008; 116:437-41.
24. Leithy S, Gaballah MS, Gomaa AM. Associative impact of bio-and organic fertilizers on geranium plants grown under saline conditions. Int J Acad Res 2009; 1(1):17-23.
25. Najafian S, Khoshkhui M, Tavallali V, Saharkhiz MJ. Effect of salicylic acid and salinity in thyme (*Thymus vulgaris* L.): investigation on changes in gas exchange, water relations, and membrane stabilization and biomass accumulation. Aust J Basic Appl Sci 2009; 3(3):2620-6.
26. Zaki MF, Abou-Hussein SD, Abou El-Magd MM, El-Abagy HMH. Evaluation of some sweet fennel cultivars under saline irrigation water. Eur J Sci Res 2009; 30(1):67-78.
27. Ben Taarit MK, Msaada K, Hosni K, M.Hammami M, Kchouk E, Marzouk B. Plant growth, essential oil yield and composition of sage (*Salvia officinalis* L.) fruits cultivated under salt stress conditions. Ind Crops Prod 2009; 30(3):333-7.
28. Queslati S, Karray-Bouraoui N, Attia H, Rabhi M, Ksouri R, Lachaal M. Physiological and antioxidant responses of *Mentha pulegium* (Pennyroyal) to salt stress. Acta Physiol Plant 2010; 32(2):289-96.
29. Tabatabaie SJ, Nazari J. Influence of nutrient concentration and NaCl salinity on growth, photosynthesis and essential oil content of peppermint and lemon verbena. Turk J Agric 2007; 31:245-53.
30. Ghavami A, Ramin A. Grain yield and active substances of milk thistle as affected by soil salinity. Comm Soil Sci Plant Anal, 2008; 39(17 & 18):2608-18.
31. Razmjoo K, Heydarizadeh P, Sabzalian MR. Effect of salinity and drought stresses on growth parameters and essential oil content of *Matricaria chamomilla*. Int J Agric Biol 2008; 10(4):451-4.
32. Jaleel CA, Lakshmanan GMA, Gomathinayagam M, Panneerselvam R. Triadimefon induced salt stress tolerance in *Withania somnifera* and its relationship to antioxidant defense system. South African J Bot 2008; 74:126-32.
33. Jaleel CA, Sankar B, Sridharan R. Panneerselvam R. Soil salinity alters growth, chlorophyll content, and secondary metabolite accumulation in *Catharanthus roseus*. Turk J Biol 2008; 32:79-83.
34. Abd EL-Azim WM, Ahmed STh. Effect of salinity and cutting date on growth and chemical constituents of *Achillea fragratissima* Forssk, under Ras Sudr conditions. Res J Agr Biol Sci 2009; 5(6):1121-9.
35. Ben Taarit MK, Msaada K, Hosni M, Hammami M, Kchouk E, Marzouk B. Plant growth, essential oil yield and composition of sage (*Salvia officinalis* L.) fruits cultivated under salt stress conditions. Ind Crops Prod 2009; 30(3):333-7.
36. Hussain K, Majeed A, Nawaz Kh, Khizar HB, Nisar MF. Effect of different levels of salinity on growth and ion contents of black seeds (*Nigella sativa* L.). Curr Res J Biol Sci 2009; 1(3):135-8.
37. Ghanavati M, Sengul S. Salinity effect on the germination and some chemical components of *Chamomilla recutita* L. Asian J Chem 2010; 22(2):859-66.
38. Said-Al Ahl HAH, Mahmoud AA. Effect of zinc and/or iron foliar application on growth and essential oil of sweet basil (*Ocimum basilicum* L.) under salt stress. Ozean J Appl Sci 2010; 3(1):97-111.
39. Najafi F, Khavari-Nejad RA, Ali MS. The effects of salt stress on certain physiological parameters in summer savory (*Satureja hortensis* L.) plants. J Stress Physiol Biochem 2010; 6(1):13-21.
40. Parida AK, Das AB. Salt tolerance and salinity effects on plants: a review. Ecotoxicol Environ Saf 2005; 60:324-49.
41. Nabizadeh E. Effect of salinity on cumin growth and yield. Iranian Field Crop Res 2002; 1:20-29.
42. Ashraf M, Mukhtar N, Rehman S, Rha ES. Salt-induced changes in photosynthetic activity and growth in a potential medicinal plant Bishop's weed (*Ammi majus* L.). Photosynthetica 2004; 442(4):543-50.
43. Ashraf M, Orooj A. Salt stress effects on growth, ion accumulation and seed oil concentration in an arid zone traditional medicinal plant ajwain (*Trachyspermum ammi* [L.] Sprague). J Arid Environ 2006; 64(2):209-20.
44. Liu J, Zhu JK. A calcium homologue required for plant salt tolerance. Science 1988; 280:1934-45.
45. Nou X, Bressan RA, Hasegawa PM, Pardo JP. Iron homeostasis in NaCl stress environments. Plant Physiol 1995; 109:735-42.

46. Greenway H, Munns R. Mechanism of salt tolerance in non-halophytes. Ann Rev Plant Physiol 1980; 31:149-90.
47. Pasternak D. Salt tolerance and crop production, a comprehensive approach. Ann Rev Phytopathol 1987; 25:271-91.
48. Malkit A, Sadka A, Fisher M, Goldshlag P, Gokhman I, Zamir A. Salt induction of fatty acid elongase and membrane lipid modifications in the extreme halotolerant alga *Dunaliella salina*. Plant Physiol 2002; 129:1320-9.
49. Ali RM, Elfeky SS, Abbas H. Response of salt stressed *Ricinus communis* L. to exogenous application of glycerol and/or aspartic acid. J Biol Sci 2008; 8(1):171-5.
50. Neffati M, Marzouk B. Changes in essential oil and fatty acid composition in coriander (*Coriandrum sativum* L.) leaves under saline conditions. Ind Crops Prod 2008; 28:137-42.
51. Ben Taarit MK, Msaada K, Hosni K, Marzouk B. Changes in fatty acid and essential oil composition of sage (*Salvia officinalis* L.) leaves under NaCl stress. Food Chem 2010; 9(3):951-6.
52. Osman MEH, Elfeky SS, Abo El-Soud K, Hasan AM. Response of *Catharanthus roseus* shoots to salinity and drought in relation to vincristine alkaloid content. Asian J Plant Sci 2007; 6:1223-8.
53. Levitt J. Responses of Plants to Environmental Stresses. Volume II, 2nd ed. Academic Press, New York 1980.
54. Singh NK, Bracker CA, Hasegawa PM, Handa AK, Buckel S, Hermodson MA, Pfankock E, Regnier FE, Bressan RA. Characterization of osmotin. Athumatin-like protein associated with osmotic adaptation in plant cells. Plant Physiol 1987; 85:126-37.
55. Mansour MMF. Nitrogen containing compounds and adaptation of plants to salinity stress. Biol Plant 2000; 43:491-500.
56. Cik JK, Klejdus B, Hedbavny J, Bačkor M. Salicylic acid alleviates NaCl-induced changes in the metabolism of *Matricaria chamomilla* plants. Ecotoxicology 2009; 18(5):544-54.
57. Abraham E, Rigo G, Szekely G, Nagy R, Koncz C, Szabados L. Light-dependent induction of proline biosynthesis by abscisic acid and salt stress is inhibited by brassinosteroid in Arabidopsis. Plant Mol Biol 2003; 51:363-72.
58. Muthukumarasamy M, Gupta DS, Panneerselvam R. Influence of triadimefon on the metabolism of NaCl stressed radish. Biol Plant 2000; 43:67-72.
59. Grattan SR, Grieves CM. Salinity-mineral nutrient relations in horticultural crops. Scientia Hort 1999; 78:127-57.
60. Said-Al Ahl HAH, Hussein MS. Effect of water stress and potassium humate on the productivity of oregano plant using saline and fresh water irrigation. Ozean J Appl Sci 2010; 3(1):125-41.
61. Said-Al Ahl HAH, Meawad AA, Abou-Zeid EN, Ali MS. Response of different basil varieties to soil salinity. Int Agrophysics 2010; 24:183-8.
62. Baher ZF, Mirza M, Ghorbanli M, Rezaii MB. The influence of water stress on plant height, herbal and essential oil yield and composition in *Satureja hortensis* L. Flav Fragr J 2002; 17:275-7.
63. Neffati M, Marzouk B. Roots volatiles and fatty acids of coriander (*Coriandrum sativum* L.) grown in saline medium. Acta Physiol Plant 2009; 31(3):455-61.
64. Petropoulos S, Daferera A, Polissiou DM, Passam G, Harold C. The effect of salinity on the growth, yield and essential oils of turnip-rooted and leaf parsley cultivated within the Mediterranean region. J Sci Food Agri 2009; 89(9):1534-42.
65. Ansari SR, Frooqi AHA, Sharma S. Interspecific variation in sodium and potassium ion accumulation and essential oil metabolism in three *Cymbopogon* species raised under sodium chloride stress. J Essent Oil Res 1998; 10:413-8.
66. Charles DJ, Joly RJ, Simon JE. Effect of osmotic stress on the essential oil content and composition of peppermint. Phytochem 1990; 29:2837-40.
67. Penka M. Influence of irrigation on the contents of effective substances in officinal plants. Acta Hort 1978; 73:181-98.
68. Morales C, Cusido RM, Palazon J, Bonfill M. Response of *Digitalis purpurea* plants to temporary salinity. J Plant Nutrition 1993; 16(2):327-35.
69. Burbott AJ, Loomis WD. Evidence for metabolic turnover of monoterpenes in peppermint. Plant Physiol 1969; 44: 173-9.
70. Anitha S, Kumari BDR. Reserpine accumulation in NaCl treated calli of *Rauvolfia tetraphylla* L. Sci Asia 2006; 32:1-3.

71. Misra N, Gupta AK. Effect of salinity and different nitrogen sources on the activity of antioxidant enzymes and indole alkaloid content in *Catharanthus roseus* seedlings. J Plant Physiol, 2006; 163(1, 4):11-18.
72. Bhat MA, Ahmad S, Aslam J, Mujib A, Uzzfar M. Salinity stress enhances production of solasodine in *Solanum nigrum* L. Chem Pharm Bull 2008; 56(1):17-21.
73. Bourgou S, Kchouk ME, Bellila A, Marzouk B. Effect of salinity on phenolic composition and biological activity of *Nigella sativa*. Acta Hort 2010, 853:57-60.
74. Stepien P, Klobus G. Water relations and photosynthesi in *Cucumis sativus* L. leaves under salt stress. Biol Plantarum 2006; 50(40):610-16.
75. Siler B, Misic D, Filipovic B, Popovic Z, Cvetic T, Mijovic A. Effects of salinity on in vitro growth and photosynthesis of common centaury (*Centaurium erythraea* Rafn.). Arch Biol Sci Belgrade 2007; 59(2):129-34.
76. Koocheki A, Nassiri-Mahallati M, Azizi G. Effect of drought, salinity, and defoliation on growth characteristics of some medicinal plants of Iran. J Herbs Spices Med Plants 2008; 14(1-2):37-53.
77. Garsia-Sanchez F, Jufon JL, Carvaial M, Syverstem JP. Gas exchange, chlorophyll and nutrient contents in relation to Na^+ and Cl^- accumulation in 'Sunburst' mandarin grafted on different rootstocks. Plant Sci 2002; 162:705-12.
78. Eryilmaz F. The relationships between salt stress and anthocyanin content in higher plants. Biotechnol Biotechnol Eq 2006; 20(1):47-52.
79. Shannon MC, Grieve CM. Tolerance of vegetable crops to salinity. Scientia Hort 1999; 75:5-38.
80. Hasegawa PM, Bressan RA, Handa AV. Cellular mechanisms of salinity tolerance. Hort Sci 1986; 21:1317-24.
81. Hasegawa PM, Bressan RA, Zhu JK, Bohnert HJ. Plant cellular and molecular responses to high salinity. Annu Rev Plant Physiol 2000; 51:463-99.
82. Ghoulam C, Foursy A, Fares K. Effects of salt stress on growth, inorganic ions and proline accumulation in relation to osmotic adjustment in five sugar beet cultivars. Environ Exp Bot 2002; 47:39-50.
83. Ashraf M, O'Leary JW. Responses of some newly developed salt-tolerant genotypes of spring wheat to salt stress: II. Water relations and photosynthetic capacity. Acta Bot Neerl 1996; 45:29-39.
84. Cushman JC, Meyer G, Michalowski CB, Schmitt JM, Bohnert HJ. Salt stress leads to the differential expression of two isogenes of phosphoenolpyruvate carboxylase during crassulacean acid metabolism induction in the common ice plant. Plant Cell 1989; 1:715-25.
85. Zh J, Meinzer CF. Efficiency of C4 photosynthesis in *Atriplex lentiformis* under salinity stress. Aust J Plant Physiol 1999; 26:79-86.
86. Smirnoff N. The role of active oxygen in the response of plants to water deficit and desiccation. New Phytol 1993; 125:27-58.
87. Foyer CH, Descourvieres P, Kunert KJ. Protection against oxygen radicals: an important defence mechanism studied in transgenic plants. Plant Cell Environ 1994; 17:507-23.
88. Mittova V, Guy M, Tal M, Volokita M. Response of the cultivated tomato and its wild salt-tolerant relative *Lycopersicon pennellii* to salt-dependent oxidative stress: increased activities of antioxidant enzymes in root plastids. Free Radic Res 2002; 36:195-202.

PRODUKCJA ROŚLIN LECZNICZYCH ORAZ AROMATYCZNYCH W WARUNKACH STRESU WYWOŁANEGO ZASOLENIEM (PRZEGLĄD)

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S t r e s z c z e n i e

Zasolenie gleb oraz wód jest jednym z najpoważniejszych problemów z zakresu ochrony roślin występujących w rolnictwie. Dlatego niezbędne jest określenie czynników środowiskowych wpływających na jakość, a także wysokość plonowania roślin leczniczych i aromatycznych. Zasolenie spowodowane obecnością nadmiaru nieorganicznych soli jest charakterystyczne dla suchych oraz półsuchych terenów powstałych w wyniku działania lokalnych warunków klimatycznych, braku ewapotranspiracji, jak również przenikania wody. Większy stopień zasolenia terenów suchych spotykany jest na obszarach, na których jakość wody jest niższa. Zasolenie gleby wpływa na fizjologię roślin, wywołując zaburzenia w metabolizmie, rozwoju, wzroście, plonowaniu oraz jakości. Zasolenie wpływa także negatywnie na zdolność kiełkowania nasion, wskaźnik przetrwania roślin, ich morfologię, wydajność oraz jakość plonu. Stres wywołany zasoleniem obniża zdolność rośliny do procesów fotosyntezy oraz procesów ich oddychania. Wynikiem tego jest obniżony poziom całkowitej zawartości węglowodanów, kwasów tłuszczowych oraz białek, a także wzrostu zawartości aminokwasów, w szczególności proliny. W hodowli roślin w warunkach stresu wywołanego zasoleniem podłoża zaobserwowano wzrost poziomu produkcji niektórych metabolitów wtórnych w porównaniu z uprawą w normalnych warunkach. Zdolność roślin do tolerancji zasolenia wynika z interakcji między czynnikami środowiskowymi a warunkami zasolenia.

Słowa kluczowe: *zasolenie, rośliny lecznicze oraz aromatyczne, prolina, wzrost i rozwój, metabolity wtórne, tolerancja na zasolenie*