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REGULAR ARTICLE

Use of images for early identification of water stress

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Abstract

The instability of climatic events intimidates the development of crops at a global level, as it can cause serious economic and social consequences in the face of increased demand for food. In this scenario, the use of images for early identification of water stress is considered a form of non-destructive identification of physical, biochemical, and plant development-related responses. Water deficit is responsible for triggering a series of responses in the plant due to the increase in the production of Reactive Oxygen Species (ROS) and the accumulation of Abscisic Acid (ABA) that promotes the closing of the stomata, limiting the evaporative cooling capacity performed by the plant, given the increase in its leaf temperature. The present article investigates the relationship between the water deficit in the plant and the consequent increase in its leaf temperature.

Keywords

Water deficit. leaf temperature. Identification. Stress. Plant.

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Introduction

In recent years, the increase in food demand associated with more intense and frequent periods of drought affected several regions in Brazil, directly impacting the energy, food, and water sectors, given their greater intensity and duration (MARENGO; SOUZA, 2018). The severity of drought periods tends to increase in regions such as Brazil, South Africa, the United States, Southern Europe, and Southeast Asia due to increased evapotranspiration and reduced rainfall (GEIRINHAS et al., 2021). In addition, these weather events can bring heat waves and consequent forest fires, thus increasing risks to population health (LINARES, 2020).

The climate has become a global issue in the face of imminent economic and social consequences due to its instability. This progressive increase in the average annual temperature of the planet was strongly intensified by the industrial revolution in the early 20th century (GOWDY, 2020). Accordingly, this change in temperature is explained by the gradual increase in economic and manufacturing activities, tied to the emission of greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), and other polluting gases (MIKHAYLOV *et al.*, 2020).

Agricultural and ecological drought events tend to increase in the coming years since the average occurrence of these episodes was only one in ten years in the period from 1850 to 1900. However, the average of drought events tends to increase over different future projections of high GHG emissions presented by the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), due to the increase in global warming levels given the influence of human activities (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2021).

The search for new techniques with the objective of mitigating the negative impacts of water deficit on plants has intensified in the current scenario of increasingly intense and frequent climatic events. In these circumstances, one of the major problems faced in agriculture is related to the reduction of crop productivity under conditions of water deficiency that depends on the intensity of the applied deficit (TAIZ *et al.*, 2017).

Water stress causes a reduction in productivity and fruit quality, in addition to directly impacting the development of the plant due to the different physiological responses, thus evidencing the need for the development of cultivars and methodologies in the search for greater tolerance of plants to situations of low availability of water in the soil (PANIGRAHI *et al.*, 2021).

The development of techniques for obtaining images as a plant analysis tool is a viable alternative because it is

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considered a non-destructive method. In addition, factors such as the possibility of real-time monitoring, subsequent storage of images in databases, and the consequent possibility of decision making in the quest to improve crop productivity are some of the advantages of this method (SILVEIRA *et al.*, 2020).

The most recent applications for obtaining plant images are classified into different categories, such as: Red, Green, and Blue (RGB) images, spectroscopy, fluorescence, thermal imaging, and three-dimensional (3D) computer graphics (SHAW, 2006). RGB, spectroscopy, and fluorescence images monitor plant nutrition through the principle of reflected light, by recording images with average grey values that represent their reflection intensity (LI *et al*., 2020). Thermal images, on the other hand, are able to represent the energy emitted by the plant by infrared radiation. Finally, 3D (three-dimensional) images are more focused on the structural physical aspects of the plant, providing the distinction between types of images through the wavelength ranges of the spectral bands (SARASKETA *et al*., 2016).

Hyperspectral Imaging (HSI) is a relatively new technology that encompasses the association of two forms of acquisition, spectroscopy, and imaging. This method performs the determination of spectral information through points mapped on each pixel in a rectangular spatial arrangement (KULKARNI, 2020). In this context, HSI can be used to acquire images of an entire plant or even just its leaves, thus making it possible to carry out quantitative or qualitative analyses. These analyses are done by obtaining individual pixels that contain spectral information on the chemical composition and, consequently, physiological state of the plant (BEHMANN *et al*., 2015).

Thermal cameras use the interaction of the plant with the environment through the processes of thermal energy exchange that can occur by conduction, radiation, and convection. These three forms of heat exchange with the environment make up the energy balance for plant leaves (BLONDER *et al*., 2020).

The objective of this article is to investigate the effect of water deficit on the increase in leaf temperature based on the assumption that a plant’s underwater insufficiency reduces its transpiration as a consequence of stomatal closure leading to a reduction in its evaporative cooling.

Water stress as a harmful factor in plants

Stress is defined as a harmful factor that causes physical, physiological, and biochemical consequences in plants, directly impacting their growth, development, and productivity. Additionally, a plant is able to develop tolerance to stress within the environment in which it is subjected. Thus, water stress is considered an abiotic factor that can occur both due to the reduction and to the excess of available water in the soil (TAIZ; ZEIGER 2006; TAIZ *et al.*, 2017).

Plants need a certain level of water present in their tissues to guarantee their development and survival. The continuous flow of water guarantees the execution of their vital processes such as photosynthesis, and nutrient absorption, as well as guarantees their evaporative cooling by the transpiration process (AUMOND, 2020). Hence, the productivity of a culture can only be fully achieved on the condition of the plant being adapted to its environment without limitations of essential resources such as water and nutrients. Yet, in recent years, studies relate the possibility of better development of plants under monitored conditions of water availability (FISHER; TURNER, 1978; AUMOND, 2020).

Water deficit directly influences plant yield as well as its evapotranspiration process, causing a limitation of its productivity if the applied deficit is not controlled (DOORENBOS; KASSAM, 1979; TAIZ *et al.*, 2017).

Reactive Oxygen Species (ROS) and the production of antioxidant enzymes

There are several types of abiotic stresses, among which drought corresponds to the term used for a period of insufficient rainfall that results in a water deficit. The plant triggers a set of strategies in order to avoid the increase in the production of so-called free radicals, identified as Reactive Oxygen Species (ROS), such as superoxide ($O_2^{\bullet-}$), hydroxyl radical ($HO^{\bullet}$), and hydrogen peroxide (H_2O_2), among others (CARVALHO; NETO, 2016).

The increase in the concentration of these reactive species is considered negative for plant development, productivity, and growth under water-stress conditions. However, it can induce the acclimatization process due to the activation of transduction pathways of the cells, characterizing a positive effect, as displayed in Figure 1 (CANDAN, 2003).

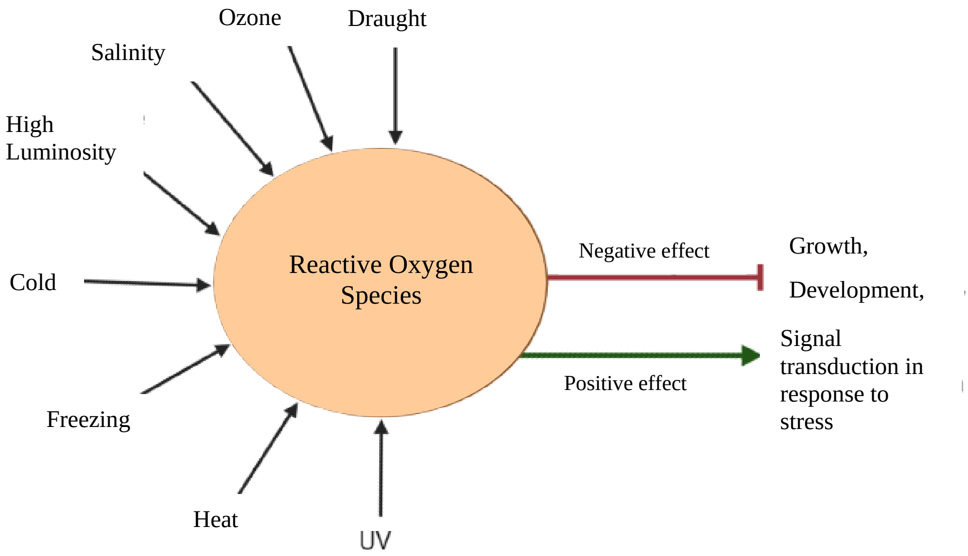


Figure 1: Abiotic stresses that influence the generation of ROS.

Source: Adapted from Taiz *et al*, (2017).

The production of antioxidant enzymes (Figure 2) is considered one of the plant strategies for the removal of ROS in view of the increase in the concentration of these species. Superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), glutathione peroxidase (GPX) and ascorbate peroxidase (APX) are considered the main ones (SHARMA *et al*., 2012; GILL; TUTEJA, 2010).

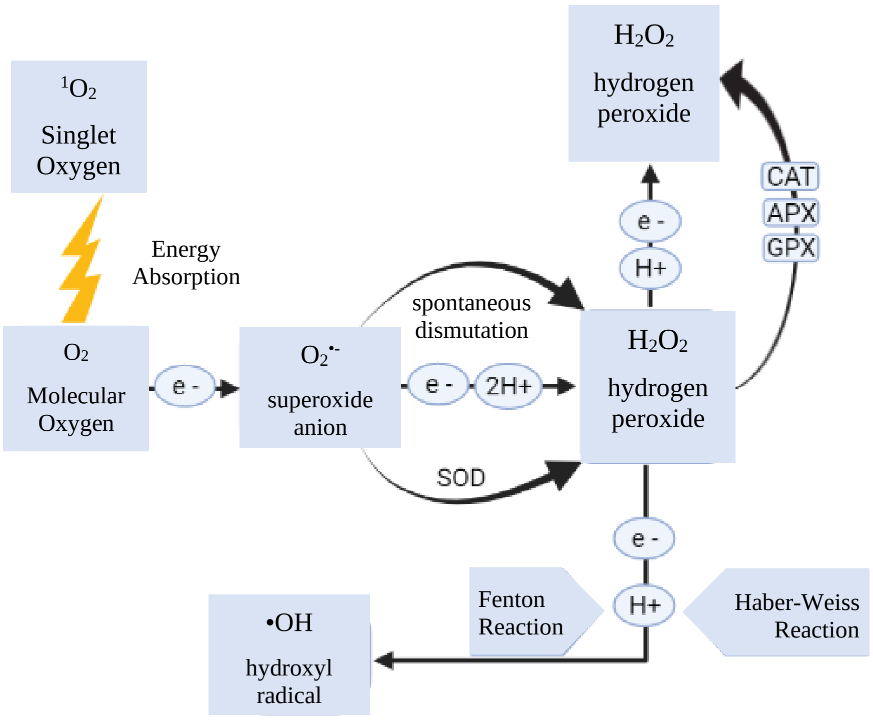


Figure 2: Route of ROS and their removal in plants.

Source: Adapted from Sharma *et al*. (2012).

These radicals are extremely reactive forms of oxygen due to the fact that they have one less electron in their orbitals, thus being able to react with proteins, DNAs, RNAs, lipids, and other cellular components. On the other hand, they can induce the production of osmoregulatory elements, more specific substances such as glycine, betaine, and proline, which are considered osmoprotective (MALLICK; MOHN, 2000).

Additionally, oxidation of photosynthetic pigments, proteins, and nucleic acids, alteration in cell wall support due to changes in the cell division cycle, and oxidation of membrane lipids are some of the consequences of increased ROS concentration (NAHAR *et al*., 2017). The production of ROS occurs from the activity of specific oxidase enzymes, such as NADPH-oxidases, aminoxidases, and peroxidases linked to the plant cell wall. The manufacture of these species (Table 1) takes place in several cellular compartments (SILVEIRA *et al*., 2010).

Table 1: Reactive Oxygen Species (ROS).

Molecules	Abbreviation	Sources
Molecular oxygen	O_2	Most common form of singlet dioxygen gas
Oxygen	$^1O_2$	UV irradiation, photoinhibition, electron transfer reactions in PSII
Superoxide anion	$O_2^{\bullet-}$	Mitochondrial electron transfer reactions, Mehler reaction (O_2 by the iron-sulphur centre of the PSI), photorespiration in glyoxysomes, reactions in peroxisomes, plasma membrane, nitrogen fixation, defence against pathogens, O_3 and OH^- in the apoplast, homologous to respiratory burn (NADPH-oxidase)
Hydrogen peroxide	H_2O_2	Photorespiration, β-oxidation, $O_2^{\bullet-}$ proton-induced
Hydroxyl Radical	$OH^{\bullet-}$	Decomposition of O_3 in the apoplast, defence against pathogens, Fenton reaction
Perhydroxyl Radical	$HO_2^{\bullet-}$	Reaction of O_3 and OH^- in the apoplast
Ozone	O_3	Electrical discharge or UV irradiation in the stratosphere, UV irradiation of troposphere combustion products
Nitric oxide	NO	Nitrate reductase, reduction of nitrite by the mitochondrial electron transport chain

Source: Adapted from Jones *et al.* (2013).

Particular metabolic cellular reactions such as photosynthesis, respiration, photorespiration, and lipid oxidation are characterized by the generation of ROS. In this way, the cell has sensors responsible for monitoring the concentration of these species. When an increase in their concentration occurs, there is the activation of the so-called inactivation mechanisms of these reactive species, such as SOD, CAT, and POD, mentioned above (TAIZ *et al*., 2017).

In the basic cycle of ROS, the signalling network is also responsible for articulating several metabolic reactions. So, the cycle seeks to carry out controlled maintenance of the levels of ROS in the cells (MAIA *et al*., 2012). Betaine glycine is responsible for preserving photochemical efficiency during the photosynthesis process, as it performs a protective function of the thylakoid membrane (ASHRAF & FOOLAD, 2007). Proline, in turn, acts in the removal of free radicals from the plant metabolism and in the regulation of the osmotic and turgidity potential in the cell, in order to guarantee the absorption of water and preserve the cellular development of the plant (MERWAD *et al*., 2018).

Stomatal closure in response to an increase in abscisic acid (ABA) concentration

Abscisic acid (ABA) is present in most tissues that make up the plant from the leaves to the hood, and even the apical bud. This means that it can be synthesized in all plant organs that have chloroplasts or other plastids, given that these represent the site of synthesis of this phytohormone (ADDICOTT *et al*., 1983).

ABA has basically two main functions, the first of which corresponds to the maintenance of seed dormancy, while the second is directly related to plant responses to water stress (TAIZ et al., 2017). The concentration of this acid depends directly on the interaction of several factors and its accumulation in plant tissues under water deficit conditions can increase up to 50 times in a few hours. This increase or decrease in the concentration of ABA in tissues is controlled through mechanisms linked to its biosynthesis, degradation, compartmentalization, and transport (PIMENTEL, 2004).

The closing of the stomata present in the leaves in response to the increase in the concentration of ABA occurs in order to reduce the loss of water caused by the transpiration process, as well as to avoid an increase in leaf temperature in the face of sunlight (DAVIES and ZHANG, 1991). From a physiological point of view, stomatal closure (Figure 3) results from the reduction in turgor pressure in the efflux channels of potassium ions (K^+) and anions (Cl^- or malate2$^-$) from the guard cells that make up the stomata. These efflux channels are voltage-regulated, and their opening is a result of the process of depolarization of the plasma membrane caused by ABA (PACHECO; LAZZARINI; ALVARENGA, 2021).

The increase in cytosolic calcium can occur either by the entry or release of the Ca^{2+} ion reserves in the endoplasmic reticulum and vacuole. Thus, the increase in cytosolic calcium causes the closing of channels and efflux present in the plasma membrane, causing its depolarization (TAIZ et al., 2017).

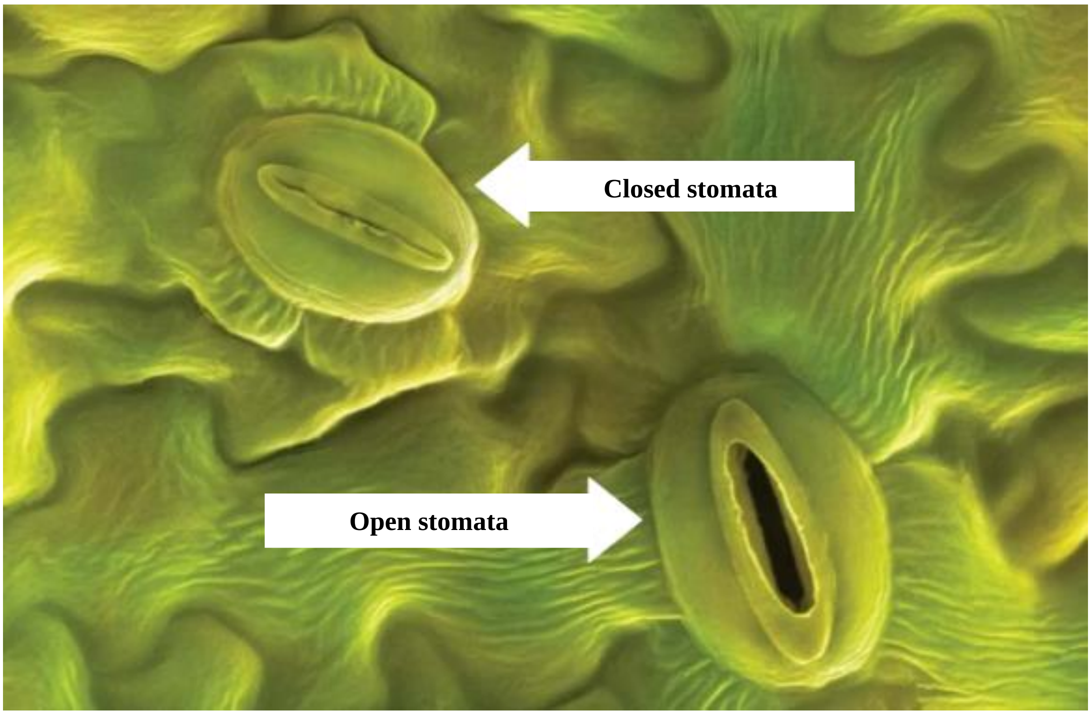


Figure 3: Closure of stomata.

Source: Adapted from Barral (2019).

In the case of corn plants, for example (Figure 4), the increase in ABA concentration causes a reduction in leaf water potential and an increase in stomatal resistance when the plant is subjected to water deficit. On the other hand, the water supply promotes a decrease in ABA concentration and stomatal resistance (BEARDSELL and COHEN, 1975).

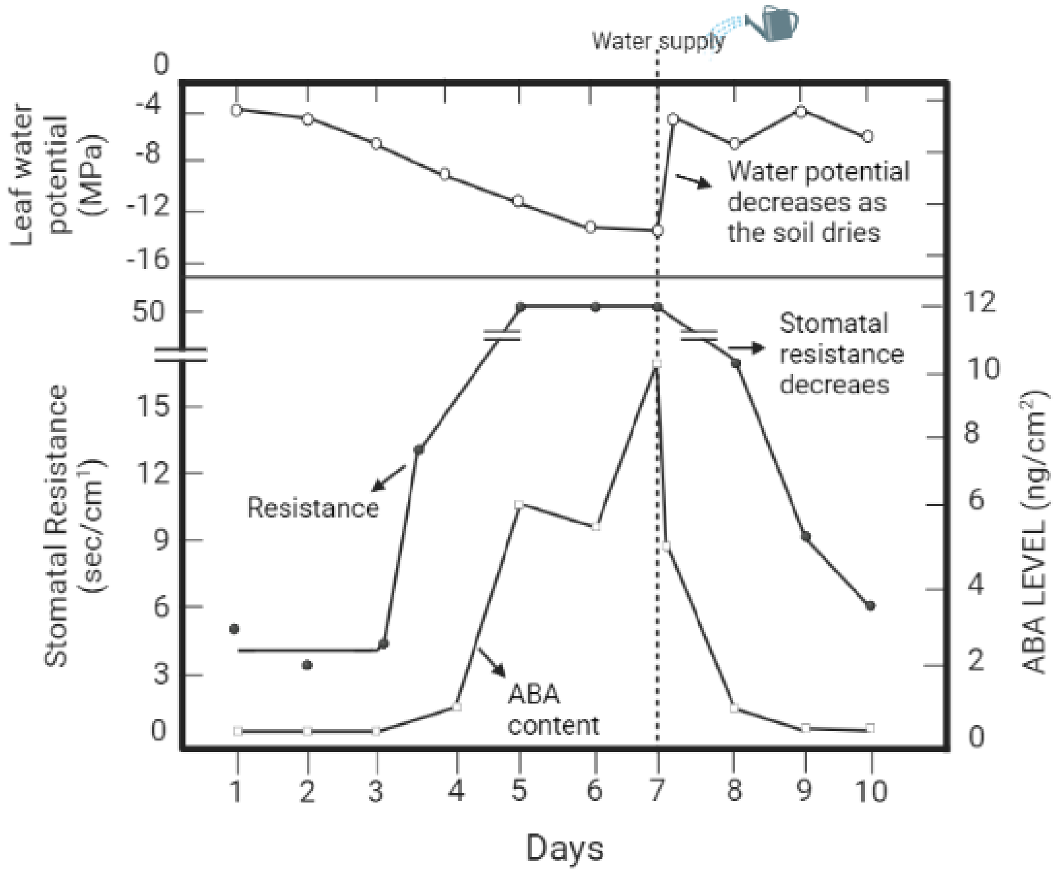


Figure 4: Behavior of parameters ABA, stomatal resistance, and water potential.

Source: Adapted from Beardsell and Cohen (1975).

The impact of water deficit on the photosynthesis cycle

Water deficit, in addition to inducing an increase in ABA production, is also responsible for inhibiting the photosynthesis process in the plant. This happens as a result of the uncoupling of photosystems I and II (PSI and PSII) that work consecutively to perform energy storage actions during photosynthesis in order to enhance cellular processes and reserve energy sources (TAIZ et al., 2017). The two photosystems are located in the thylakoid membranes of chloroplasts and differ according to their light absorption properties. Electron transport between them occurs through plastoquinone and plastocyanin proteins (VIEIRA et al., 2010).

Photosynthesis occurs in photochemical reaction centers and in light-gathering antennas. An amount of light is absorbed by chlorophylls and carotenoids in order to be stored as chemical energy through chemical bonds. However, this energy conversion is a complex process that directly depends on pigments and electron transfer proteins (ZHEN; IERSEL, 2017). Most of these pigments are characterized by the so-called antenna complex, which is responsible for collecting sunlight and transferring energy to the reaction centers (PSI and PSII) where the chemical reactions of reduction and oxidation occur (BARBER, 2009).

It is important to highlight that the photosystems are the main sites of the generation of ROS. PSI, for example, easily reduces molecular oxygen giving rise to the superoxide anion (O2-) through its ferredoxin acceptor, while PSII is responsible for the excitation of oxygen in its ground state (3O2), giving rise to its singlet (1O2) (ASADA, 2006).

Water deficit causes the inhibition of photosynthesis since the free electrons produced by the reaction centers are not transferred to coenzyme NADP+, causing the generation of ROS. Consequently, the plant starts a series of responses such as inhibition of protein synthesis, damage of DNA, oxidation of photosynthetic pigments, and peroxidation of membrane lipids (MELO et al., 2019; TAIZ et al., 2017).

The effects of water deficit on photosynthesis can be observed in a study (Figure 5) by Boyer (1970) for sunflowers (Helianthus annuus). The study shows an evident reduction of this process in the plant in view of the decrease in leaf water potential (BOYER, 1970).

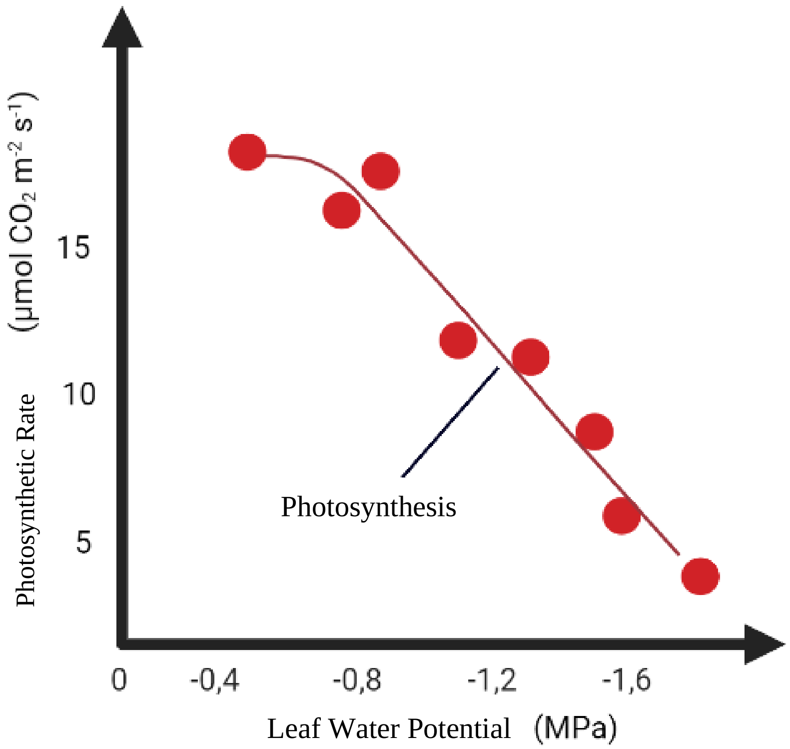


Figure 5: Effect of water stress on the photosynthetic rate of *Helianthus annuus*.

Source: Adapted from Boyer (1970).

Plant status

Plant status is related to its water potential, as this governs the transport of water across plasma membranes and is directly influenced by osmotic, pressure, and gravitational potentials. These factors are entirely associated with the limitation of plant physiological processes as described in previous topics (FLOWERS; YEO, 1986). Thus, it is evident that a plant under water deficit conditions triggers a series of initial physiological measures, such as energy consumption, to carry out the accumulation of solutes in order to maintain its turgor pressure and the development of its root in the search for water in deeper regions of the soil (MUNNS, 2002).

Physiological processes such as cell growth, photosynthesis, and crop productivity are directly influenced by the plant water potential. Normally, plant cells present a potential between 0 MPa or less (MORGAN 1984; TAIZ et al., 2017). Well-hydrated leaves have a potential between -0.2 to -1.0 MPa, whereas plants with arid climate exhibit a lower value, decreasing from -10 MPa to more extreme drought conditions. These values depend on the type of plant and the conditions to which the plant is submitted, as well as on abiotic factors (VIEIRA *et al.*, 2010; TAIZ et al., 2017), such as drought, salinity, and others (Figure 2).

In the process of transpiration associated with photosynthesis, plants undergo daily changes in their water potential due to water loss. As the water potential decreases from 0 to lower values, such as -1.2 MPa, for example, the relative water content decreases by approximately 5%. This percentage decline occurs due to the reduction of the pressure and osmotic water potential given the increase in the concentration of solutes in the plant cell (PEÑUELAS *et al.*, 1993).

Plant cells will have mechanical characteristics that vary according to the species and types of cells, causing considerable changes in cell extension and volume. *Opuntia ficus-indica*, for instance, have more flexible, larger, and thinner-walled water cells when compared to other types. So, in water deficit conditions, a water cell tends to lose a greater portion of its content than a photosynthetic cell (LEE *et al.*, 1997; TAIZ et al., 2017).

Solute concentration in water cells decreases in periods of drought due to the conversion of soluble sugars into insoluble starch granules by the polymerization reaction, generating an accumulation of solutes. *Opuntia ficus-indica* cells have more flexible walls and the decrease in solute concentration enables water loss to occur preferably in water cells, preserving their hydration (BEN-YEHOSHUA; RODOV; TAIZ et al., 2017). As the water potential decreases, ABA accumulates (Figure 6) increasing the accretion of solutes inside the cell. Yet, one can also verify the decrease in photosynthesis processes, stomatal conductance, protein synthesis, wall synthesis, and cell expansion (TAIZ et al., 2017).

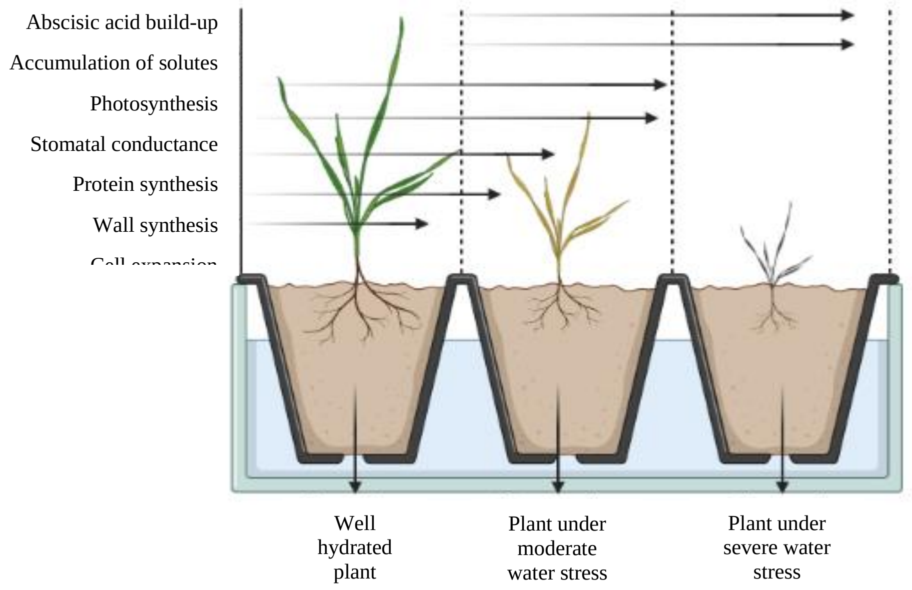


Figure 6: Plant physiological changes due to dehydration.

Source: Adapted from Hsiao and Acevedo (1975).

Anatomical plant responses to water deficit

A decrease in leaf area is considered an early adaptive response to lack of water in the cells due to the loosening of the walls which in turn results in the reduction of turgor pressure in order to reduce the amount of lost water in the transpiration process. In addition, the number of plant leaves is also affected under conditions of water stress, due to the reduction of the growth rate of the branches and the beginning of senescence and leaf abscission (COSTA *et al*., 2011).

The modification of leaf area due to phenotypic alteration of the plant is called phenotypic plasticity and includes not only changes in its size, but also involves mechanisms related to leaf orientation and leaf curling. These techniques are considered fundamental in the long term, given that a smaller leaf area directly implies a reduction in carbon and energy consumption and, consequently, in the loss of water in the transpiration process (BARTOLI *et al*., 1999).

Table 2, below, summarizes the primary and secondary responses of the plant submitted to water deficit conditions, where it is possible to verify the anatomical effects of the plant, such as reduced leaf expansion and leaf abscission.

Table 2: Primary and secondary effects of water deficit on the plant

Environmental factor	Primary effects	Secondary effects
Water deficit	Reduction of water potential Cellular dehydration Hydraulic resistance	Reduction of cellular/foliar expansion Reduction of cellular and metabolic activities Stomatal closure Photosynthetic inhibition Leaf abscission Change in leaf partition carbon Cytorrisis Cavitation Destabilization of membranes and proteins Eros production Ionic cytotoxicity Cell death

Source: Jones *et al.* (2013).

Plant interaction with light

The interaction between light and leaf can occur, basically, in four ways: reflection, scattering, absorption, and transmission. The magnetic field (MF) of light enters the sheet and interacts with atoms within its surface. The light reflection process occurs when light is directly reflected (Figure 6 (a)) (LI *et al*., 2020).

In mirroring (Figure 6 (b)), the light spreads below the surface level due to the interaction of the light ray with the structures present in the leaves. In the absorption process (Figure 6 (c)), the leaf face absorbs and accumulates the thermal energy of the photons of light that are incident on the leaf surface. Finally, in the transmission (Figure 6 (d)), the leaf atoms absorb the incident light and emit it in the waveform at the other end of the sheet (CHEN; MORRIS; MARTIN, 2006).

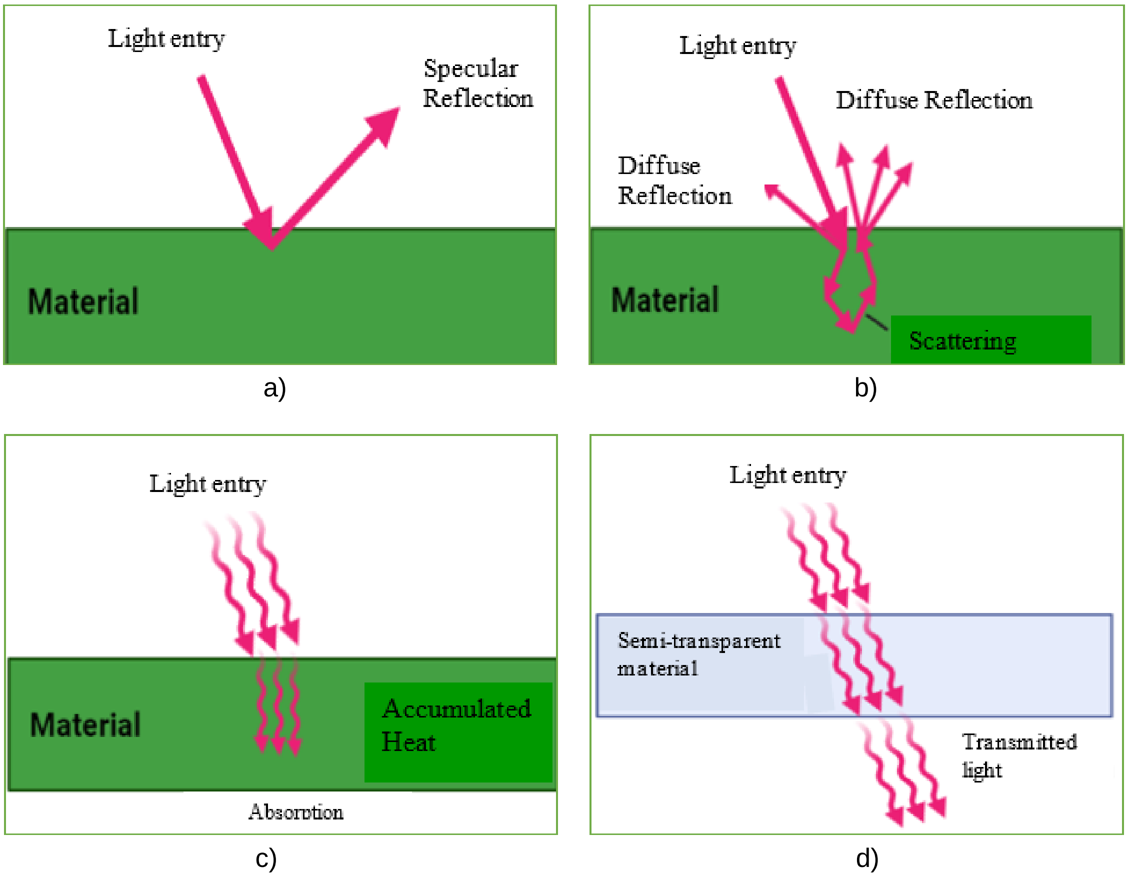


Figure 6: Interactions between light and leaf.

a) Specular reflection; b) Spreading; c) Absorption; d) Transmission.

Source: Adapted from Mirsha *et al.* (2017).

The leaves are the elements responsible for the photosynthetic activity of the plant, so the interaction between light (radiation) and the leaf is a fundamental concept for understanding this process. Electromagnetic radiation (EMR) in leaves is distinguished by the frequencies of light whose unit of measure is nanometres (nm). For example, in green leaves, a spectrograph records a reflectance in a range of the visible spectrum (VIS) between 400-700 nm (JACQUEMOUD; USTIN, 2001).

Water deficit promotes the deterioration of the chlorophyll content in the leaf resulting in an increase in the visible spectrum reflectance (VIS) for hyperspectral images (HSI). This means that the reflectance attributes of the plant are directly related to the physical and biochemical aspects of the leaf, making it possible to obtain data related to the concentration of leaf constituents (LI *et al.*, 2020).

Fundamentally, the plant has in its biochemical composition four essential elements: oxygen (O_2), carbon (CO_2), hydrogen (H), and nitrogen (N). The interaction of light with the plant is essentially related to the interaction of the bonds between these elements with light (KOKALY; CLARK, 1999). Pigments associated with plant photosynthetic activity such as chlorophylls, carotenoids, and anthocyanins are predominant in the VIS spectrum range. In response to water stress, their concentration in the leaf is directly affected due to changes in photosynthesis activities as described in previous topics (SPRINGOB *et al.*, 2003).

Images for plant analysis can be obtained through different non-destructive methods as mentioned above. Each of them has different limitations and advantages, such as the use of RGB images that are more applied in monitoring phenotypic changes of the plant specifically related to its nutrition, as it does not allow the acquisition of information on the chemical components present in the plant (GE *et al.*, 2016). On the other hand, hyperspectral, multispectral, fluorescent, and thermography images are considered passive imaging techniques, since their acquisition is based precisely on the spectral properties of radiation, reflection, and fluorescence of the leaves, enabling the provision of data at the physiological level of plant constituents (LI *et al*., 2020).

Materials and methods

A descriptive, systematic bibliographic research was carried out to select materials that could answer the research question. A literature review was carried out through the main databases, such as Scielo, Scopus, Web of Science, Google Scholar, Elsevier, Science Direct, and the journal portal from the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES) as well as some chapters of related books. Topics related to the use of images to identify water stress in plants and its relationship with the increase in leaf temperature were researched. The topic of this review is prominent and relevant currently, being present in the main journals in the area. Thus, the search for articles begun with the words “stress”, “plants”, “deficit”, “identification”, “images”, “water”, and “analysis”. Furthermore, a temporal cut was made between the years 2005 to 2021.

The abstracts of the articles were then read, in oderder to see if they fit within the objective of the study. The research question that we sought to answer in this article was: Does the effect of water deficit cause changes in leaf temperature? And what types of images exist that can help in early detection?

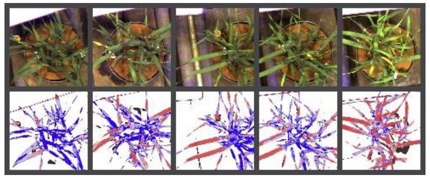
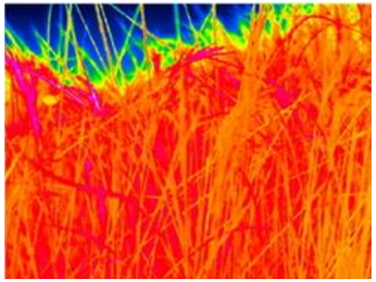
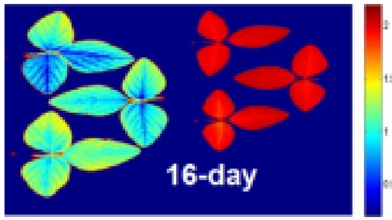
Results and discussion

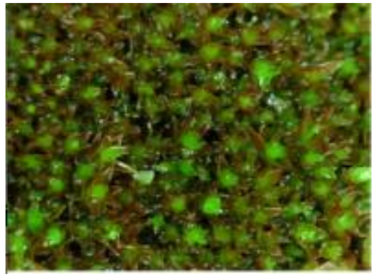
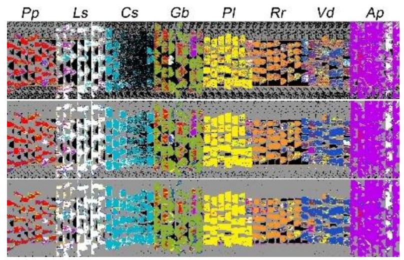
Recent applications of HSI and other methods for understanding the functional characteristics of the plant through measurements of spectral reflectance of images in the detection of water insufficiency are presented in Table 3. The control and water stress conditions directly influence the results of the analysed variables. Water deficit application can be measured in different ways using different methods of water application to the plant. Plant status relates to the evaporative demand of the soil and atmosphere, depending on the type of soil and the environment in which the plant is inserted (SCHEPERS *et al*., 1996; HATFIELD; DOLD, 2019).

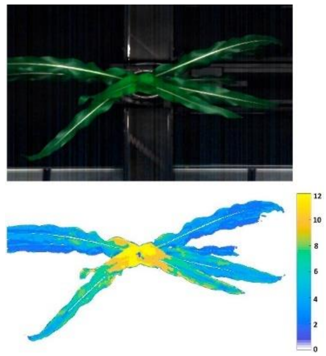
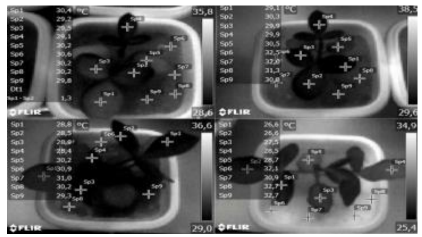
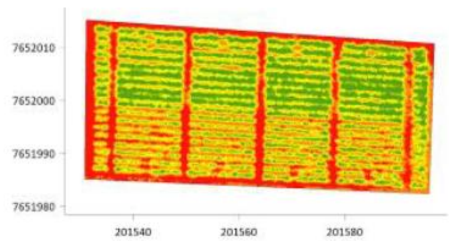
Many of the studies presented in Table 3 mention the increase in leaf temperature of different cultures subjected to conditions of different water deficits. However, the influence of external factors must be considered, since not all experiments are conducted in a greenhouse that allows greater control of these conditions, such as the incidence of sunlight that directly affects the increase in leaf temperature.

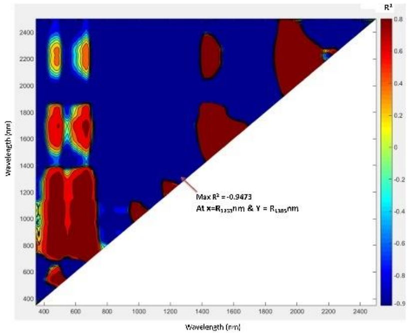
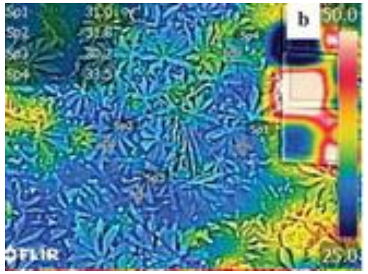
For Mittler (2006), the association of different types of abiotic stresses affects more intensely the productivity, physiology, and biomolecular responses of the plant. The combination of drought and heat is thus responsible for the greatest losses in crops due to the complete closure of the stomata and consequent increase of leaf temperature given the inhibition of water loss from the plant to the atmosphere in the form of vapor.

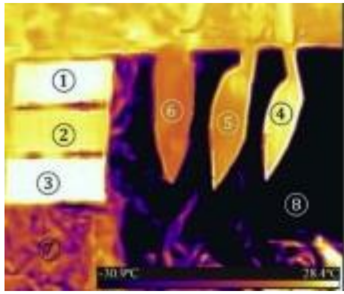
Table 1: Applications of images in the detection of water stress.

Title	Journal	Analysis Method	Culture(s)	Analyzed variables	Reference	Experimental image
Detection of early plant stress responses in hyperspectral images	*Plant, Cell & Environment*	RGB	Corn	Vegetation indexes	BEHMANN; STEINRÜCKEN; PLÜMER (2014)	
Application of thermal imaging and hyperspectral remote sensing for crop water deficit stress monitoring	*Geocarto International*	HSI	Rice	Relative water content (WRC)	KRISHNA, Gopal *et al.*, (2021)	
Detecting Drought Stress in Soybean Plants Using Hyperspectral Fluorescence Imaging	*Journal of Biosystems Engineering*	Fluorescence HSI	Soy	Fluorescence spectra	MO, Changyeun *et al.* (2015)	

Stress evaluation of Antarctic moss based on chlorophyll content and leaf density recovered from image spectroscopy data	*New Phytologist*	HSI	Moss	Vegetation indexes: Leaf pigments, leaf density	MALENOVSKÝ, Zbyněk *et al.* (2015)	
Plant species discrimination using emissive thermal infrared imaging spectroscopy	*International journal of applied Earth observation and geoinformation*	HSI (TIR)	*Prunus pérsica,* *Liquidambar styraciflua,* *Cornus sericea,* *Ginkgo biloba,* *Prunus lauracerasus,* *Rhododendron repens,* *Viburnum davidii,* *Platanoides Acer*	Stomatal conductance, leaf temperature, leaf water content and spectral emissivity	ROCK *et al.* (2016)	

Analysis of hyperspectral images for detection of drought stress and recovery in maize plants in a high-throughput phenotyping platform	*Computers and Electronics in Agriculture*	HSI	Corn	vegetation indexes	ASAARI, Mohd Shahrimie *Mohd et al.* (2019)	
Infrared thermography as a tool for early diagnosis of severe water stress in soybean	*Agrarian academy*	infrared thermography	Soy	chlorophyll fluorescence, leaf temperature and biochemical analysis: identification of antioxidant enzymes	SARAIVA, G.; ANDRADE, R.; SOUZA, G. (2014)	
Use of multispectral and thermographic images to monitor the water conditions of sugarcane	Irriga	multispectral HSI	sugarcane	vegetation indexes	DE CARVALHO SILVEIRA, Jane Maria *et al.* (2020)	

Comparison of various modelling approaches for water deficit stress monitoring in rice crop through hyperspectral remote sensing	*Agricultural water management*	HSI	rice	Relative water content (RWC)	KRISHNA, Gopal *et al.* (2019)	
Temporal dynamics of corn plant growth, water use and leaf water content using high-throughput automated RGB and hyperspectral imaging	*Computers and Electronics in Agriculture*	RGB and HSI	Corn	Leaf water content	GE, Yufeng *et al.* (2016)	
Application of infrared thermography to assess cassava physiology under water deficit condition	*Plant Production Science*	infrared thermography	Cassava	Crop water stress index (CWSI)	PIPATSITEE et al. (2018)	

Modeling of reference temperatures for calculating crop water stress indices from infrared thermography	*Agricultural Water Management*	infrared thermography	Almond	CWSI and Leaf Water Potential (LWP)	POIRIER-POCOVI, VOLDER, BAILEY, (2020)	 THERMAL PICTURE

Conclusions

The use of different techniques to obtain images of plants is an innovative and non-destructive alternative for an early identification of responses of plants submitted to conditions of water insufficiency. Nevertheless, there are still challenges regarding the standardization of evaluation of the variables that are to be analysed given the combinations of abiotic stress that can intensify the effects on the plant. Additionally, other external factors can also interfere in obtaining data related to only one factor, such as leaf temperature, which is the focus of this article.

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