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Research Article

Plants physiology in response to the saline stress interconnected effects

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Abstract

Global climatic changes pose pressure both upon plant growth and also on crop distribution. Romania is threatened by the increase of salinity areas, reason of which, this topic becomes a relevant need to deepen and adapt the strategies of crop choice on a regional scale for sustainable cropping systems. Plants provide a series of physiological responses. Therefore, this study aim is to project and analyze the main interest of interconnected effects studies about salinity and crops physiological responses to this abiotic stress. A synthesis of 99 articles based on Web of Science Core Collection from the last five years was selected. The topics assessed were "climat change" combined with "soil salinity" also "plant physiological response" combined with "salt soil". The most intensive connected topics studied in the analyzed period were about abiotic stresses as restrictors of crop yield. Among stresses, drought was highlight and most researches promote various techniques regarding plant growth enhancement with obtaining salt tolerant plants. Future research trend should be placed around different principal valuable crops. Starting with plant metabolism and responses to saline stress, continuing with soil, water, gas emissions, microbiological applications, all impacted by high salt content represent an important area on future development of research.

Keywords: future trends; interconnected topics; physiological adaptive mechanisms; responses; salinity; strategies

Introduction

In Romania the concerning's about soil salinization needs a special and increased attention taking into account the associated problems that converge to global food security (Mukhopadhyay *et al.*, 2021; Eswar *et al.*, 2021), environment sustainability (Mukhopadhyay *et al.*, 2021) and sustainable development (Mukhopadhyay *et al.*, 2021; Singh, 2021) caused by the current global climate change (Corwin, 2021). As it is considered a part from the vast abiotic stress pool, soil salinity affects more than one billion hectares from over 100 countries (Singh, 2021). This extensive issue could be seen in our country on a very large scale. European Commission through Joint Research Centre Institute for Environment and Sustainability updated the digital map of salt affected soil from European Union Countries (Tóth *et al.*, 2008). This so-called digital

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soil assessment map, highlights that Romania is part of the top European countries with large areas affected by salinity together with France and Portugal (Tóth *et al.*, 2008). Many other areas from our country are classified as potentially salt affected for the assessment of increased salinity susceptibility. Hereby, Romania in clearly on the first place in Europe regarding this position of largely areas with high potential for salinization. These areas with increased potential to be affected by salinity in the future are spread along the southern, south-eastern and south-western borders (Tóth *et al.*, 2008).

Current trends of increased drought periods (Hu and Schmidhalter, 2005) and instable weather patterns have a negative impact on agriculture. The agricultural areas need irrigation; therefore, they will be threatened by salinization (Corwin, 2021). Romania has a need of promoting and assessing the soil salinity drivers at a regional scale. A hot topic is represented by plant physiological mechanism, biochemical responses (Yan *et al.*, 2013) and genetic adaptation to salinity (Fan, 2020). In recent years it was considered that the major issue is the yield. Crop yield decrease when soil salinity exceeds crop-specific range, as opposite examples highly sensitive plants are maize, wheat and very tolerant are sugar beet and barley (Zörb *et al.*, 2019).

This review aims to gather the most actual publications in the field of soil salinity based on analyzed researches, relevant information about how plants react to salinity in terms of physiological responses, were extracted to provide an overview of plant growth limits in saline environment.

Materials and Methods

Data mining was done from Web of Science Core Collection. The search was performed from four combined topics, "*global climate change*" × "*soil salinity*" and "*plant physiological response*" × "*salt soil*" respectively, accessed on 10 December 2021. The results obtained from the summary search were then refined after quick filters to address only to review articles. To highlight the changes in research topics from the last period with significant climate changes and to extract the future topic trends, the data base was refined for the period 2017-2021 publication years. After applying the filters, an excel file with 36 positions was exported for topic combination "*global climate change*" × "*soil salinity*" and another one with 63 positions for topic combination "*plant physiological response*" × "*salt soil*". In both excel files, filters were applied to search for "author keywords" (AK) and "keywords plus" (KP) separately. The articles with unique keywords had been not considered for further analysis. The most common keywords from the refined articles were listed separately along with the total number of the research articles and their corresponding sources.

Results and Discussion

The data mining process on the four combined topics resulted in a large database, which imposed the application of two different filters, in order to extract the most relevant AK and KP. The use of reviews articles as the main source of information, and a primary filter, was done based on their general, condensed and dual form of components: both quantitative and qualitative (Palmatier *et al.*, 2017). The 2017-2021 filter interval was chosen from climatic considerations, based on the proposal of World Meteorological Organization to provide prediction models annually, for a period of 5 years in advance (Hermanson *et al.*, 2022). For the topics "*global climate change*" × "*soil salinity*", a total number of 394 articles were found for the period 1991-2021. From these, only 57 were review papers. The appliance of 2017-2021 filter on this database resulted 394 articles (59.39 of the total), respectively 36 reviews (63.16%). The second combination of topics, "*plant physiological response*" × "*salt soil*", resulted in a total number of 1114 articles, from which 114 were reviews. The 2017-2021 filter reduced primarily the database to 677 articles (60.77%), from which 63 (56.25%) were reviews.

A total of 27 AK and 30 KP were found and fitted after applying the proposed methodology. After reading the abstract of all these articles and the entire articles with open access, it was extracted the most important ideas about this major threat with respect to plants physiological responses on salt stress interconnected effects. It is obvious that after a keywords search, the percent of article findings will be concentrated particularly on those topics, however, it is essential for future research to establish a field of current interest.

Results obtained from Web of Science Core Collection after searching by topic "Global Climate Change" and "Soil Salinity"

Global climate change has an impact on global food security by changing the regional conditions (Mukhopadhyay *et al.*, 2021). First there will be encountered issues regarding agricultural quantity and quality of the yield, then this will become a major threat to human health. The environment is continuously altering due to an increased intensity of water deficit, uncontrolled and unsustainable irrigation, native soil salinity, accumulation of heavy metals, soil acidity or pollution (Vives-Peris *et al.*, 2020; Mukhopadhyay *et al.*, 2021; Ondrasek and Rengel, 2021). It is also predicted that due to climate rapid changes, the sea level will rise, and the intrusion of salt water could increase soil salinity particularly in the regions close to the sea and ocean (Alae-Carew *et al.*, 2020). Salt stress interconnected effect refers to changes in metabolic, physiologic and morphologic crops characters (Vives-Peris *et al.*, 2020; Calleja-Cabrera *et al.*, 2020) because of abiotic stresses from water, soil and the improper use of nutrients (Vives-Peris *et al.*, 2020; Calleja-Cabrera *et al.*, 2020). These interconnected factors limit crop yield (Miransari and Smith, 2019) and causes ecosystem vulnerability (Del Buono, 2021).

The most dangerous abiotic stress for the root area is drought, which is nowadays enhanced by the global warming. In the last five years, many researchers took into account drought for intensive studies (Table 1).

Table 1. Background into deep around author keywords (AK) of the most important scientific work from the last five years after a search regarding: "global climate change" × "soil salinity"

AK	No.	Source
Salinity	**18**	Vives-Peris *et al.*, 2020; Del Buono, 2021; Fiodor *et al.*, 2021; Corwin, 2021; Dahal *et al.*, 2019; Bhat *et al.*, 2020; Ayuso-Calles *et al.*, 2021; Wani *et al.*, 2021; Ezquer *et al.*, 2020; Pushpalatha and Gangadharan, 2020; Wu *et al.*, 2021; Egamberdieva *et al.*, 2019; Thorne *et al.*, 2020; Singh, 2021; Chourasia *et al.*, 2021; Wen *et al.*, 2021; Ondrasek and Rengel, 2021; Chele *et al.*, 2021
Climate Change	**13**	Mukhopadhyay *et al.*, 2021; Calleja-Cabrera *et al.*, 2020; Del Buono, 2021; Majumdar and Prakash, 2020; Soares *et al.*, 2019; Ayuso-Calles *et al.*, 2021; Ajayi and Samuel-Foo, 2021; Ezquer *et al.*, 2020; Pushpalatha and Gangadharan, 2020; Egamberdieva *et al.*, 2019; Singh, 2021; Schmidt *et al.*, 2021; Borsai *et al.*, 2018
Crop Yield	**11**	Calleja-Cabrera *et al.*, 2020; Miransari and Smith, 2019; Del Buono, 2021; Alae-Carew *et al.*, 2020; Dahal *et al.*, 2019; Bhat *et al.*, 2020; Ayuso-Calles *et al.*, 2021; Ezquer *et al.*, 2020; Egamberdieva *et al.*, 2019; Wen *et al.*, 2021; Borsai *et al.*, 2018
Drought	**9**	Vives-Peris *et al.*, 2020; Del Buono, 2021; Fiodor *et al.*, 2021; Dahal *et al.*, 2019; Wani *et al.*, 2021; Ezquer *et al.*, 2020; Wu *et al.*, 2021; Thorne *et al.*, 2020; Wen *et al.*, 2021
Phytohormones/Plant Growth-Promoting/PGR/PGPR	**9**	Vives-Peris *et al.*, 2020; Bhat *et al.*, 2020; Ayuso-Calles *et al.*, 2021; Del Buono, 2021; Majumdar and Prakash, 2020; Romano-Armada *et al.*, 2020; Wu *et al.*, 2021; Egamberdieva *et al.*, 2019; Ayuso-Calles *et al.*, 2021
Abiotic Stress	**7**	Vives-Peris *et al.*, 2020; Fiodor *et al.*, 2021; Wani *et al.*, 2021; Ezquer *et al.*, 2020; Pushpalatha and Gangadharan, 2020; Chourasia *et al.*, 2021; Chele *et al.*, 2021
Environmental Quality	**6**	Mukhopadhyay *et al.*, 2021; Alae-Carew *et al.*, 2020; Soares *et al.*, 2019; Xu *et al.*, 2019; Singh, 2021; Chele *et al.*, 2021

Many approaches were found to overcome the salinity signaling such as selection of tolerant genotypes, the use of phytohormones, bioremediation, sustainable strategies for land use, soil drainage and irrigation (Miransari and Smith, 2019), the so called environmentally friendly agriculture adapted to the local and regional conditions (Mukhopadhyay *et al.*, 2021). In the case of high solutes concentration in the irrigation water, soil can immediately reach levels to which sensitive species are negatively affected. The specialists could not know for sure how many irrigated areas are affected by salt; however, it is estimated that 20% (62 million hectares) from the entire irrigated land around the world could be in this situation (Egamberdieva *et al.*, 2019). The excess of salt in the soil usually come from the accumulation of Ca, Mg, Na, sulphate, nitrate, carbonate and bicarbonate, chloride etc.

The most studied topics from the last five years after excluding the topic search keywords were issues combined with crop yield (15%), drought (12%), phytohormones (12%) and abiotic stress (10%) (Table 1; Figure 1, A). The KP fitted on AK were water use efficiency (20%), abiotic stress (12%), growth, drought and gene expression (11%) (Figure 1, B).

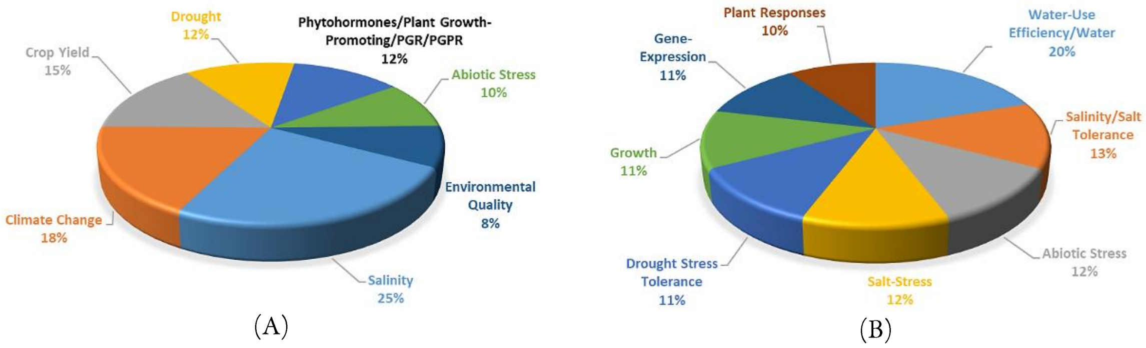


Figure 1. Percent of high interest around author keywords (A) and keywords plus (B) after "global climate change" × "soil salinity" search

The KP selected by the refined articles placed water use-efficiency on a first place (Table 2) together with AK salinity. This is based on an already known concept which present the water management, usually by unsustainable irrigation, as a driver for unbalances in the soil, such as increased salinity (Egamberdieva *et al.*, 2019; Majumdar and Prakash, 2020; Corwin, 2021; Singh, 2021).

Table 2. Background into deep around keywords plus (KP) of the most important scientific work from the last five years after a search regarding: "global climate change" × "soil salinity"

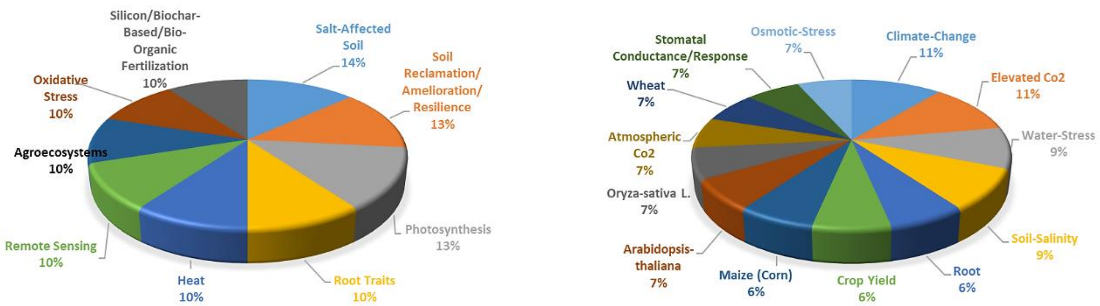
KP	No.	Source
Water-Use Efficiency/Water	12	Miransari and Smith, 2019; Del Buono, 2021; Majumdar and Prakash, 2020; Corwin, 2021; El-Ramadyao *et al.*, 2020; Ajayi and Samuel-Foo, 2021; Edokossi *et al.*, 2020; Pushpalatha and Gangadharan, 2020; Singh, 2021; Schmidt *et al.*, 2021; Chourasia *et al.*, 2021; Ondrasek and Rengel, 2021
Salinity/Salt Tolerance	8	Vives-Peris *et al.*, 2020; Ayuso-Calles *et al.*, 2021; Corwin, 2021; Bhat *et al.*, 2020; Wani *et al.*, 2021; Chourasia *et al.*, 2021; Wen *et al.*, 2021; Borsai *et al.*, 2018
Abiotic Stress	7	Vives-Peris *et al.*, 2020; Vives-Peris *et al.*, 2020; Ezquer *et al.*, 2020; Thorne *et al.*, 2020; Chele *et al.*, 2021; Borsai *et al.*, 2018
Salt-Stress	7	Vives-Peris *et al.*, 2020; Calleja-Cabrera *et al.*, 2020; Dahal *et al.*, 2019; Xu *et al.*, 2019; Ezquer *et al.*, 2020; Ullah *et al.*, 2020; Chele *et al.*, 2021
Drought Stress Tolerance	7	Vives-Peris *et al.*, 2020; Del Buono, 2021; Fiodor *et al.*, 2021; Ayuso-Calles *et al.*, 2021; Wani *et al.*, 2021; Uga, 2021; Egamberdieva *et al.*, 2019
Growth	7	Vives-Peris *et al.*, 2020; Alae-Carew *et al.*, 2020; Romano-Armada *et al.*, 2020; Ayuso-Calles *et al.*, 2021; Uga, 2021; Ullah *et al.*, 2020; Chourasia *et al.*, 2021

Gene-Expression	7	Fiodor *et al.*, 2021; Bhat *et al.*, 2020; Xu *et al.*, 2019; Uga, 2021; Arbelet-Bonnin *et al.*, 2019; Ondrasek and Rengel, 2021; Chele *et al.*, 2021
Plant Responses	6	Miransari and Smith, 2019; Corwin, 2021; Soares *et al.*, 2019; Ajayi and Samuel-Foo, 2021; Uga, 2021; Pushpalatha and Gangadharan, 2020

When trans-passing the plants tolerance threshold, even if is studied salinity range or drought effect on rhizosphere, or the entire plant, the effects are causing severe damages (Wen *et al.*, 2021). These two abiotic stresses are the main factors of limiting crop yield (Wen *et al.*, 2021).

This phenomenon could be reduced by crop biotechnologies, changes in gene expression to produce new varieties with adapted responses to different environmental stress (Vives-Peris *et al.*, 2020; Calleja-Cabrera *et al.*, 2020). If the crop tolerance would increase with the help of genetic engineering, then the effect on growth will be mitigated. With respect to anthropic intervention to target several genes (Dahal *et al.*, 2019) regulating stress tolerance enhancements to plants takes into account two main groups classification: native plants from saline soils, the group of halophytes, and plants that are not able to complete their life cycle in saline environment, the group of glycophytes. The last, only resist to a specific salt degree. Cotton, sugar beet and barley are highly tolerant crops; wheat, soybean, sorghum, lettuce - moderately tolerant; tomato, potato, cabbage, maize, sugar cane, peanut were classified as moderately sensitive and onion, carrot, melon, strawberry, peas as extremely sensitive. The plant saline syndrome seen in physiological responses could be avoided if only a single gene, the so called ‘silver bullet approach’ (used by molecular breeders) would be transferred with increases in yields on saline soils (Zörb *et al.*, 2019). Different pathways can be encountered in soil referred to sodicity as high Na^+ concentration and also the increase in total salts which produces salinity. Na ions in an unbalanced amount could decrease soil porosity, change water permeability and causes soil structure degradation, all these visible in plants physiological responses.

Based on the results with medium interest over the last five years in terms of AK, place issues like soil reclamation/amelioration/resilience (13%) and photosynthesis (13%) (Figure 2, A). Also, a number of articles approached as KP elevated CO_2 represented 11% from the total KP and only a small share about water stress (9%) (Figure 2, B).



(A) (B)

Figure 2. Percent of middle interest around author keywords (A) and keywords plus (B) after “global climate change” × “soil salinity” search

The pressure on agroecosystems soil is principally due to fertilization and improper management practices and there are conventional methods of saline soil reclamation with amendments (gypsum, $CaCl_2$), leaching, flushing or scraping. For a sustainable development, it is recommended to take into account the environment quality. The air quality is principally correlated with photosynthesis, so as high gas-changes intensity between plant and atmosphere, as much oxygen is released and biomass accumulation. In the field’s studies, the osmotic potential is assessed if salinity is present because of the irrigation water used and it is measured as electrical conductivity (Thorne *et al.*, 2020; Ayuso-Calles *et al.*, 2021). Only four articles were concentrated around AK soil reclamation/amelioration/resilience (Davidson *et al.*, 2017; Pushpalatha and

Gangadharan, 2020; Mukhopadhyay *et al.*, 2021; Ondrasek and Rengel, 2021) and photosynthesis (Dahal *et al.*, 2019; Ezquer *et al.*, 2020; Pushpalatha and Gangadharan, 2020; Thorne *et al.*, 2020), also KP highlight the general interest for water stress (Vives-Peris *et al.*, 2020; Majumdar and Prakash, 2020; Corwin, 2021; Wen *et al.*, 2022). Three articles have as author keywords agroecosystems (Egamberdieva *et al.*, 2019; Thorne *et al.*, 2020; Ondrasek and Rengel, 2021), oxidative stress (Mukhopadhyay *et al.*, 2021; Miransari and Smith, 2019; Thorne *et al.*, 2020), a root stress (Calleja-Cabrera *et al.*, 2020; Uga, 2021; Bhat *et al.*, 2020) because of heat negative effects (Dahal *et al.*, 2019; Vives-Peris *et al.*, 2020; Calleja-Cabrera *et al.*, 2020). In-between it was found remote sensing assessments (Corwin, 2021; Singh, 2021; Wen *et al.*, 2021) and unconventional fertilization methods using Silicon/Biochar-Based/Bio-Organic Fertilization (El-Ramadyao *et al.*, 2020; Thorne *et al.*, 2020; Schmidt *et al.*, 2021). The KP present in the same number of articles highlight the most important crops studied maize: (Fiodor *et al.*, 2021; Wani *et al.*, 2021; Ajayi, Samuel-Foo, 2021), wheat (Miransari and Smith, 2019; Soares *et al.*, 2019; Calleja-Cabrera *et al.*, 2020), *Oryza sativa* L. (Majumdar and Prakash, 2020; Ezquer *et al.*, 2020; Thorne *et al.*, 2020) and *Arabidopsis thaliana* (Bhat *et al.*, 2020; Ezquer *et al.*, 2020; Fiodor *et al.*, 2021) within analysed traits crop yield (Dahal *et al.*, 2019; Alae-Carew *et al.*, 2020; Corwin, 2021), roots (Thorne *et al.*, 2020; Wani *et al.*, 2021; Uga, 2021), stomatal conductance (Dahal *et al.*, 2019; Pushpalatha and Gangadharan, 2020; Wani *et al.*, 2021) and osmotic stress (Ezquer *et al.*, 2020; Thorne *et al.*, 2020; Chele *et al.*, 2021).

Due to the low number of articles with only two keyword presence from the last five years, it was selected the current trends for research regarding the influence of climate change on soil salinity and connections (Table 3).

Table 3. Studies with only two articles on one keyword (AK × KP) from the last five years after a search regarding: "global climate change" × "soil salinity"

AK	Source
Biotechnology	Miransari and Smith, 2019; Ezquer *et al.*, 2020
Seed Priming/Enhancement	Miransari and Smith, 2019; Ullah *et al.*, 2020
Water Quality	Miransari and Smith, 2019; Pushpalatha and Gangadharan, 2020
Osmotic Stress	Ayuso-Calles *et al.*, 2021; Thorne *et al.*, 2020
Carbon Sink	Ezquer *et al.*, 2020; Schmidt *et al.*, 2021
Wheat	Mukhopadhyay *et al.*, 2021; Miransari and Smith, 2019
Genetic Engineering	Xu *et al.*, 2019; Chourasia *et al.*, 2021
Nutrients	Miransari and Smith, 2019; Soares *et al.*, 2019
Oxidation Process/Oxidative Stress	Mukhopadhyay *et al.*, 2021; Wu *et al.*, 2021
Defence Mechanism/Stress-Responses	Majumdar and Prakash, 2020; Xu *et al.*, 2019
Soil Microbes	Mukhopadhyay *et al.*, 2021; Miransari and Smith, 2019
KP	**Source**
Arbuscular Mycorrhizal Fungi	Miransari and Smith, 2019; Del Buono, 2021
Electrical-Conductivity	Corwin, 2021; Singh, 2021
Electromagnetic Induction	Corwin, 2021; Ondrasek and Rengel, 2021
Solanum-tuberosum	Dahal *et al.*, 2019; Chourasia *et al.*, 2021
Nitrous-Oxide Emissions	Soares *et al.*, 2019; Schmidt *et al.*, 2021
Chemical-Composition	Soares *et al.*, 2019; El-Ramadyao *et al.*, 2020
Nutrient Concentration	Calleja-Cabrera *et al.*, 2020; Soares *et al.*, 2019
Fertilizer	El-Ramadyao *et al.*, 2020; Schmidt *et al.*, 2021
Temperature	Calleja-Cabrera *et al.*, 2020; Wu *et al.*, 2021

A water sample conductivity is due to the quantity of the ions dissolved. A primarily effect of osmotic stress in a high soil salinity field can be seed in leaf decreased rate growth and by chemical analyses is decreased quantity of antioxidants. Also, leaf cells lose more water as the soil salinity increases. The leaf appearance takes more time and reach only smaller size because of the reduction of cell division and elongation. The first growth stages are endangered while the soil solution osmotic pressure increases it restricts the seeds water absorption. Some concentrations of salt (anions like chloride, nitrate, sulphide, carbonate) act as toxic to the seedling by affecting the embryo first. The plant natural metabolism is inhibited by salt stress. During intensive growth and vegetative stages, the gas exchange is tangled because of stomata closure mechanism as a response to water stress induced by salt presence. So, a decrease assimilation of CO_2 is usually reported and a reduction of transpiration rate. Leaf expansion is drastically reducing by the lower turgor potential. Finally, the photosynthetic rate is lower because of the light interception of the reduced leaves and the organic material result in a reduced accumulation. Photosynthesis is inhibited because of high ions concentrations of sodium and chloride in the chloroplast. The involved enzyme (carbon assimilation enzyme and photosynthetic enzyme) in photosynthetic reaction is very sensitive to NaCl presence.

The nitrogen metabolism developed by nitrate reductase; the key enzyme is very sensitive to NaCl. When we analyze salt stressed plants, the level of proline is usually determined reason on which this alpha amino acid accumulates in large amounts. Plant root zone is under pressure if dissolved salts are present in high quantities. A low osmotic is generated and this decreases the soil water potential. The plant responses in this situation is in cells where chloride, sulphide and sodium are accumulating, hereby toxicity responses occur. Physiological drought was declared when the soil solution become unavailable to the plants because of salt excess and reduced soil water potential. Other plant responses to avoid salt injury are explained by excluding salt from the meristems especially from the shoots and leaves. The Casparian strip is restricting the ion movements into the xylem. Because of the passively cell membrane transition of the ions into the roots (negative electric potential), cells roots must extrude back these sodium ions to soil solution. Halophytes at moderate salinity levels grows and develops optimally because of vacuole capacity to accumulates the ions. The cell osmotic potential is regulated without damaging the salt-sensitive enzymes. Intracellular sodium concentration is affected both by calcium and potassium ions. Under saline stress, flowering is delayed, number of flowers is much reduced, abnormal metabolism and at the end a reduction of crop yield quality and quantity.

All these aspects could be further studied and developed because it could be considered taken into consideration the low number of AK and KP apparition, all these combinations represent the new research trends. It is expected that the following research period would clarify new crops under salt stress and also would highlight the best techniques for an easy adaptation of the plants when ions are present into the soil.

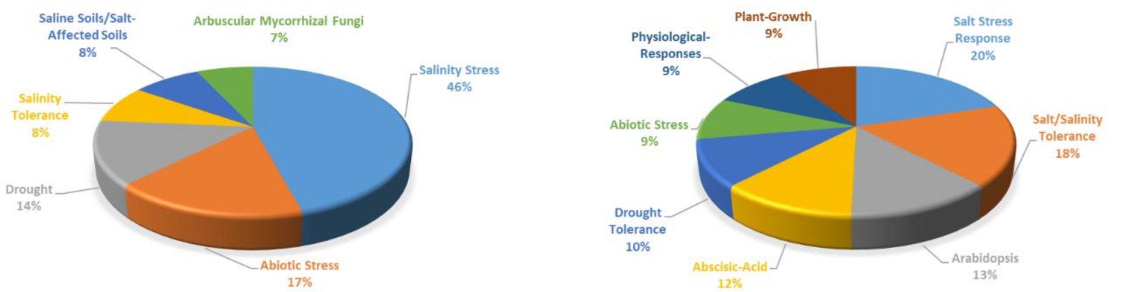
Results obtained from Web of Science Core Collection after searching by topic "plant physiological response" and "salt soil"

The previous search was considered essential because it goes into more details regarding the studies made to highlight the plant responses to salinity stress. The number of AK were extended to the same number of 27 like the previous section and keywords plus were divided into 30 categories. Same as before, the most important ideas related to plant physiological responses studies to soil salinity and connected studies were discussed further. The refined search provided the higher number of articles with keywords as topic interest slightly similar with the first database. The only difference could be seen upon the fact that soil salinity affects the plant tolerance level (Table 4). The main concern in the present is related with new ways of increasing the plant tolerance for different levels of salt present in the soil water solution.

Table 4. Background into deep around author keywords (AK) of the most important scientific work from the last five years after a search regarding: "plant physiological response" × "salt soil"

AK	No.	Source
Salinity Stress	33	Kanwar *et al.*, 2021; Zou *et al.*, 2021; Gamalero *et al.*, 2020; Ketehouli *et al.*, 2019; Evelin *et al.*, 2019; Zoerb *et al.*, 2019; Pandey *et al.*, 2019; van Zelm *et al.*, 2020; Arora *et al.*, 2020; Kirova *et al.*, 2021; Marusig *et al.*, 2020; Chourasia *et al.*, 2021; Sagar *et al.*, 2021; Chandrasekaran *et al.*, 2019; Fan, 2020; Napieraj *et al.*, 2020; Ferreira *et al.*, 2019; Akyol *et al.*, 2020; Delgado *et al.*, 2021; Mokrani *et al.*, 2020; Hao *et al.*, 2021; Cirillo *et al.*, 2018; Hussain *et al.*, 2017; Luo *et al.*, 2017; Chun *et al.*, 2018; Santander *et al.*, 2017; Shah *et al.*, 2018; Geilfus, 2018; Ilangumaran and Smith, 2017; Che-Othman *et al.*, 2017; Radhakrishnan *et al.*, 2017; Al-Thani and Yasseen, 2018; Rouphael and Kyriacou, 2018
Abiotic Stress	12	Wang *et al.*, 2020; Shahid *et al.*, 2020; Wani *et al.*, 2021; Ronga *et al.*, 2019; Kirova *et al.*, 2021; Saleem *et al.*, 2021; Chourasia *et al.*, 2021; Zou *et al.*, 2021; Rajput *et al.*, 2021; Cirillo *et al.*, 2018; Shah *et al.*, 2018; Hasanuzzaman *et al.*, 2018
Drought	10	Vives-Peris *et al.*, 2021; Wang *et al.*, 2020; Dubois *et al.*, 2020; Asthir *et al.*, 2020; Wani *et al.*, 2021; Marusig *et al.*, 2020; Chun *et al.*, 2018; Santander *et al.*, 2017; Radhakrishnan *et al.*, 2017; Al-Thani and Yasseen, 2018
Salinity Tolerance	6	Yadav *et al.*, 2021; Singh *et al.*, 2020, Sehrawat *et al.*, 2019; Fan, 2020; Napieraj *et al.*, 2020; Chourasia *et al.*, 2021
Saline Soils/Salt-Affected Soils	6	Romano-Armada *et al.*, 2020; del Rosario Marinoni *et al.*, 2019, Rahman *et al.*, 2021; Wani *et al.*, 2021; Vives-Peris *et al.*, 2021; Ferreira *et al.*, 2019
Arbuscular Mycorrhizal Fungi	5	Chandrasekaran *et al.*, 2019; Evelin *et al.*, 2019; Chun *et al.*, 2018; Santander *et al.*, 2017; Zou *et al.*, 2021

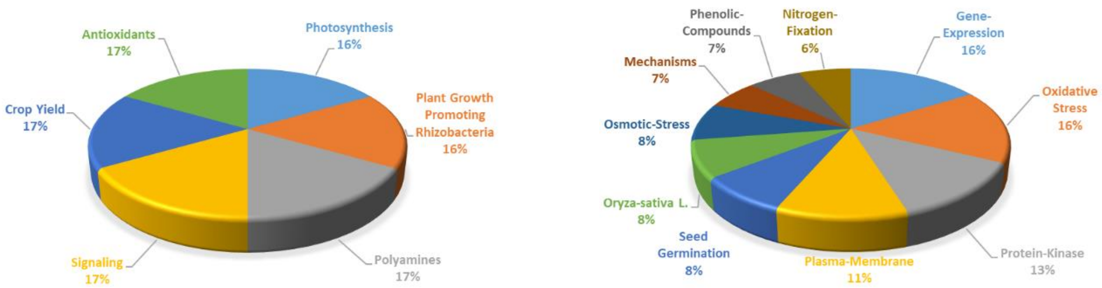
A major stress from abiotic stress pool (17%) was intensively studied drought impacts (14%) plant physiological responses if we look at AK (Figure 3, A). The keywords plus (Figure 3, B), concentrates on responses in salt stress (20%), tolerance (18%), tests were made especially on *Arabidopsis thaliana* test species (13%).



(A) (B)

Figure 3. Percent of high interest around author keywords (A) and keywords plus (B) after "plant physiological response" × "salt soil" search

The most increased interest of the last five years of studies were connected generally on salinity (46%) - as soil salinity, abiotic stress – in general (17%) and salt/saline/salt affected soils. In comparison with the first database, in terms of keywords plus, it could be seen an increased interest on test plant (*Arabidopsis*, 15%), abscisic acid and physiological responses (12%), also Protein-Kinase (9%) studies (Figure 4).



(A) (B)

Figure 4. Percent of middle interest around author keywords (A) and keywords plus (B) after "plant physiological response" × "salt soil" search

The other two main stress-related signalling pathways are salt overly sensitive pathway and abscisic acid pathway (Table 5). These and other physiological responses like plant roots morphology, plant survival rate or essential organs morphology are of high interest in present research.

Table 5. Background into deep around keywords plus (KP) of the most important scientific work from the last five years after a search regarding: "plant physiological response" × "salt soil"

KP	No.	Source
Salt Stress Response	**24**	Miransari *et al.*, 2019; Zou *et al.*, 2021; Asthir *et al.*, 2020; Ferreira *et al.*, 2019; Akyol *et al.*, 2020; Saleem *et al.*, 2021; Sagar *et al.*, 2021, Yadav *et al.*, 2021; Dubois *et al.*, 2020; Zoerb *et al.*, 2019; Wang *et al.*, 2018; Chun *et al.*, 2018; Santander *et al.*, 2017; Geilfus, 2018; Manivannan and Ahn, 2017; Ilangumaran and Smith, 2017; Hasanuzzaman *et al.*, 2018; Ahanger *et al.*, 2017; Syranidou *et al.*, 2017; Radhakrishnan *et al.*, 2017; Al-Thani and Yasseen, 2018; Teixeira *et al.*, 2017; Hussain *et al.*, 2018
Salt/Salinity Tolerance	**21**	Vives-Peris *et al.*, 2021; Wang *et al.*, 2020; Salwan *et al.*, 2019; Rahman *et al.*, 2021; Evelin *et al.*, 2019; Wani *et al.*, 2021; Singh *et al.*, 2020; Delgado *et al.*, 2021; Arora *et al.*, 2020; Kirova *et al.*, 2021; Chourasia *et al.*, 2021; Mokrani *et al.*, 2020; Hao *et al.*, 2021; Rajput *et al.*, 2021; Cirillo *et al.*, 2018; Shahid *et al.*, 2020; Zoerb *et al.*, 2019; Chourasia *et al.*, 2021; Mokrani *et al.*, 2020.
Arabidopsis	**15**	Kanwar *et al.*, 2021; Zou *et al.*, 2021; Fan, 2020; Ketehouli *et al.*, 2019; Rahman *et al.*, 2021; Zoerb *et al.*, 2019; Pandey *et al.*, 2019; van Zelm *et al.*, 2020; Akyol *et al.*, 2020; Delgado *et al.*, 2021; Hao *et al.*, 2021; Wang *et al.*, 2018; Ilangumaran and Smith, 2017; Che-Othman *et al.*, 2017; Teixeira *et al.*, 2017
Abscisic-Acid	**14**	Dubois *et al.*, 2020; Salwan *et al.*, 2019; Wani *et al.*, 2021; Singh *et al.*, 2020; van Zelm *et al.*, 2020; Ronga *et al.*, 2019; Delgado *et al.*, 2021; Chourasia *et al.*, 2021; Hao *et al.*, 2021; Hussain *et al.*, 2018; Hussain *et al.*, 2017; Wang *et al.*, 2018; Hasanuzzaman *et al.*, 2018; Che-Othman *et al.*, 2017
Drought Tolerance	**12**	Vives-Peris *et al.*, 2021; Chandrasekaran *et al.*, 2019; Fan, 2020; Romano-Armada *et al.*, 2020; Wani *et al.*, 2021; Akyol *et al.*, 2020; Arora *et al.*, 2020; Rajput *et al.*, 2021, Dubois *et al.*, 2020; Fan, 2020; Saleem *et al.*, 2021, Santander *et al.*, 2017; Chun *et al.*, 2018; Shah *et al.*, 2018; Manivannan and Ahn, 2017; Hasanuzzaman *et al.*, 2018; Radhakrishnan *et al.*, 2017
Abiotic Stress	**11**	Vives-Peris *et al.*, 2021; Napieraj *et al.*, 2020; Salwan *et al.*, 2019; Ketehouli *et al.*, 2019; Rahman *et al.*, 2021; Akyol *et al.*, 2020; Chourasia *et al.*, 2021; Hao *et al.*, 2021; Hussain *et al.*, 2018; Manivannan and Ahn, 2017; Che-Othman *et al.*, 2017
Physiological-Responses	**11**	Miransari *et al.*, 2019; Chandrasekaran *et al.*, 2019; Romano-Armada *et al.*, 2020; Ferreira *et al.*, 2019; Rahman *et al.*, 2021; Evelin *et al.*, 2019; Ronga *et al.*, 2019; Mokrani *et al.*, 2020; Sagar *et al.*, 2021; Radhakrishnan *et al.*, 2017; Chun *et al.*, 2018
Plant-Growth	**11**	Romano-Armada *et al.*, 2020; Kumar *et al.*, 2021; Ronga *et al.*, 2019; Kirova *et al.*, 2021; Chourasia *et al.*, 2021; Yadav *et al.*, 2021; Sehrawat *et al.*, 2019; Chandrasekaran *et al.*, 2019; Napieraj *et al.*, 2020; Evelin *et al.*, 2019;

A group of four articles was found when filtering the last five years after analysing the AK for the proposed topics. This middle interest found is enhanced by the increased interest which came from the previous keywords plus presented. Plant resistant to salty environments, halophytes, represent 11% interest. The same percent was found for antioxidants (Hasanuzzaman *et al.*, 2018; Evelin *et al.*, 2019; Saleem *et al.*, 2021; Hao *et al.*, 2021), signalling (Ilangumaran and Smith, 2017; Wang *et al.*, 2018; Dubois *et al.*, 2020; Hao *et al.*, 2021), photosynthesis (Luo *et al.*, 2017; Manivannan and Ahn, 2017; Yadav *et al.*, 2021), polyamines (Manivannan and Ahn, 2017; Shahid *et al.*, 2020; Napieraj *et al.*, 2020; Zou *et al.*, 2021), plant growth promoting rhizobacteria (Ilangumaran and Smith, 2017; Salwan *et al.*, 2019; Ferreira *et al.*, 2019; Arora *et al.*, 2020). Water relations resulted from water quality and different relations represent 10% interest from the total author keywords found. Plant physiological responses to salt soil were assessed by studies about plants plasma membrane (13%) (Geilfus, 2018; Ketehouli *et al.*, 2019; Miransari *et al.*, 2019; Pandey *et al.*, 2019; Dubois *et al.*, 2020; Rahman *et al.*, 2021; Hao *et al.*, 2021), gene expression to oxidative stress (13%) (Manivannan and Ahn, 2017; Al-Thani and Yasseen, 2018; Hussain *et al.*, 2018; Shah *et al.*, 2018; Wang *et al.*, 2020; Asthir *et al.*, 2020; Arora *et al.*, 2020; Delgado *et al.*, 2021; Sagar *et al.*, 2021; Rajput *et al.*, 2021), plant growth under soil salinity (11%) and issues related to seed germination (9%) (Cirillo *et al.*, 2018; Salwan *et al.*, 2019; Sehrawat *et al.*, 2019; Fan, 2020; Mokrani *et al.*, 2020).

The biological function of polyamines, a biological compound with implication on different physiological mechanisms is intensively evaluated because it improves plants salt tolerance, regulates rhizogenesis and somatic embryogenesis, ionic homeostasis and cell pH (Table 6).

Table 6. Studies with very low articles number on one keyword (author × plus) from the last five years after a search regarding: "plant physiological response" × "salt soil"

AK	No.	Source
Nitrogen Fixation	3	Yadav *et al.*, 2021; Kirova *et al.*, 2021; Rouphael and Kyriacou, 2018
Abscisic Acid ABA	3	Kanwar *et al.*, 2021; van Zelm *et al.*, 2020; Marusig *et al.*, 2020
Water Quality/Status/Relations	3	Miransari *et al.*, 2019; Chandrasekaran *et al.*, 2019; Zou *et al.*, 2021
Plants/Transgenic Plants	3	Chandrasekaran *et al.*, 2019; Rahman *et al.*, 2021; Shah *et al.*, 2018
Osmotic Stress	3	Dubois *et al.*, 2020; van Zelm *et al.*, 2020; Hao *et al.*, 2021
Adaptation	3	Fan, 2020; Du *et al.*, 2020; Saleem *et al.*, 2021
Crop Management	3	Arora *et al.*, 2020; Sagar *et al.*, 2021; Cirillo *et al.*, 2018
Halophytes	3	Fan, 2020; Rahman *et al.*, 2021; Akyol *et al.*, 2020
Plant Physiology	3	Hussain *et al.*, 2017; Gajic *et al.*, 2018; Sehrawat *et al.*, 2019
Seed Priming	2	Miransari *et al.*, 2019; Kumar *et al.*, 2021
Iron/Iron Deficiency	2	Kanwar *et al.*, 2021; Ferreira *et al.*, 2019
Enzyme Regulations	2	Napieraj *et al.*, 2020; Hasanuzzaman *et al.*, 2018
Nitric Oxide	2	Napieraj *et al.*, 2020; Wani *et al.*, 2021
Aridity	2	Gamalero *et al.*, 2020; Ferreira *et al.*, 2019
Chloroplast	2	Luo *et al.*, 2017, Geilfus, 2018
KP	**NO.**	**Source**
Nutrient-Uptake	3	Evelin *et al.*, 2019; Sagar *et al.*, 2021, Rouphael and Kyriacou, 2018
Seedling Growth	3	Sehrawat *et al.*, 2019; Kumar *et al.*, 2021; Hussain *et al.*, 2017
Mineral-Nutrition	3	Chandrasekaran *et al.*, 2019; Evelin *et al.*, 2019; Rouphael and Kyriacou, 2018
Tomato	3	Chandrasekaran *et al.*, 2019; Ronga *et al.*, 2019, Rouphael and Kyriacou, 2018
Biosynthesis	3	Zou *et al.*, 2021; Asthir *et al.*, 2020, Hussain *et al.*, 2017

Biomass Production	3	Ronga *et al.*, 2019; del Rosario Marinoni *et al.*, 2019; Hussain *et al.*, 2017
Sodium-Chloride	2	Yadav *et al.*, 2021; Shahid *et al.*, 2020
Climate Change	2	Cirillo *et al.*, 2018; Chourasia *et al.*, 2021
Chlorophyll Fluorescence	2	Luo *et al.*, 2017; Evelin *et al.*, 2019
Biochemical Changes	2	Yadav *et al.*, 2021; Rahman *et al.*, 2021
System Architecture	2	Zou *et al.*, 2021; van Zelm *et al.*, 2020
***Brassica napus* L**	2	Shahid *et al.*, 2020; Sagar *et al.*, 2021

Even if it the literature was performed with different combination of topics keywords, the result obtained is in the same direction. This is questioning the ability of a research team to find an expertise field without reporting general keywords and get on the subject of another field. In the middle of obtained classed based on author keywords and keywords plus found after a search between „plant physiological response" × "salt soil", it is clear the same trend with similar keywords as for the first search upon „global climate change" × "soil salinity".

Future research perspectives could be represented by seed different priming methods to accomplish salinity tolerance higher degree to as many varieties as possible. Also, interdisciplinary approaches with soil microbiology, especially the topic of arbuscular mycorrhizal fungi interaction in rhizosphere.

Furthermore, the biochemical links between nutrient uptake, mineral nutrition, nitrogen fixation and connected mechanisms ongoing because of sodium-chloride presence represent possible future research to be carried out in this field.

Conclusions

A deeper understanding of plant specific response to salinity is needed to secure the global food cropping systems. To prevent environmental, economic and social losses, the management and strategies must be adapted to create multiple interdisciplinary scenarios. Climate changes are visible in the continuous decrease of environmental quality, in the constant presence of drought, which increase the impact of soil salinity on potential crop yields. Plant tissue tolerance and osmotic adjustment are relatively unknown, a context that makes harder the development of the new generation salt tolerant varieties. Phytohormones and plant growth-promoting microorganisms represent a viable biotechnological solution for seed priming and enhancement of plant development, even from the first growing stages. The assessment of plants physiological response to salinity stress should be integrated as a main indicator for the development of new agronomic solutions.

Authors' Contributions

Conceptualization VS and TM; Data curation ȘG, AV and SV; Formal analysis VS, TM and SV; Funding acquisition ȘG and SV; Investigation TM and SV; Methodology TM, VS and SV; Project administration ȘG and SV; Resources TM, VS and SV; Software TM and VS; Supervision ȘG and SV; Validation AV and SV; Visualization ȘG, VS and SV; Writing - original draft TM, ȘG, VS and SV; Writing - review and editing TM, ȘG, VS and SV. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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