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WATER IN BIOLOGICAL SYSTEMS - A CHALLENGE FOR PLANT PHYSIOLOGY AND BIOPHYSICS WITHIN A CLIMATE CHANGE PERSPECTIVE

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Abstract

As the world handles with the multifaceted challenges of climate change, understanding the profound implications of water in plant system is of high interest. The aim of this study was to explore the challenges posed by water in plant physiology under climate change context. Three searches were performed in the Web of Science database using three combination of key words "water and plant physiology", "water and biophysics" and "water and climate change". Full records were assessed following author keywords and keywords plus. The database was refined by quick filters "review articles" from the last 5 years. The results from the first search highlight drought, in a share of 16%, as the most studied abiotic stress on plants (32%) and overall stress (30%), root zone (13%) and salinity effects within 13%. The second assessment brings an increased interest upon mathematical modelling (26%) and different elements dynamics (17%). The third specific search points out the present interest in genetic analysis (18%) for assessing stress tolerance (12%) that impact plant physiology (6%), stomata (6%) and chlorophyll content (3%). The perspectives for future research must be concentrated to increase especially the fields with low percentages.

Key words*: abiotic stress, crop growth, dynamics, seed, stress response.*

INTRODUCTION

Water, so called "life matrix", is the most encountered substance on our planet, and represents an essential element that sustains all living organisms (Ball, 2008). Its significance cannot be overstated, as it serves as the foundation upon which life as we know it is built (Rathi et al., 2021). As our world encounters more and more often disruptive forces of climate change, the intricate interplay between water and biological systems has become increasingly critical to our understanding of the natural cycles. Water key parameters and relations in plants and soil water availability are close connected with global climate change (Grossman, 2023). The influence upon these comes first of all from the regional patterns regarding precipitation (Feller et al., 2017).

The effects of climate change are clear in various forms, from rising temperatures and shifting weather patterns to more extreme and unpredictable events such as droughts, floods and false springs (Bartok et al., 2021; Bagheri et al., 2023; Grossman, 2023). These changes have a profound impact on ecosystems, particularly in the context of plant physiology and biophysics. Plants, which play a pivotal role in the Earth's ecosystems, are linked to water availability (Ball, 2008; Lambers el al., 2019). They serve as the primary converters of sunlight and carbon dioxide into the energy that fuels life, a process that relies heavily on water as a crucial ingredient (Aresta and Dibenedetto, 2021). The assumption that life could not exist without water is empirical because the only general prove is that an environment could not sustain live without liquid water (Ball, 2008). Within the broader spectrum of climate change, understanding the role of water in plant physiology and biophysics is of high importance. Water regulates the opening and closing of stomata (Fanourakis et al., 2020), the small pores on plant leaves that enable gas exchange, including the crucial intake of carbon dioxide for photosynthesis (Leakey et al., 2019). It also acts as a transport medium for

nutrients, minerals, and other essential compounds within the plant (Yadav et al., 2021).

The relationship between plants and water is not one-sided. It is deeply linked and intersected with the broader environment. The availability of water resources directly affects plant distribution, growth, and survival, and it has waves effects on the entire ecosystems (Rossati, 2017). Climate change introduces a new layer of complexity, as shifting precipitation patterns, prolonged droughts, and increased evaporation rates it poses different threats and challenges to the delicate equilibrium that has evolved over time (Ostmeyer et al., 2020).

In this context, the interconnected effects between water in the biological systems especially on plant functioning and physiology, holds great significance. This complex relationship between water, the environment, and plant science was taken into different studies (Lambers el al., 2019; Snyder et al., 2022; Dickman et al., 2023). The exploration of all representative studies could offer the opportunity to unlock the interest of scientists toward water role in shaping life as a unique perspective between biology and climate change.

This review aim was set to explore the challenges posed by climate change particularly in the context of plant physiology but also for a better understanding of potential solutions for mitigating its impact on biological systems. By exploring the multifaceted implications of water in the current context of a changing climate, we can highlight knowledge and insights that are crucial for the preservation of several ecosystems and the well-being of all living organisms.

METHODOLOGY

The Web of Science Core Collection–WOS database was interrogated and accessed on 25 October 2023 using three keywords in a two by two combination (Figure 1).

First search was performed with keywords combination „water and plant physiology" and resulted in 6626 articles. Then, they were first refined with quick filters by review articles in a number of 721 and the last filter applied was publication year, only the articles from the last 5 years (2019-2023) were selected and resulted in a final number of 298 reviews.

The second search was done with the keywords combination "water and biophysics" and resulted in 898 articles. All were first refined by quick filters only into reviews and there were 110 in number. The second refining following the last 5 years of publication was applied and it was obtained only 23 review on this topic combination.

The third search was made according keywords combination "water and climate change". A total of 143562 results were found, from which 9442 were review articles of which only 4168 were published in the last 5 years. The results were then refined following Web of Science Categories into Plant Sciences and it were extracted 378 reviews.

After applying all the filters and the number of reviews were refined, three excel files were downloaded with full records on all final selected documents. All data bases were further analysed based on the author keywords and keywords plus. Essential information was summarized and highlighted from all the records consulted. A *prisma diagram* was compiled to highlight the methodology used for refining the information consulted (Figure 1).

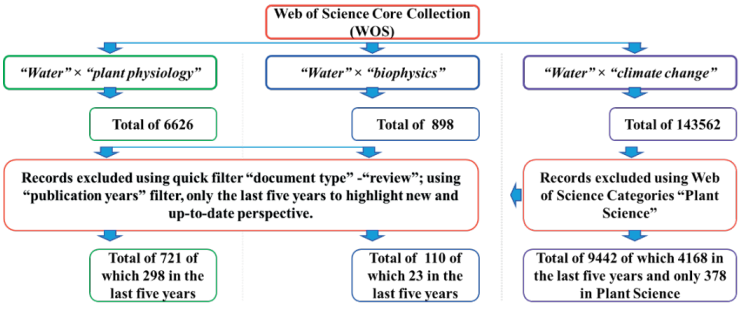

Figure 1. Prisma diagram representative for the methodology of consulted data base

RESULTS AND DISCUSSIONS

Overview on "water and plant physiology"
Regarding the results obtained from the first search in the data base, the highest percentage within author key words from this combined fields is represented by plants (32%) (Figure 2). The following area of interest was drought with 16%. This particular abiotic stress is produced in the present mainly because of extreme heat events and climate change (10%) (Da Costa et al., 2021; Abdelhakim et al., 2022; Grossman, 2023). Other type of abiotic stresses and pollution with heavy metals represents <10% of the studies regarding author key words. Bioremediation of heavy metals is essential for human wellbeing and plant physiology. Some plant species were included in the category of heavy metal absorbers for example, *Helianthus*, *Hibiscus*, *Allium* and *Eucalyptus* (Vaid et al., 2022). Phenotyping, phenology (York, 2019) and stomata (Misra et al., 2019) altogether within plant physiology domain represent a slightly low share of 6% (Chen et al., 2022). Nano-science and carbon dynamics keywords were used in less than 5% from the total of the most ten used **author key words** from the selected data base (Maswada et al., 2020; Irshad et al., 2021; Venzhik and Deryabin, 2023).

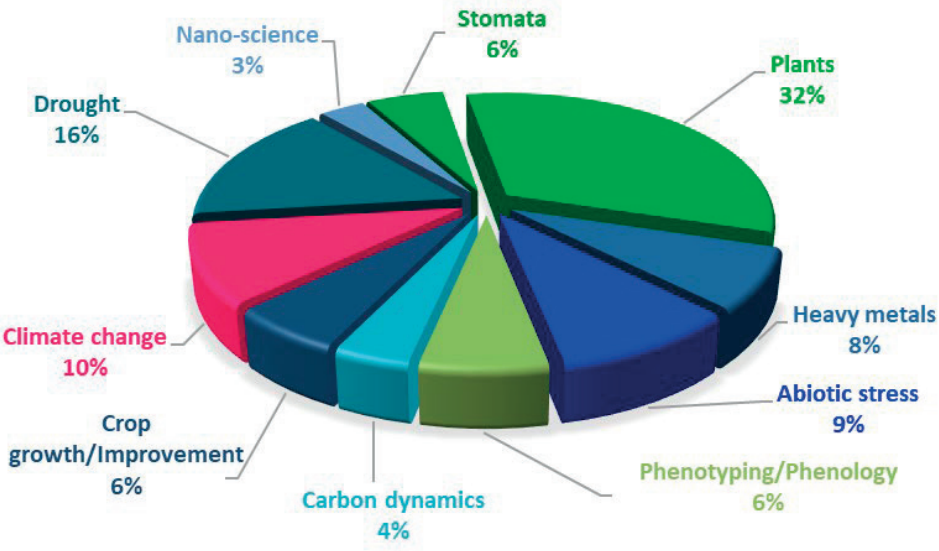

Figure 2. Principal selected author key words in percetages to highlight the importance of key words combination "water and plant physiology"

All physiological activities of the plants depend on water. Therefore, water is essential for all living organisms because is the main component of the cells (Rathi et al., 2021). The water properties are responsible for many plant functions - uptake, transport and transpiration (Lambers et al., 2019; Scharwies and Dinneny, 2019) (Figure 3).
Its distribution varies within a plant (Lambers et al., 2019). Woody plants contain low water content and other parts contain higher water content. Water represents a medium in which solutes diffusion happens through plant cells (Bhatla et al., 2018). Acts as a solvent for plant nutrition. Soil mineral nutrients from the soil solution are absorbed into the plant and transported to each cells assuring turgidity (Jones, 2012). Water sustains many biochemical reactions. An optimum water supply in plants assures and regulates the mechanical support and the rigidity to the plants. Water content is influencing plant movements. Plants adapted and developed a waxy cuticle to control and limit the water loss (Scharwies and Dinneny, 2019).

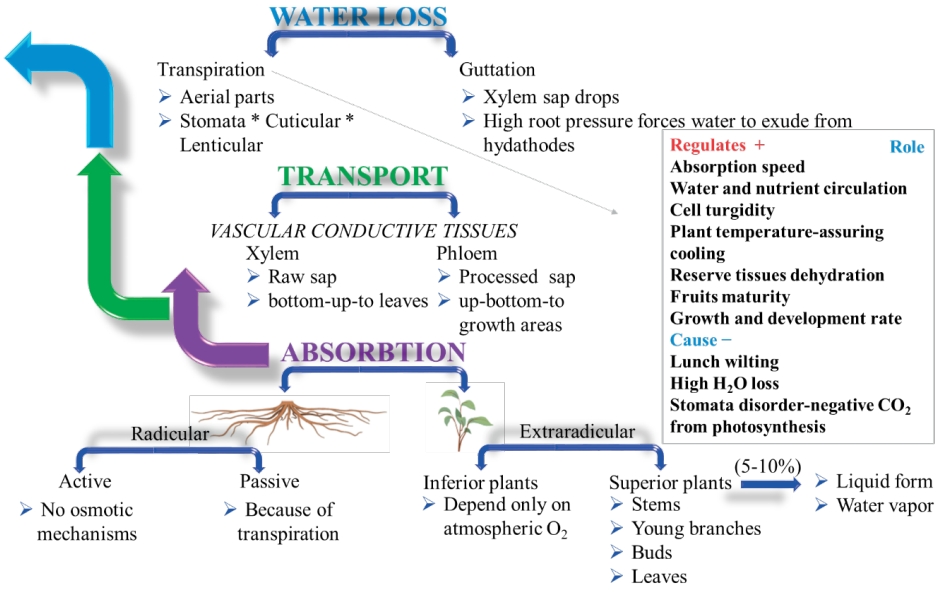

Figure 3. Plant water regime respectively uptake throughout absorption, nutrients transport and water loss ways

Low water content produce leaf folding of sensitive plants, reduce opening or closing of the flowers and of leaves stomata with direct role in gas exchange. Plant growth elongation depends on water availability. Water in photosynthesis represents the principal source of O_2. Plant heat is also regulated by water content. Water represent the medium for dissolving the fertilizers, mandatory for the foliar types. Some spores, fruits and seeds depend on water to spread and multiply. A seed appears dry, however to be viable it still must contain water. All terrestrial plants consume high water amount each day, increasing their transpiration rates throughout evaporation from the stomata leaves. Altogether certify the decisive role of water that can limit plant growth, development and productivity for all environments.

The key words plus emphasize several stresses (Vincent et al., 2020; Dalal, 2021; Venzhik et al., 2021) as being with high interest in the last five years' research field with 30% from the total ten selected keywords (Figure 4). A very specific type of stress, salinity (Javed et al., 2019), was very intensively studied with 13% share together with plant roots morphology (Arif et al., 2020). Other plant physiological parameters were mention in the scientific papers like photosynthesis (12%), stomata (8%), oxidative stress (8%) and osmotic adjustment (4%). Several essential physiological processes like photosynthesis and respiration are influenced by the electron transfer between proteins and different other biomolecules (Ball, 2008). A very low share only of 4% was formed by the keywords plus growth promoting rhizobacteria, plasma membrane and a plant test *Oryza sativa* L.

Osmotic stress tolerance can be faced by inducing a particular physiologic state starting with seed treatments previous germination. Seed priming represent a traditional physiologic method with many proved advantages (Paul et al., 2022). Seed priming emerged for obtaining equal seedlings, controlled growth and development. The seedlings obtained by primed seeds were resistant to abiotic and biotic stress.

To comply with the new agenda of SDGs (Sustainable Developmental Goals), SDG 2, SDG 12 and SDG 15, agriculture must be resilient and sustainable (Stoian et al., 2018; Pop-Moldovan et al., 2022) and within this purpose seed priming could assure a useful crop starter tool. In the context of plant stress physiology, optimizing plant physiology function by means such as seed priming is indeed a powerful, cost-effective and efficient tool (Vincent et al., 2020).

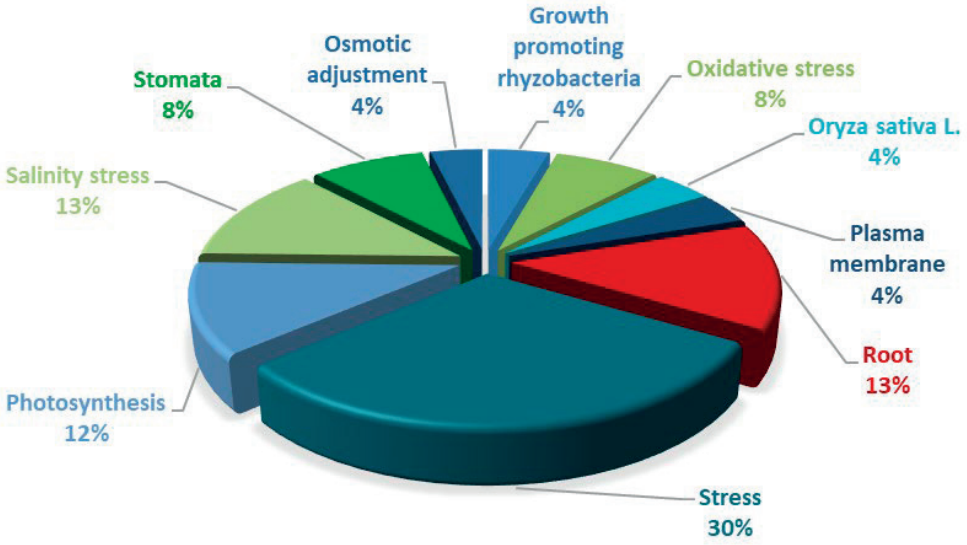

Figure 4. Principal selected key words plus in percetages to highlight the importance of key words combination "water and plant physiology"

Hydropriming pre-sowing technique, implies seed imbibition enough for enzymes activation and necessary for germination however insufficient and without germination to take place (Paparella et al., 2015). The imbibition is followed by forced dehydration suspending the seeds. Altogether induce an optimization of seeds imbibition in the field condition, uniformity at emergence, and strong vigorous seedlings and with high degree of resistance to pest and diseases (Jisha and Puthur, 2018).

Interest regarding "water and biophysics"

Author key words and key words plus are very important and offer an overview of different research fields connected to biophysics and water. Usually, independent of the obtained results, setting up models and mathematical (Wade, 2020) aspect in the most frequent accessed domain (26%) toward explaining different patterns (Figure 5). The use of biophysics methods and technologies often determines some cell wall parameters (Yoo et al., 2019), hereby cell biology (Vlasov et al., 2020; Theillet and Luchinat, 2022) stand together with the same percentages of 15%. With a medium percentage of 10% representing one of the most important trends in the present it could be found different molecular simulation (Cerutti and Case, 2019; Filipe et al., 2020) and the use of laser for different purposes (Satta et al., 2022).

In lower range percentage between 3-8, different aspects were assessed like seed aging (Nadarajan et al., 2023), membrane (8%) (Sanders, 2019; Corin and Bowie, 2022), fluorescent membrane (Filipe et al., 2020), molecular dynamics by X-ray diffraction (Cerutti and Case, 2019) and fluorescent RNA aptamer together with assessing solvation dynamics 5% (Cao et al., 2021).

Plant genetic resources conservation is necessary to avoid losing important species with different site specific adaptation qualities (Nadarajan et al., 2023). The studies concluded that seed longevity it could be influenced by many factors grouped by two categories, internal features and external environment. The internal features refer to chemical composition and structure and the external storage conditions are related with temperature, humidity and oxygen. Seeds aging can be assessed throughout different analysis such as physiological, cytological, physico-chemical, molecular and even genetic (Nadarajan et al., 2023).

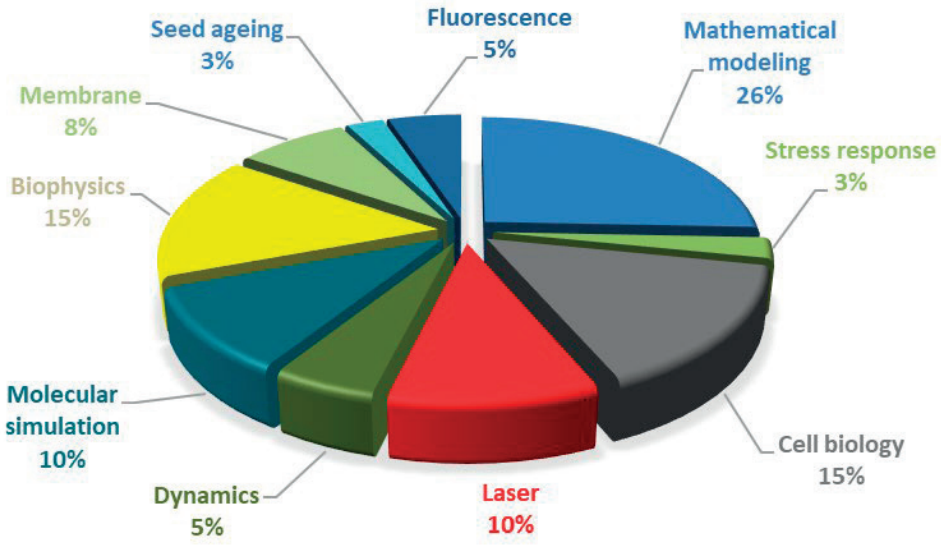

Figure 5. Principal selected author key words in percetages to highlight the importance of key words combination "water and biophysics"

The Nuclear magnetic resonance (NMR) (Figure 6) spectroscopy represents a powerful technique for assessing mobility, structure and water molecules movement in various biological systems (Kumar et al., 2022). The NMR represents the most extensively used method of assessing the water properties in biological systems (Cooke and Kuntz, 1974).

Dynamics and protein (17%), assessments were made in the last 5 years especially on the cell level. Continuous degradation of proteins, lipids and nucleic acids, are damaging the cell constituents (Nadarajan et al., 2023). The disordered proteins were used to protect the cellular environment, after exhibiting some dynamical and structural reordering (Romero-Perez et al., 2023). Therefore, protein folding is a fundamental process of life with important implications throughout biology (Corin and Bowie, 2022). Between 2011-2020, molecular dynamics (MD) simulations were studied for all major classes of fluorescent membrane probes. The cell was assessed in a share of 11% using RNA (Cao et al., 2021), DNA, Raman spectroscopy- RS (Vlasov et al., 2020) and NMR, analysis (Theillet and Luchinat, 2022). Also in the study context of bilayer-inserted fluorescence probe behavior (Filipe et al., 2020), the lipid membranes have shown 10% interest. Interest regarding keywords plus keywords NMR and X-Ray analysis was 15% respectively 10%. Since its beginnings (1950) NMR spectroscopy has been applied to cells and tissues analysis and generated valuable knowledge about this subjects (Theillet and Luchinat, 2022). X-ray crystallography has made possible the current knowledge of the structures of biological macromolecules (Cerutti and Case, 2019). Interest for Raman spectroscopy was 6%, this analysis makes important contributions to the study of structural biology, biophysics, cells, and tissues imaging towards development of various medical diagnostic tools (Vlasov et al., 2020). Low percentages interest regarding keywords plus data were seed and RNA of 4%. The emerging development of fluorescent RNA aptamers and their potential application in live cell imaging was followed (Cao et al., 2021). The evolution of knowledge on seed longevity over the last five decades in terms of seed aging mechanisms were also assessed. Seed longevity represents a complex trait and varies greatly between species and even seed lots of the same species (Nadarajan et al., 2023). Also three type of stresses were assessed respectively osmotic (Romero-Perez et al., 2023), oxidative (Yoo et al., 2019) and drought stress (Boursiac et al., 2022).

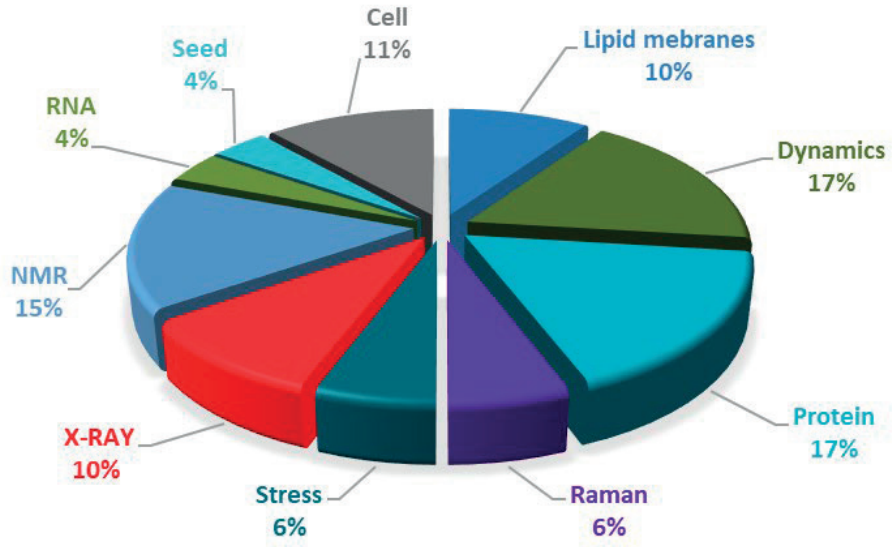

Figure 6. Principal selected key words plus in percetages to highlight the importance of key words combination "water and biophysics"

The dipole-dipole interaction in a water molecule between two protons is a cause of the Brownian rotations. Therefore, the fluctuations produce the most important mechanism of proton relaxation in liquid phase of water (Cooke and Kuntz, 1974). The water interactions strength is in the following order water and anions, water and cations and water and dipole (Cooke and Kuntz, 1974).

At a larger scale, several emerging technologies could be used to fill gaps between quantitative, morphologic and functional measurements to highlight different plant stresses. These emerging technologies could refer to nuclear, medical physics like computer tomography, positron emission tomography or magnetic resonance imaging (Galieni et al., 2021).

Studied trends regarding "water and climate change"

Omics approaches (Da Costa et al., 2021) represent quantitative methods such as metabolomics, genomics (Matallana-Ramirez et al., 2021; Singh et al., 2022), phenomics (Roitsch et al., 2022), nutrigenomics (Fischer and Efferth, 2021), proteomics (Singh et al., 2022) and offer very sensitive parameters stress dependent, representing a dynamic disruptive approach (Galieni et al., 2021).

The cell walls structure could present some microbarriers that influence the water diffusion (Figure 7). These microbarriers from the cell membrane has a length between 1-10 μm, these could be measured by pulsed NMR. Because of the role of these barriers decrease the intracellular water coefficient of diffusion, and the measurement could be done by a magnetic field gradient over a time range (Cooke and Kuntz, 1974). Further, analyzing **author keywords** from the third search (Figure 7), it can be synthetized that the climate changes have the highest share of 34%, and plant responses to abiotic stresses (16%) such as drought, salinity as well as extreme temperatures are of high interest (Ma et al., 2022; Shelake et al., 2022). These factors cause plants a certain degree of stress tolerance (12%) quite significant (Khadka et al., 2020; Rosero et al., 2020).

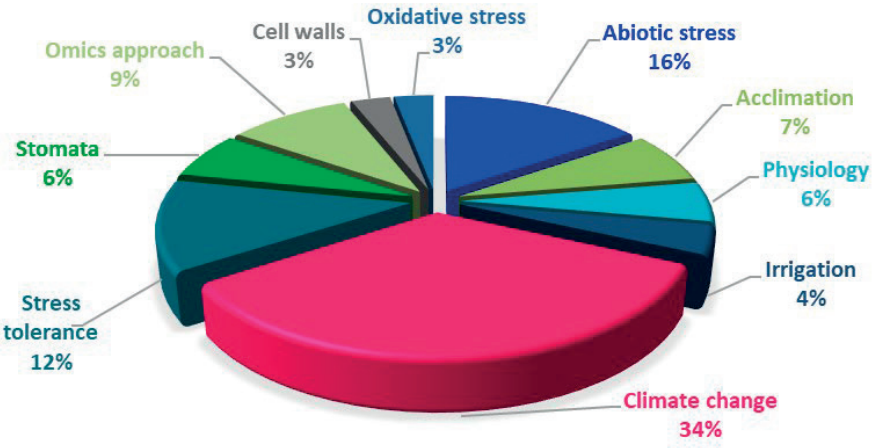

Figure 7. Principal selected author key words in percetages to highlight the importance of key words combination "water and climate change"

Newest initiatives of assessing stress tolerance are represented by Omics with 9% (Baslam et al., 2020; Kapazouglou et al., 2023). Here comes acclimatization with a percentage of 7% which presents its advantages and disadvantages, observed primarily in the physiological properties of plants (Grossman, 2023). A parameter of interest evaluated in plant physiology (6%) would be the stomata which has a percentage of 6%, similar to the percentage in Figure 2 (Driesen et al., 2020; Buckley et al., 2020; Han et al., 2021). Moreover, irrigation (4%) can have an important impact on the structure of cell walls (3%) and adaptation through mechanisms resistant to oxidative stress (3%) (Marc et al., 2022; Atta et al., 2023; Pais et al., 2023).

The highest share obtained after the third search "water and climate change" among the keywords plus (Figure 8) was climate change with 22%.

Climate change is a challenging issue for habitats (Noun et al., 2022; Soares et al., 2022; Oneț et al., 2024) and has a major impact on water availability (Hajek and Knapp, 2022; Lin et al., 2023). This has direct implications for the development of genetic analyses (18%) (Hyun, 2020; Trono and Pecchioni, 2022) and for determining the effects of drought stress (17%) (Serna, 2022; Yang and Qin, 2023) and salinity (15%) (Ahmad et al., 2022; Kumari et al., 2022; Khalid et al., 2023) on plants. The assessment of root development (7%) (Calleja-Cabrera et al., 2020; Hill et al., 2021; Heredia et al., 2022) for several plants, and the resistance of plants to various stressors signalled via abscisic acid (7%) (Habibi et al., 2023) are the focus of recent relevant research in the field. Abscisic acid, a hormone synthesized by plants in the presence of abiotic stress (5%) (Kaya et al., 2009), can counteract the negative effects on the vegetal organism (Li et al., 2020). A low share of 3% is representative of different analyzed parameters such as chlorophyll content and greenhouse gases (GHG). Climate change has occurred as a consequence of the global atmosphere deterioration caused by the elevated levels of GHG emissions (Engonopoulos et al., 2021). Chlorophyll content represents an indirect parameter of plant physiological processes function (Bhardwaj et al., 2021; Ahmad et al., 2022). Arbuscular mycorrhizal fungi (3%) can also decrease the harmful effects of some abiotic stresses through their nutrient supply (Zou et al., 2021; Corcoz et al., 2022). Moreover, these symbiotic interactions imply sustainable and eco-friendly alternatives in agricultural strategies supporting food security (Vega et al., 2021; Stoian et al., 2022).

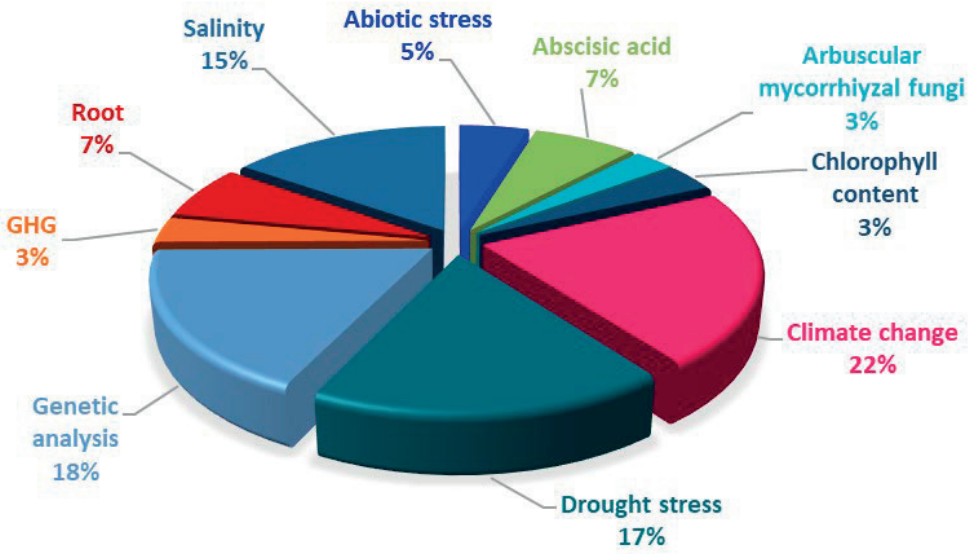

Figure 8. Principal selected key words plus in percetages to highlight the importance of key words combination "water and climate change"

CONCLUSIONS

This study provides scientometric analysis insights within the water essential role in plant physiology connected with biophysics from the Web of Science database.

The last five years' studies were concentrated mainly to assess different stress (osmotic, oxidative and drought) response mechanisms in plants with help of genetics and chemistry analysis.

The plant physiology field needs to be intensively studied to increase the studies range of 3-6% with future studies on chlorophyll content change with climate change and different applied stresses together with detailed stomata assessments.

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