Review

Elicitors and Biostimulants to Mitigate Water Stress in Vegetables

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Abstract: The acceleration of the climate crisis and increased demand for water have caused water stress in many agricultural lands worldwide. This issue is of utmost importance as water stress represents one of the most crucial challenges for the agricultural sector and food security, affecting the growth and yield of crops. Developing agricultural strategies to mitigate the adverse effects of water stress and improve crop stress tolerance and crop yield is therefore crucial. This review aimed to analyze the effect of agricultural practices such as elicitation and biostimulation on mitigating the effects of water stress in vegetables. This manuscript provides relevant and recent information about the studied effects on various vegetable species and their responses under water deficit and agricultural and non-agricultural strategies to mitigate water stress, highlighting the use of elicitors and biostimulants. Inclusion criteria were scientific reports and book chapters published from 2000 to 2024, including keywords as follows: water stress + vegetables, water deficit + effects, drought stress management, agricultural strategies for water stress management, eustressors + water stress, elicitors and biostimulants + water stress mitigation. According to the reported literature, it was found that the physiological, biochemical, and molecular responses of vegetables to water stress depended on factors such as the severity and duration of the water deficit, the plant species, and the phenological state of the plants. Traditional agronomic strategies such as tillage, mulching, and intercropping for crop drought management were evaluated. Recently, alternative strategies for mitigating the effects of water stress have gained significant interest, such as the exogenous application of phytohormones and osmoprotectants, nutrient management, and the use of UV-B light, radiation, and acoustic waves, among others, whose eustressive effects (as biostimulants and elicitors) have been demonstrated. Among these eustressors, those of physical origin show great potential for mitigating water stress. To improve the individual potential of eustressors for water stress mitigation, we proposed the combination of practices such as tillage, mulching, application of hormones and osmoprotectants, and physical elicitors and biostimulants such as gamma rays, He-Ne laser, and UV-B. Further exploration is required to establish doses, application conditions, and effects on water stress mitigation and vegetable yield, underscoring the importance and ongoing nature of this research.

Keywords: agronomic strategies; crops; drought stress; eustressor

1. Introduction

Vegetable crops are the primary source of vitamins (A, B2, B6, C, and K) and minerals. They are an important source of folic acid, dietary fibre, phenolics, and flavonoid compounds that are required for human metabolic processes [1,2]. Vegetable production is vulnerable to abiotic stresses such as extreme temperatures, salinity, mineral deficiency, and water stress [2,3]. Among these abiotic stresses, vegetable crops are highly sensitive to water stress since it reduces their yield and quality [4–6]. The effects of water stress on crop productivity depend on the plants’ phenological states. Tomatoes, eggplants, chilies,
and cucumbers are more sensitive to water stress during flowering, fruit setting, and fruit development; leafy vegetables are more sensitive during the growth and development stages; while carrots, radishes, potatoes, and turnips are more sensitive to water stress during root and tuber enlargement [5].

Plants develop various strategies to cope with water stress; however, plant responses and adaptation mechanisms depend on the vegetal species, duration, and intensity of stress [7]. Some plants adopt strategies of escape from water stress, while others have developed various resistance mechanisms through avoidance or tolerance [8,9]. Escape from drought occurs in plants that are not resistant to water deficit, but other plants have great plasticity when adapting their vegetative and reproductive cycles to water availability, with rapid phenological development [9,10]. Avoidance mechanisms consist of retaining enough water in the plant, either by modifying the root structure to improve water absorption efficiency or through stomatal closure, leaf curling, leaf abscission, reducing transpiration, and retarding growth. Tolerance mechanisms allow the plant to remain functional by regulating and adjusting diverse metabolic pathways and genes to reduce damage due to water deficit, including osmotic adjustment, elastic adjustment, and protoplastic tolerance [9,11].

Vegetables’ tolerance to water stress includes changes in physiological and biochemical metabolism mediated by the accumulation of osmoprotectants, synthesis of antioxidant compounds, osmotic adjustment, and the biosynthesis of hormones such as abscisic acid (ABA) [8,11], as well as by the expression of genes associated with stress tolerance [12,13].

Recently, efforts have intensified to study the effects of environmental stress factors on vegetables due to the challenge that climate change represents for agricultural production and food security, with the goal of establishing strategies for stress management or mitigation. Various agronomic approaches have been evaluated to alleviate the adverse effects of water stress in vegetables, such as mulching, intercropping, nutrient management, deficit irrigation, or exogenous application of hormones and osmoprotectants, with positive effects on growth and biomass accumulation [14–18], crop yield [16,19,20], and physiological or biochemical stress responses. The evidence supports the elicitor and biostimulant effect of these agronomic approaches [18,20–23]. The mechanisms by which these agronomic approaches help improve drought tolerance have been poorly elucidated.

Controlled irrigation deficit, the use of phytohormones and osmoprotective substances (i.e., abscisic acid, salicylic acid, melatonin, tocopherol), and nutrient handling (i.e., Zn, P, K, biochar-N) have been studied among hormetic approaches (with dose-dependent activity) [18,20,22,24–27], because at certain doses they can cause positive effects (eustress effects) on the morphology of the plants, biomass production and improvement in crop yields (stimulation), or on increasing stress tolerance (elicitation) [28,29]. The study of eustressors or stress factors with positive effects (of biological, chemical, and physical origin) on crops under conditions of water stress is a practice that has increased in recent years, where physical eustressors have gained great interest due to their potential for alleviating water stress, low environmental impact, and developing plant tolerance to stress, with a large field of study on types, doses, application times, and mechanisms of action in plants [30].

Common agricultural approaches, combined with elicitors and biostimulants, can mitigate water stress in vegetables, improving their stress tolerance and yield. This review aims to analyse the effects of traditional agricultural strategies and eustressor agents (elicitors and biostimulants) on water stress mitigation in vegetables. Knowledge of vegetables’ responses to water stress and the study of the doses, application conditions, effects, and mechanisms of action of biostimulants and elicitors are essential to understanding their combined potential to alleviate the effects of water stress and establish adequate agricultural management.
2. Vegetable Responses to Water Stress

2.1. Germination and Growth Responses to Water Stress

Plants have diverse growth parameters such as seed germination, leaf area, stem length, root system, number of branches, and yield biomass. These parameters have been reported to be affected during water deficit. Mardaninejad et al. (2017) [31] induced water deficit at different field capacity levels (100, 80, 60, and 40%) and evaluated its effect on chili plants (Capsicum annuum L.). Results suggested that chili plants showed sensitivity to water restriction. The freshness and dry weight of the shoots, roots, and fruits showed an inverse effect with drought stress, with yield reductions of 29.4, 52.7, and 69.5% for 80, 60, and 40% of field capacity, respectively. Similarly, Wang et al. (2019) [32] simulated drought stress conditions by sowing potatoes (Solanum tuberosum) in sand with 10% polyethylene glycol (PEG-600), and they achieved significant reductions in the biomass, diameter, and root volume average.

Khodabin et al. (2020) [33] evaluated the effects of drought on plant growth and physiological characteristics in a canola crop (Brassica napus). The seedlings were subjected to different concentrations of PEG-600 (0, 150, and 300 g L\(^{-1}\)) to simulate drought stress conditions and grown in a phytotron chamber for 45 days. Results showed that plant height, stem height, root length, and fresh and dry weight were reduced under the highest drought conditions compared with untreated plants.

Germination and seeding development conditions are vitally essential stages for optimal plant growth. During these phenological stages, water deficit can decrease biomass formation and consequently reduce crop productivity [34–36]. Ahmad et al. (2009) [37] found that stress tolerance indices decreased with increased water stress. Mut and Akay (2010) [38] reported decreases in the size of seeds and the mean germination time, and reductions in the percentage of final germination and the lengths of the roots and shoots under drought stress conditions (seeds imbibed in solutions of PEG6000 at −0.5 and −0.75 MPa). Similarly, Sun et al. (2011) [39] evaluated the effects of drought stress on amaranth (Amaranthus mangostanus L.) seeds and observed a decrease in germination rate (97.0 to 95.3) and germination potential (96.3 to 90.33%). However, the root and shoot lengths increased significantly. Likewise, Rahimi (2013) [40] evaluated the effects of osmoprimation on the final germination percentage, the germination rate and uniformity, and the radical and plumule length in cumin seeds (Cuminum syminum L.). They found that osmoprimation accelerated seed germination rate and uniformity. In addition, root sensitivity decreased under drought stress conditions during the development of shoots due to an osmotic adjustment for water maintenance [41]. However, the root’s morphology strongly influences its capacity to absorb water and nutrients [42]. In the same way, according to higher drought conditions, Chun et al. (2021) [43] observed a reduction in length, surface, and the number of roots in soybean (Glycine max L. Merr.) and adzuki bean plants (Vigna angularis L.).

Roots can also be affected by water stress, which absorbs nutrients and water from the soil. Consequently, they are the first organs exposed to water deficit conditions [44]. Growth, size, density, proliferation, and distribution of roots are highly related to growth, development productivity, and response to drought stress in plants [45–48]. In this sense, stressed plants grow with fewer and smaller leaves, and the growth of the youngest leaves is compromised; the induction of the pre-saturated death of older leaves also occurs, which turns them yellow [34,49]. In this sense, changes have been evaluated in growth parameters and yield in various vegetables and other crops of commercial importance for different regions worldwide. Bean plants (Phaseolus vulgaris) exposed to water deficit conditions during the flowering and pod formation stages were associated with short shoots, small leaves, and pod size [50]. Correspondingly, in spider plants (Cleome gynandra L.), it was evidenced that the greater the water stress severity, the more significant the reduction in the number of leaves [51]. Likewise, in tomato plants grown at 100, 80, 60, and 40% of field capacity, a significant decrease in the height of the plants and stem diameter was observed under the most severe drought conditions [52]. Adversely, crops of Amaranthus cruentus
L., *Beta vulgaris* L., under harsh drought conditions, achieved a reduction in height and yield; however, these characteristics were not affected for *Corchorus olitorius* L. and *Vigna unguiculata* L. crops [53]. In rice (*Oryza sativa* L.), irrigation with saturation at 50 and 75% decreased the number, length, and volume of roots, with a consequent impact in grain yield [54]. Leafy greens such as lettuce (*Lactuca sativa* L.) and tubers such as potato (*Solanum tuberosum* L.) experienced yield losses under water deficit, while the growth and yield of eggplant (*Solanum melongena* L.) and onion (*Allium strain* L.) were not reduced during water stress exposure [55].

### 2.2. Physiological Responses to Water Stress

Physiological characteristics of crops, such as photosynthesis, transpiration, gas exchange, stomatal conductance, leaf water content, and leaf and canopy temperature, can also be negatively affected by water deficit [56].

Photosynthesis is a sunlight-activated process by which water and carbon dioxide (external inorganic reactants) are converted into carbohydrates (organic products within the plant), which allow maintenance, growth, development, reproduction, and adaptation responses of plants to environmental conditions [57,58]. This process is considered the most important way for plants to acquire energy and is reduced under drought conditions as a consequence of stomatal closure [25,59,60].

Transpiration is caused by the difference in water vapor (water loss) between the intercellular space of the plant and the surrounding air [61]. Thus, transpiration occurs from cell surfaces towards the stomatal cavity, and the diffusion of water arises from plant tissue in the air [62]. Moreover, transpiration results from photosynthesis, a physiological process that plays a relevant role in maintaining optimal leaf temperature and protecting the plant from extreme temperatures [4,25,63]. When plants are exposed to drought conditions, transpiration decreases due to stomatal closure, which prevents water loss from leaves and stems; the above also causes a decrease in the flow of CO$_2$ and, thus, a reduction in plant photosynthesis [64,65]. Due to transpiration being sensitive to water deficit, its measurement determines the stress effect on plants [66,67].

Gas exchange is the process in which CO$_2$ enters the plant leaves, and both water vapor and O$_2$ are released through the stomata. This process regulates transpiration, respiration, photosynthesis, and water loss from plant cells [4,68]. Due to water stress, gas exchange decreases when photosynthesis and transpiration are reduced [69].

Stomatal conductance is a water status indicator of plants, which represents the degree of opening of the stomata. It regulates photosynthesis and transpiration [70,71]. This physiological variable is inversely related to water stress conditions; the greater the state of drought severity, the lower the value of the stomatal conductance [66,72].

Another important physiological variable is the leaf water content (LWC), which also participates in photosynthesis and cellular respiration processes [73]. LWC decreases when water stress levels increase [72,74]. Also, leaf and canopy temperatures are indirect indicators of the water absorption capacity of plants. They are related to stomatal conductance under drought conditions [75]. Due to low water availability in the soil, stomatal closure reduces transpiration and contributes to increasing canopy temperature [76]. In this context, Helyes (2010) [77] evaluated the behaviour of leaf temperature in tomato crops subjected to three irrigation conditions. They found that the leaves’ temperature was higher with less irrigation volume because the transpiration rate decreased and prevented the leaves from cooling below air temperature. Biriah et al. (2016) [78] studied the effect of water stress on canopy temperature, yield performance, and growth of cowpeas. They found that water stress increased the canopy temperature and decreased its growth, adversely. The grain yield increased due to the greater efficiency in water use after stomatal closure.

Figure 1 shows the physiological effects of water stress. Under water deficit, ABA promotes stomatal closure, impeding CO$_2$ and H$_2$O fluxes, which cause the consequent decreases in gas exchange, stomatal conductance, photosynthesis, and transpiration.
Damage to physiological processes in plants exposed to water stress can be minimized through osmotic adjustment, a crucial adaptation mechanism [79,80]. Osmotic adjustment is the decrease in the osmotic potential of a plant caused by the accumulation of water-soluble compounds (sugars, organic acids, and ions) in response to the overproduction of reactive oxygen species (ROS) during stress [81]. The primary compounds for osmotic adjustment include K\(^+\), Na\(^+\), Ca\(^{2+}\), sucrose, sorbitol, glycoalcohols, and betaines such as glycine betaine and proline. Osmotic adjustment is instrumental in improving soil water extraction by promoting root growth, increasing the relative water content in plants. This process is crucial for maintaining stomatal conductance and helps maintain intracellular CO\(_2\) concentration, preventing a decrease in photosynthesis [60,82].

In Table 1, water stress simulation experiments in tomato, cucumber, chili, cabbage, carrot, and leafy vegetables (amaranth, corchorus, vigna, and beet) are described. According to the studies, water stress affected photosynthetic rate, transpiration rate, intercellular CO\(_2\) content, stomatal conductance, chlorophyll, and relative water content in leaves. The studies were conducted under different water stress conditions, ranging from reducing irrigation water supply to different field capacities (50, 60, 75, and 80\%) or crop evaporation rates (30, 40, 60, 70, 80 \%) or suppressing irrigation for up to 17 days. Physiological variables monitored included photosynthesis, transpiration, and stomatal conductance, and the most studied was chlorophyll content. Some studies also considered leaf area, temperature, relative water content, and water use efficiency. Moreover, water stress conditions were not analyzed during all crop phenological stages, and water stress was applied permanently only for cucumber. Regarding the frequency of variable measurements, some of the reports did not provide information for all phenological stages, while others made sparse measurements for a brief time (for up to 36 days, every third day). Because of this, it is difficult to determine the effects of drought on plants under constant stress, which is how it occurs in many regions in the world.

![Diagram of physiological processes affected by water stress](image-url)

**Figure 1.** Physiological processes affected by water stress. ABA: abscisic acid; ROS: reactive oxygen species.
Table 1. Water stress simulation conditions and physiological plant responses.

<table>
<thead>
<tr>
<th>Vegetable Crop</th>
<th>Water Stress Condition</th>
<th>Phenological Stage of Application of Water Stress</th>
<th>Frequency of Measurement of Responses to Water Stress</th>
<th>Plant Responses</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato (Lycopersicum Esculentum L.)</td>
<td>100, 75, and 50% FC</td>
<td>Growing period</td>
<td>N.R.</td>
<td>↓ pn, gs, and CRV.</td>
<td>[83]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>↓ gs, E, Pn, Ci, and leaf area.</td>
<td>[25]</td>
</tr>
<tr>
<td>Cucumber (Cucumis sativus)</td>
<td>100, 80, 60, 40% ETc.</td>
<td>Complete cycle (2019–2020)</td>
<td>36, 48, 62, and 76 DATs (2019), and 30, 46, 58, and 71 DATs (2020).</td>
<td>↑ stomatal limitations, WUE, and leaf temperature. Significant effects at 40–60% ETc.</td>
<td></td>
</tr>
<tr>
<td>Chili (Capsicum annuum L.)</td>
<td>Irrigation suppression (17 d), recovery irrigation (5 d).</td>
<td>From 13 DAS to fruit setting (before reaching total fruit weight potential) on the 30th day</td>
<td>Daily—36 DASs</td>
<td>↓ Tr and VWC; ↑ WUE.</td>
<td>[84]</td>
</tr>
<tr>
<td>Leafy vegetables (Amaranthus cruentus L., Corchorus olitorius L., Vigna unguiculata L. Walp., Beta vulgaris L.)</td>
<td>30, 60, and 100% ETc.</td>
<td>Growth stage</td>
<td>Once per season (2015/2016 and 2016/2017)</td>
<td>↓ Chlorophyll content index, significant effects at 30% ETc.</td>
<td>[33]</td>
</tr>
<tr>
<td>Cabbage (Brassica oleracea)</td>
<td>100, 80, and 60% FC (irrigation every 3rd day).</td>
<td>Growth stage</td>
<td>Once—last week before the harvest</td>
<td>↓ Chlorophyll, SPAD, LRWC, gs, Ci, and Tr.</td>
<td>[85]</td>
</tr>
<tr>
<td>Carrot (Daucus carota L.)</td>
<td>100 and 50% FC (5 weeks), 4 weeks after germination</td>
<td></td>
<td>N.R.</td>
<td>↓ Total chlorophyll</td>
<td>[86]</td>
</tr>
</tbody>
</table>

Summary of conditions of water stress imposition and effects on physiological processes in vegetables of economic interest. Increases or decreases in physiological responses to water stress are represented by ↑ and ↓, respectively. Ci: intercellular CO$_2$ content; CRV: chlorophyll reading value; DASs: days after sowing; DATs: days after transplant; E: transpiration; ETc: crop evapotranspiration; FC: field capacity; gs: stomatal conductance; LRWC: leaf relative water content; pn: photosynthetic rate; Tr: transpiration rate; VWC: volumetric water content; WUE: water use efficiency; N.R.: not reported.

2.3. Biochemical Responses to Water Stress

When plants are subjected to water stress conditions, they undergo a series of biochemical changes, including the biosynthesis of secondary metabolites such as osmolytes and antioxidant compounds [36,87]. Osmolytes are chemical substances produced and accumulated by plants to protect or neutralize the negative effects caused by abiotic stressors and to generate tolerance to stress [88,89]. Previous reports have classified osmolytes according to their chemical properties in amino acids, sugars (non-reducing and alcohols) such as trehalose, mannitol, sorbs, inositol, and others, and betaines, which are glycine betaine and β-alanine betaine [90,91]. Osmolytes have several functions in plants, such as osmotic regulation, protection of cellular components, stabilization of proteins, maintenance of cell integrity, defense of antioxidant compounds, and ROS scavenging [89].

Other compounds in plants are antioxidants, which are biomolecules that allow their acclimatization and adaptation to abiotic stress factors. They can reduce oxidative stress by free radical elimination as well as preventing damage caused by stress conditions at the cellular level [92]. Exposure of plants to drought stress conditions induces oxidative stress by decreasing stomatal conductivity and consequently reducing the available CO$_2$ inside the leaves, followed by the formation and accumulation of ROS [87,93]. ROS are molecules from molecular oxygen formed by electronic excitation or oxidation–reduction reactions [94]. Some reported ROS molecules include the superoxide radical (O$_2$•$^-$), alkoxyl (RO•), and hydroxyl (HO•). However, some are not radicals, such as hydrogen peroxide.
(H\textsubscript{2}O\textsubscript{2}) and diatomic oxygen (O\textsubscript{2}) \cite{87,95,96}. ROS are metabolic by-products endogenously generated by some plant organelles such as chloroplasts, mitochondria, and peroxisomes. Due to their high rates of electron transport, ROS function as cellular regulators of chemical oxidation–reduction processes \cite{97,98}. The accumulation of ROS in plant cells generates less growth and development of roots, plant height, and leaf area because cell homeostasis is interrupted by enzyme inactivation and damages proteins, lipids, carbohydrates, and DNA \cite{99,100}. Secondary metabolites such as ascorbate, carotenoids, and proline are generated as a plant response against the accumulation of ROS due to the activity of antioxidant enzymes such as catalase (CAT), peroxidase (POD), superoxide dismutase (SOD), and ascorbate peroxidase (APX), among others \cite{93,101–104}.

Biochemical variables in response to water stress have been studied in different crops, such as hot pepper, cucumber, lettuce, chili pepper, cabbage, and carrot (Table 2). Studies have evaluated the effects of different water stress conditions on biochemical variables such as antioxidant activity, antioxidant enzymes, osmolytes content (capsaicin, proline, total soluble sugar, sucrose, abscisic acid, among others), and antioxidant compounds (phenols and flavonoids). According to the research reported in Table 2, the findings are interesting. Water deficit (0, 35, 50, 60, 65, and 80% FC) promotes the accumulation of osmolytes such as proline during the vegetative growth stage in cucumbers, onions, and carrots, and also during the early stages of flower bud and pod formation in hot and bell peppers. The production of other osmolytes, such as sucrose and glycine betaine, is also favoured during the exposure of vegetables to water stress. The responses related to the non-enzymatic antioxidant system through the production of phenols, flavonoids, and carotenoids were increased regardless of the crop, phenological stage, or water deficit conditions. However, regarding the activation of the enzymatic antioxidant system, the responses of plants are contrasting; increases in CAT activity were reported in carrots and hot and bell peppers exposed to water deficits between 35 and 65% FC, however, the activity of that enzyme was inhibited in chili pepper and cabbage plants, with 40 and 60–80% FC, respectively. POD activity was favoured with a water deficit between 40–50% FC for chili and carrot during seedling and growth stages; however, it was inhibited in cabbage maintained at 60% FC during its growth period. On the other hand, SOD activity decreased in cabbage with 60% FC, while it increased in carrot with a more severe drought level (50% FC), even during the vegetative growth stage. It is important to state that during these experiments, constant water stress was not evaluated, in addition to the fact that measurement of variables was not frequent, and the research did not include studying different phenological states of the crops.

Table 2. Water stress simulation conditions and biochemical plant responses.

<table>
<thead>
<tr>
<th>Vegetable Crop</th>
<th>Water Stress Condition</th>
<th>Phenological Stage of Application of Water Stress</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Hot pepper (Pussajuala and Ghotki) and bell pepper (Green Wonder and PPE-311) genotypes</td>
<td>Irrigation: 300 mL (control), 100 mL (moderate water stress). 3 times/week; Without irrigation (severe water stress) for 19 days.</td>
<td>35 and 65% FC. Early floral bud stage and pod formation stage.</td>
<td>Once—fruits harvested 45 d after flowering.</td>
<td>(\uparrow) Proline, Na\textsuperscript{+}, and K\textsuperscript{+} ions; (\downarrow) photosynthetic pigments, flavonoids, and MDA.</td>
<td>[105]</td>
</tr>
<tr>
<td>Cucumber (Solanum muricatum)</td>
<td></td>
<td></td>
<td>Once, at the end of treatments</td>
<td>(\uparrow) Proline, Na\textsuperscript{+}, and K\textsuperscript{+} ions; (\downarrow) photosynthetic pigments, flavonoids, and MDA.</td>
<td>[99]</td>
</tr>
</tbody>
</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Vegetable Crop</th>
<th>Water Stress Condition</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Lettuce (Lactuca sativa L.)</td>
<td>100, 90, and 80% of soil saturation, and water restriction.</td>
<td>The water supply was stopped 4 d before the harvest</td>
<td>During storage time (days 0, 3, and 7)</td>
<td>↑ Total phenols, total flavonoids, and antioxidant activity at 80% of soil saturation; ↓ carotenoids and total phenolic compounds at 90% of soil saturation.</td>
<td>[106]</td>
</tr>
<tr>
<td>Chili pepper (Capsicum annuum L.)</td>
<td>100 and 40% FC, for one week.</td>
<td>Seedling (one week’s growth)</td>
<td>Once, at the end of treatments</td>
<td>↑ Phenolic content; ↑ PAL and POD activities; ↓ CAT activity.</td>
<td>[107]</td>
</tr>
<tr>
<td>Cabbage (Brassica oleracea var. capitata cv. Yalova 1)</td>
<td>100, 80 and 60% FC.</td>
<td>Growth period</td>
<td>Once, one week before the harvest</td>
<td>↑ Proline, sucrose, MDA, and H$_2$O$_2$ with drought severity; ↓ SOD, CAT, and POD.</td>
<td>[85]</td>
</tr>
<tr>
<td>Carrot (Daucus carota L.)</td>
<td>100 and 50% FC.</td>
<td>After 4 weeks of germination, for 5 weeks</td>
<td>Not reported</td>
<td>↑ Proline, glycine betaine, H$_2$O$_2$, ascorbic acid, total phenols, total soluble proteins, and MDA; ↑ CAT, SOD, POD.</td>
<td>[86]</td>
</tr>
</tbody>
</table>

Summary of conditions of water stress imposition and effects on biochemical processes in vegetables of economic interest. Increases or decrease in physiological responses to water stress are represented by ↑ or ↓, respectively. APX: ascorbate peroxidase; CAT: catalase; FC: field capacity; GXP: guayacol peroxidase; MDA: malondialdehyde; POD: peroxidase; SOD: superoxide dismutase.

2.4. Molecular Responses to Water Stress

Water stress also causes molecular changes affecting plant growth and crop yield. At the molecular level, plants respond to water stress through genetic expression, where genes can be inhibited or expressed. Figure 2 represents the process of plant drought adaptation and tolerance development. In the first step, plants respond to water stress by generating several molecules in a signaling cascade to activate ion channels, kinase cascade, ROS, and accumulation of phytohormones such as ABA [108]. The signal perception of water stress is one of the physiological activities that occurs as the first step in the responses of plants to water stress; this occurs through receptors that remodel signal transduction pathways and promote appropriate responses for the plant to adapt to stress [109]. Plants detect water stress through their roots, and from there, they communicate stress signals to their aerial zones [5,110]. The signal perception of water status outside plant cells is influenced by the presence of protein receptors in the plasma membrane, which are essential in various signaling pathways and the transmission of information to their target cells in the cytoplasm [111]. Water stress signal molecules include ABA, open stomata 1 (OST1), calcium ions (Ca$^{2+}$), ROS, and nitric oxide (NO), and others [60,65].
The role of ABA and its effect on stomatal regulation as a defense mechanism of plants promotes the translation of stress signals through its calcium-binding proteins [110], thus the mediation of ABA [121].

Ca$^{2+}$ drought levels in this crop [120]. On the other side, it was reported that the in situ flow of that the early responses of Ca$^{2+}$ decrease in photosynthesis in soybean plants under drought. It has also been suggested that leaf mesophyll Ca$^{2+}$ accumulation at the intracellular level is one of the first signaling steps of water stress. It promoting the translation of stress signals through its calcium-binding proteins [110], thus inducing various biochemical reactions to face stress and regulating the homeostasis of the cell membrane [119]. The Ca$^{2+}$ signaling process includes the specific signaling stages of the stimulus that mobilizes Ca$^{2+}$ signals, entry of Ca$^{2+}$ into the cytoplasm, stimulation of Ca$^{2+}$ signaling pathways, and the restoration of calcium from the cytosol after the exit of Ca$^{2+}$, having a developing potential for water stress tolerance in plants [110] (Ghosh et al., 2022). It has been reported that leaf mesophyll Ca$^{2+}$ flux was involved in stomatal closure and a decrease in photosynthesis in soybean plants under drought. It has also been suggested that the early responses of Ca$^{2+}$ efflux could serve as chemical signals and indicators of drought levels in this crop [120]. On the other side, it was reported that the in situ flow of Ca$^{2+}$ in the guard cells of barley plants supported the stomatal closure mechanism through the mediation of ABA [121].

ABA has been suggested as the main mediator of water stress. The transport of this hormone from the roots to the shoot is the main signal of water deficit [112]. ABA content in vegetative tissues increases in response to water stress. It also improves drought tolerance [113]. ABA triggers the closure of the stomata to prevent water loss by reducing transpiration and models the root system by stimulating the elongation of root cells and intervening in transcriptional and post-transcriptional gene-expression activation [65,114]. The role of ABA and its effect on stomatal regulation as a defense mechanism of plants against drought has been studied in crops such as corn, tomato, sunflower, and wheat [115]. It was reported that ABA controlled the accumulation of H$_2$O$_2$ in rice leaves under water stress [116], and regulated gene expression levels in arabidopsis [117] and rice [118] subjected to water stress treatment.

Ca$^{2+}$ is an important secondary messenger in signaling abiotic stress conditions. It is also involved in the response and adaptation of plants to stress. The increase in Ca$^{2+}$ accumulation at the intracellular level is one of the first signaling steps of water stress. It promotes the translation of stress signals through its calcium-binding proteins [110], thus inducing various biochemical reactions to face stress and regulating the homeostasis of the cell membrane [119]. The Ca$^{2+}$ signaling process includes the specific signaling stages of the stimulus that mobilizes Ca$^{2+}$ signals, entry of Ca$^{2+}$ into the cytoplasm, stimulation of Ca$^{2+}$ signaling pathways, and the restoration of calcium from the cytosol after the exit of Ca$^{2+}$, having a developing potential for water stress tolerance in plants [110] (Ghosh et al., 2022). It has been reported that leaf mesophyll Ca$^{2+}$ flux was involved in stomatal closure and a decrease in photosynthesis in soybean plants under drought. It has also been suggested that the early responses of Ca$^{2+}$ efflux could serve as chemical signals and indicators of drought levels in this crop [120]. On the other side, it was reported that the in situ flow of Ca$^{2+}$ in the guard cells of barley plants supported the stomatal closure mechanism through the mediation of ABA [121].
Open stomata 1 (OST1), an essential molecule in ABA signaling, mediates microtubule disassembly during stomatal closure in Arabidopsis thaliana [122]. OST1 is a serine/threonine protein kinase, critical in binding ABA receptors, transcription factors, and anion channels to regulate the response to water stress. OST1 regulates the stomatal opening and mediates early flowering and root growth in response to water deficit [123]. Also, it is known that OST1, in interaction with RAF22 and ABI1, optimizes plant growth and responses to water stress [124].

ROS trigger defense mechanisms in plants due to water stress; in excessive amounts, ROS activate the defense machinery at the level of enzymatic (SOD, POD, CAT, APX, GR) and non-enzymatic antioxidants [125–127]. On the other hand, NO is an important redox signaling molecule that activates the ROS scavenging enzyme and may participate as a mediator in the prevention of water loss through the stomatal response induced by ABA throughout signaling pathways, such as protein mitogen-activated kinase (MAPK) and CA$^{2+}$.

Signal transduction, the second step in the development of plant adaptation and tolerance to drought, involves the expression of functional and regulatory genes (Figure 2). These genes produce functional genetic products such as proline, glycine betaine, soluble sugars, aquaporins, and LEA proteins, which are instrumental in plant metabolism and indirectly trigger morphological and physiological changes. The regulatory genetic products (MAPKs, CDPKs, MYB, WRKY) induce direct morpho–physiological modification in plants by regulating signal transduction pathways or acting as transcription factors for downstream gene regulation, thereby aiding plants in surviving drought conditions [60].

Acosta-García et al. (2015) [128] found that expression of the CaLEA73 gene in A. thaliana increased drought tolerance. Zhang et al. (2022) [129] observed that TaPYL4, an ABA receptor gene of T. aestivum, regulated drought tolerance by modulating processes associated with osmotic stress; also, the TaFBA1 gene positively regulated plant water stress tolerance according to the increases in antioxidant compounds and the decreases in ROS accumulation [130]. In Oryza sativa L., Thomas et al. (2022) [131] found increased levels of expression of sucrose transporter (SUC2) and sucrose synthase (OsSuSy) genes under conditions of water stress. Other authors revealed a great diversity of aquaporins (AQP) in plants, with more than 30 isoforms estimated in certain species (arabidopsis, corn, rice, soybean, tomato, and cotton; likewise, AQP has also been reported in C. annuum. Most of the AQP reports in plants have focused on gene cloning and expression analysis. Among the cloned genes, the gene CaPIP1-1 plays an essential role in the modulation of water, growth, and the improvement of stress tolerance in chili pepper plants [132,133].

3. Management Strategies

The main problem with water is its scarcity, which considerably affects agriculture and compromises food security [134]. Knowing the soil water content is essential for establishing water management strategies for crops and mitigating water stress [135]. The gravimetric method is the most common approach to determining soil moisture content because it is a direct and reliable method; however, it is destructive and requires much time for analysis [136,137]. Other methods to determine soil water content include neutron probes, time domain reflectometry (TDR), frequency domain reflectometry, and humidity sensors. These methods benefit water management as they are non-destructive, real-time, and low-cost [136–138]. In addition, remote monitoring techniques, such as satellite images to monitor soil moisture and determine the water status of crops, have gained significant interest. These techniques work by capturing data from satellites and processing it to provide information about soil moisture and crop water status [139]. They offer benefits such as real-time monitoring, large-scale coverage, and the ability to identify water stress in crops before it becomes visually apparent. Satellite-monitored data have been used to establish valuable indices for drought management, such as the water stress index (WSI) used in the central Nile to identify regions where water content for agriculture was inefficient [140]; the ecosystem stress index (ESI) used to estimate actual evaporation...
from crops in Africa [141]; the crop water stress index (CWSI) to determine water status both under open field conditions and in protected greenhouse environments [142]; and the normalized difference vegetation index (NDVI), used in various regions of the world, including the humid Atlantic regions, to detect irrigation anomalies due to reflective changes in the electromagnetic spectra of plants [143].

Based on soil water content and crop water status, soil water management strategies can be improved, which is essential to reduce the impact of drought by increasing the soil’s capacity to capture and retain water. Agronomy, plant physiology, biotechnology, plant breeding, and water engineering are required to propose and execute new strategies to manage drought in agriculture and increase water use efficiency [144]. Adopting agronomic and non-agronomic practices that increase soil surface cover with less disturbance can improve soil water capture and retention, improving soil resilience to drought conditions [135]). Various practices for soil moisture conservation have been proposed, such as tillage, mulching, conservation buffers, crop rotation, cover crops, and regulated deficit irrigation, as well as the selection of water-efficient crops and the development of drought-tolerant crops through genetic improvement, among methods. Among the agronomic practices used for drought management in crops also include nutrient management, applying hormones and osmoprotective substances, using mycorrhizal fungi, and early sowing. Regarding non-agronomic practices, the identification of tolerant plants is important (Figure 3).

**Figure 3.** Agronomic and non-agronomic approaches for water stress management [9,144,145].

### 3.1. Agronomic Approaches for Water Stress Management

The effects of water stress on the growth, development, and productivity of crops can be managed through agronomic approaches such as tillage, mulching, intercropping, nutrient management, the use of crops with low water demand, selection of drought-resistant varieties, controlled irrigation conditions, and exogenous application of hormones and osmoprotectants [146,147]. According to Rakshit et al. (2020) [144], these agronomic approaches are economically viable and technically feasible to counteract the problem of water stress in drought areas.
3.1.1. Tillage

Tillage is an agricultural practice consisting of mechanical manipulation of land. Its purpose is to promote germination conditions and crop growth and development by structurally modifying the soil to improve its airflow, temperature, and water retention [148]. Moreover, through tillage, it is possible to use crop residues, regulate weed growth, control soil conditions, improve soil drainage, and facilitate land irrigation due to better water absorption and retention [149,150]. However, if tillage use is excessive, soil properties may be modified until evaporation is increased, and water availability for plants could also be compromised [151].

There are diverse types of tillage; the most common are conventional, minimum, and zero tillage [152]. They all act on soil’s physicochemical and biological properties and impact crop productivity and the environment [153]. Some authors have reported that zero tillage or no-tillage is where soil disturbance is not carried out and allows maintenance of the structure of the surface soil, increasing nutrients, reducing erosion risks, and improving soil water retention [154,155]. On the other hand, conventional tillage refers to a reduced manipulation of soil, which improves its physical, chemical, and biological characteristics and allows the accumulation of organic matter, reducing erosion and water runoff. Meanwhile, minimum tillage allows adaptation to climatic changes and higher crop yields than conventional tillage [148].

In contrast, a disadvantage of minimum tillage is its low effectiveness for controlling weeds and promotion of the herbicides that are usually used [156]. On the other hand, conventional tillage consists of removing a deep layer of soil to destroy plant residues for decomposition and subsequent supply of soil nutrients. Additionally, it exposes soil pests to sunlight for their control and levelling of the terrain. It has also been reported that this type of tillage causes erosion and reductions in soil structure, stability, and compaction, affecting the hydraulic properties of soil [149].

No research reports were found evaluating the effects of tillage on morphological, physiological, or biochemical properties, nor on the yield, water savings, or efficiency of its use in vegetable crops subjected to water stress conditions. The study of deep and conventional tillage for maize (Zea mays L.) without irrigation for a maximum of 20 days was reported [157], in which increases in root length, yield, and water retention in the soil were observed. In lentils (Lens culinaries), it was reported that minimum tillage increases the leaves’ chlorophyll content, the plant’s growth rate, and the yield, in addition to conserving soil moisture and improving the relative water content in the crop [158]. In contrast, in faba bean (Vicia faba), excluding rainfall [159], tillage did not affect photosynthesis, stomatal conductance, or crop yield. However, in terms of the water potential of the leaves and germination, no clear effects were found relating to water storage in the soil.

Among other studies about tillage, the effects of irrigation and tillage conditions on the seed yields of main stems and branches and the number of seeds per branch of soybean (Glycine max) plants were evaluated [160]. Drought conditions with no deep tillage had a significant effect on the seed yield in the main stem (55.5%), followed by deep tillage without irrigation (46.6%) and irrigation without deep tillage (34%); it was found that drought stress increased the seed formation in stems. Interestingly, yields and seed numbers on branches were higher with irrigation and without deep tillage (66% and 1248, respectively), but lower values (44.5% and 60.4%) were achieved without irrigation or tilling. Moreover, better results were obtained for the same variables using treatments with tillage but without irrigation (53.4% and 74.1%). There was no evidence of the effect of deep tillage with irrigation. Furthermore, different tillage types and drought stress conditions have been evaluated to determine their impacts on several crops, including bean, cotton, soybean, wheat, and corn as the most reported [157,161–163].

Zheng et al. (2014) [164] studied the effects of different tillage practices on water consumption and water use efficiency in wheat crops (Triticum aestivum L.) using supplemental irrigation in addition to rainfall (75 and 85% FC). They found that rotary tillage in strips and rotary tillage of the subsoil caused a higher consumption of water, use efficiency, and
yield of wheat crop, which suggests its application for this crop. Boydston et al. (2018) [165] evaluated the effects of deficit irrigation in pinto bean (*Phaseolus vulgaris*) cultivars at 52 and 100% of evapotranspiration (irrigation reduction 30 days after emergence) with two types of tillage (conventional and strip); crop yield was decreased (47%) by the exposure to water deficit; however, conventional and strip tillage increased the crop yield by 52.5 and 53.5%, respectively. Interestingly, the implementation of strip tillage was suggested because soil water slightly decreased under a hydric deficit, and cultivar growth was considered acceptable. On the other hand, reduced tillage or no tillage increases crop resistance to water stress, and traditional tillage causes erosion and soil compaction [159].

From the above findings, enough evidence was achieved to apply different tillage types depending on the crop under study, such as water stress and experimental conditions. In this sense, it is difficult to determine a better option for drought management. According to our search, there has been a lack of application of this strategy on vegetables.

3.1.2. Mulching

Another water management practice is mulching, which is an agricultural practice that covers the soil surface with a layer of organic matter (straw, hay, compost, sawdust, wood chips, and animal manure) or inorganic cushioning, mainly plastics (polyvinyl chloride or polyethylene films), after germination or transplantation of vegetables. Mulches protect plants from environmental stress, such as drought, high temperatures, and solar radiation [166]. This practice reduces water infiltration into the soil, evaporation, erosion, and water stress, and maintains soil temperature [167]. Other authors have remarked on other advantages, such as soil moisture conservation, control of pests, and improved plant growth and crop yield [168]. According to Taromi Aliabadi et al. (2019) [14], using mulch with drip irrigation can be a good option to save water and improve crop yield.

Miransari (2016) [152] reported that mulching increased the yield of soybean (*Glycine max*) crops because water evaporation from soil and its temperature were reduced. In addition, Amiri et al. (2020) [23] evaluated the effects of date straw and plastic mulches on biochemical, physiological, and qualitative variables in eggplant (*Solanum melongena* L.) under water deficit (40, 70, and 100% FC). They found that carotenoids, protein content, and total soluble solids were decreased; furthermore, they also mitigated adverse effects of water deficit. Behzadnejad et al. (2020) [167] determined the impact of 7.5 ton ha$^{-1}$ of wheat straw on the physiology, seed yield, and oil content of sesame (*Sesamum indicum* L.) crops subjected to different irrigation conditions (40, 60, 80 and 100% FC). Wheat straw allowed the mitigation of adverse effects caused by water deficit, and it did not affect CAT or SOD activity or water use efficiency. The authors suggested using wheat straw at 60% FC as a water management strategy in areas with water scarcity, because there was only a 20% yield reduction compared with a well-irrigated crop (100% FC).

3.1.3. Intercropping

Intercropping is an agricultural practice where two or more crops are sown on the same land simultaneously [169]. According to Singh et al. (2014) [170], intercropping is generally recommended for rainfed crops with stable yields. According to Zhang et al. (2012) [171], intercropping allows drought management because it reduces soil evaporation, allows water conservation in root zones, and promotes favorable microflora for plant growth. In addition, intercropping also improves water retention in the ground, reduces runoff, increases the efficient use of water, and allows higher yields based on the water supplied [172,173].

No studies were found that evaluated the effect of different intercropping systems in interaction with water stress for vegetables, except the lettuce–radish system [15], where under conditions of water stress, intercropping degraded the yield of lettuce while that of radish increased. The uses of water efficiency showed no differences in comparison to the monoculture of these vegetables. This strategy has been mainly applied for beans (*Vicia faba* L.) [174], soybean–canola systems in the cultivation of apple trees [175], wheat–corn
(Hussain et al. 2023), sorghum–clover [176], and barley–chickpeas [177], under different water stress conditions (reduction of irrigation and non-irrigation levels). According to the results obtained in these studies, the intercropping system can increase plant growth, chlorophyll fluorescence, proline, protein content, and the activity of the antioxidant enzymes SOD, POD, and CAT, as well as improving the performance of crops and efficiency in water use.

3.1.4. Nutrient Handling

Nutrient handling is a type of management that constitutes an agricultural strategy to counteract water stress in plants. The rational application of nutrients to soil improves crop productivity and reduces the adverse effects of drought [178]. Its application also improves water absorption by plants and increases water efficiency in their metabolism [144,179].

Mirbahar et al. (2012) [180] evaluated the effects of water stress and fertilization with three macronutrients (phosphorus, potassium, and zinc) on physiological variables such as stomatal conductance, photosynthetic rate, transpiration rate, and efficient use of water and yield of cotton seeds. The induction of water stress harmed the mentioned variables, whereas applying the different doses of nutrients improved these responses and, notably, the cotton crop yields. The highest yields were obtained at conditions of 43.6 kg P ha$^{-1}$ (24.8%), 124 kg K ha$^{-1}$ (31%), and 20 kg Zn ha$^{-1}$ (11%), which suggested that higher levels of studied nutrients reduced the effects of water stress and increased the cotton crop productivity.

Mannabi et al. (2020) [181] evaluated the effects of different soil fertilization and drought conditions and their impact on canola plants (Brassica napus). They considered four levels of irrigation (70, 100, 130, and 160 mm of evaporation) and four levels of fertilization (no fertilizer, chemical fertilization, biological fertilization [seed inoculation with P. flourescens, A. oryzae and A. chroococcum], vermicompost, and combinations of all). Using fertilizers combined reduced the proline content and leaf temperature but increased antioxidant enzyme activities, soluble sugars, chlorophyll and leaf water content, membrane stability index, and stomatal conductance under different irrigation intervals. Furthermore, the crop yields were significantly higher under this treatment than the control (no fertilization).

On the other hand, Fang et al. (2023) [182] evaluated the application of 60, 120 and 180 K$_2$O kg ha$^{-1}$ against the effects of drought stress in sesame plants exposed to 50% field capacity for 6 days during their flowering stage. Their findings revealed that potassium played a significant role in mitigating the effects of drought by enhancing photosynthesis and regulating hormones involved in stomatal closure as such abscisic acid and jasmonic acid. The optimal potassium concentration for drought mitigation was found to be 120 kg ha$^{-1}$, promoting increased photosynthetic capacity and plant water retention. Nutrient management remains controversial due to the absence of an effect on water stress, because it is necessary to have a certain water content for nutrients to be absorbed and function in the metabolism [147,183].

3.1.5. Deficit Irrigation

Deficit irrigation is an agricultural strategy in which crops are provided with less water than needed, with a low impact on yield and production quality [184,185]. This practice has two approaches: sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI). SDI refers to a reduction of irrigation water below than necessary for the crop during the growth stage, while RDI supplies a lower amount of water than necessary for the crop during phenological stages when it is less sensitive to water stress [185,186]. For both approaches, a degree of water stress may be observed and can negatively affect the physiological and biochemical processes of plants [187]. In addition, this technique increases water efficiency; up to 80% of water was saved in tomato crop irrigation [188,189], 73% in pear crops [190], and 50% in wine crops [191]. It also reduces the plant’s biomass production and yields, and physiological and biochemical variables in plants and fruits [192,193]. According to Durán
et al. (2011) [192], the SDI effect in mangos was determined by the yield, fruit quality, and the growth and mineral state of the trees (Mangifera indica L.). Severe drought treatment decreased yields despite these yield losses, and SDI allowed better efficiency in water use. Moreover, Mena et al. (2013) [193] evaluated the effects of water deficit on color, antioxidant activity, phenolic compounds, anthocyanins, punicalin, and ellagic acid in pomegranate juice. Pomegranate trees (Punica granatum L.) were watered at 75% (control), 43% (moderate deficit), and 12% (severe deficit). These conditions affected the physicochemical quality of pomegranate juice, giving it a more yellowish color, lower antioxidant activity, and lower content of phenolic compounds, punicalin, and anthocyanins compared with the control.

The purposes of RDI are to reduce the amount of irrigation water used in crops, increase the efficient use of crop water, and improve the plants’ response to water stress [194]. However, several reports have pointed out decreased crop yields [188,195,196]. In this context, Coyago-Cruz et al. (2019) [188] exposed two cultivars of red cherry tomato (Solanum lycopersicum L.) to conditions of regulated water deficit. They achieved a foliar water threshold of -1 MPa and well-irrigated plants, although with RDI application, there was a saving of 85% in water irrigation, and higher content of soluble sugars, carotenoids, and total phenols, smaller fruit sizes were obtained, and cultivar yields were reduced during spring and autumn cycles.

Parkash et al. (2021) [25] evaluated the effects of different irrigation regimes (100, 80, 60, and 40%) on the physiology, plant growth, and yield of two cucumber cultivars (Poinsett 76 and Marketmore 76). They found that severe water deficit conditions (40 and 60%) harmed the plant’s growth, physiology, and fruit yield. In contrast, a water deficit of 80% improved growth, physiology, and yields, comparable to the results obtained for the control (100%), in Poinsett 76. Based on these results, the authors suggested a regime of irrigation of 80% for Poinsett 76 for successful cucumber production.

Other authors applied RDI in vine crops (Vitis vinifera) to also induce a certain degree of water stress, mainly during fruit setting and veraison, to control the vigour and adjust the development of the grapes as well to promote quality parameters of wine production [197,198].

3.1.6. Phytohormones and Osmoprotectants

Phytohormones and osmoprotectants play a highly relevant role in controlling plants’ different adaptation processes under abiotic stress conditions, even in generating plants’ tolerance to drought and other types of stress. Among them are abscisic acid (ABA), auxins (IAAs), gibberellins (GAs), cytokinins (CKs), brassinosteroids (BRs), ethylene (ET), salicylic acid (SA), and jasmonic acid (JA) [199,200]. Plants in drought environments synthesize many of these mentioned phytohormones to control common processes associated with tolerance mechanisms [201]. Phytohormones act as activators of some physiological processes in plants, such as osmolyte accumulation, stomatal closure, and stimulation of root growth) in defense against water stress [200,202].

The effects of exogenous application of phytohormones have been evaluated to improve plant growth, metabolism, and crop productivity under water stress conditions [203]. Ramachandran et al. (2021) [204] assessed the effect of ABA on rice (Oryza sativa L., ADT 45 and 49 cultivars). After 10 days of drought stress induction, followed by foliar spray application of ABA for five days, new water irrigation was applied. They monitored plant growth (stem and root length, fresh and dry weight), relative content of water, photosynthetic pigments, reducing sugars, soluble starch, protein, amino acids, malondialdehyde, activity of antioxidant enzymes (CAT, POD, APX, and SOD) and yields. Plants treated with ABA at 100 µM increased their growth, improved physiological and biochemical variables values, and increased their yields under drought conditions, suggesting a greater tolerance to drought. Yan et al. (2022) [67] applied ABA at 150 µM on tomato seeds (Solanum lycopersicum) subjected to water stress and found that plant height, stem diameter, root length photosynthesis, and the activity of antioxidant enzymes were increased; thus, drought tolerance was improved. Other plant hormones, such as auxins essential
for their reproductive development, have also been studied under drought conditions. For example, Sharma et al. (2018)\[^{205}\] applied a $10^{-5}$ M IAA solution in a foliar way to different rice genotypes after suspending irrigation during the anthesis stage. They conclude that water stress reduces pollen viability and fertility of rice spikelets; however, the exogenous application of IAA improved pollen viability, spikelet fertility, and yield even in drought conditions.

Similarly, some substances participate in the signalling and regularization of plants' responses against abiotic stress and are called osmoprotectants; within this group are proline, glycine betaine, trehalose, fructans, and mannitol, among others. These substances have an adaptive function to protect the subcellular plant structures by osmotic activity if water stress conditions are applied [146,206]. Semida et al. (2020)\[^{24}\] evaluated the role of exogenous proline application in onion (Allium) exposed to abiotic stress, and they found that foliar application (1 and 2 mM) positively affected growth, defense system, physiological and biochemical variables, and bulb yield. Their results suggest that onion bulb yield and water efficiency usage significantly increased, even 50% more than well-irrigated plants. Furthermore, they also indicated that the combined effect of proline with an irrigation deficit of 80% would allow optimal onion crop yields and water-saving of up to 40%. Other osmoprotectants such as glycine betaine and trehalose have also been studied in wheat [207,208], corn [209], and rice crops [210]; reports suggested that efficient water use was improved under stress conditions and tolerance to drought also increased. These investigations suggested improved efficient water use under conditions of water stress and increased tolerance to drought.

Finally, other natural or synthetic biostimulants have also been reported to promote plant growth. Moreover, they could help mitigate the adverse effects of water stress since plants can improve their defense strategies against this type of abiotic stress. In this sense, Sharma et al. (2019)\[^{211}\] achieved positive effects on drought tolerance in wheat crops using an extract of Gracilaria dura with the exogenous use of silicon and hydrogen sulphide in sesame plants, with the foliar application of beeswax and licorice extract (Glycyrrhiza glabra). The application of biostimulants is an emerging strategy that is still under evaluation. It seeks to improve plant productivity to give resistance against several environmental stress conditions [212].

In Figures 4–8, some agricultural strategies to management water stress effects are reported, including tillage, mulching, nutrient handling, regulated deficit irrigation and exogenous application of hormones and osmoprotectants. Figures show water stress conditions, agricultural strategy conditions, morpho–physiological and biochemical effects of treatments, yield, and management or water savings. These studies were carried out on crops of tomato, eggplant, chili, potato, carrot, broccoli, cucumber, garlic, maize, lentil, and wheat; they were distributed in Asia (68.8%), Africa (12.5%), Europe (12.5%), and America (7.2%), mainly in regions with semi-arid, subtropical, or tropical climates. Evaluated conditions of water stress were diverse, from suppression of irrigation for a few days (4, 10, 12, 15, and 20 days) to provision of irrigation less than crop water requirements (40, 50, 70, 80, and 90%), evapotranspiration (40, 60, 70, and 80%), or field capacity (40, 50, and 80%), and with different application times, generally by growing season.
Figure 4. Effects of tillage treatments on water stress mitigation in maize [157], lentil [158], spring wheat [213], and faba bean [159]. CAT: catalase; CT: conventional tillage; gs: stomatal conductance; MDA: malondialdehyde; NT: no tillage; NTS: no tillage with straw mulching; pn: photosynthesis; POD: peroxidase; RWC: relative water content; TS: conventional tillage with straw incorporation; WUE: water use efficiency. The increase or decrease in crop responses to treatments is represented by ↑ or ↓, respectively.

Figure 5. Effects of mulching treatments to water stress mitigation in tomato [14], eggplant [23], and chili [16]. CWR: crop water requirement; ETc: crop evapotranspiration; WUE: water use efficiency. Increases or decreases in crop responses to treatment are represented by ↑ or ↓, respectively.
**Figure 6.** Effects of nutrient handling treatments to water stress mitigation potato [20] and tomato [19,27]. Ca: calcium; CAT: catalase; E: transpiration; gs: stomatal conductance; K: potassium; P: phosphorus; pn: photosynthesis; POD: peroxidase; Zn: zinc. Increases or decreases in crop responses to treatment are represented by ↑ or ↓, respectively.

**Figure 7.** Effects of regulated deficit irrigation treatments in cucumber [25], garlic [26] and carrot [22]. Ci: chlorophyll index; CWR: crop water requirement; E: transpiration; ETc: crop evapotranspiration; gs: stomatal conductance; WP: water productivity; WUE: water use efficiency. The increases or decreases in crop responses to treatments are represented by ↑ or ↓, respectively.
Wood chip and plastic mulches positively affected morphological variables such as growth, leaf area, and stem diameter in tomato crops, at 70% of water requirements, which meant greater efficiency, with a saving of 30% of water in this crop. The use of straw and plastic mulches in eggplant crops showed an increase in the content of carotenoids and total soluble solids, which improved water use efficiency; however, biochemical variables such as vitamin C were affected. Elsewhere, the exogenous application of potassium to potato crops did not mitigate the effects of water stress on photosynthesis, transpiration, or stomatal conductance; however, it improved nutrient assimilation, shoot and root growth, and increased the activity of antioxidant enzymes, which led to an increase in yield, especially at a concentration of 100 kg of potassium*Ha\(^{-1}\) under partial root irrigation, which could represent water savings for this crop. The exogenous application of zinc improved crop growth for tomato plants, but no information was given on any effect on yield or water use. Moreover, using biochar and nitrogen reduced lycopene content, sugars, and vitamin C; however, it improved crop yield and water productivity by up to 51.8%. For cucumber and garlic crops with deficit irrigation, a reduction in humidity volume was achieved, which significantly affected the yields, by 10% and 25%, with 80% ETC and 70% water requirements, respectively, representing a 20–30% water saving. In contrast, carrot crops irrigated with 70% of their requirement showed an increase in yield and water savings of 10%. Finally, for broccoli, chili, and eggplant crops, the exogenous application of hormones and osmoprotectants mitigated the effects of water stress by increasing the activity of antioxidant enzymes and the content of osmolytes such as proline. Furthermore, they also increased the content of metabolites such as carotenoids, ascorbic acid, and polyphenols; however, the effects on performance or savings in water use were not mentioned.

According to the studies, in general, minimal or no tillage improved the yield of grain maize, lentil, and spring wheat and improved soil water conservation, increasing water use efficiency. Using mulches increased water use efficiency for tomato, eggplant, and chili crops under water deficiency from 20% to 30% without affecting plant growth. The exogenous application of nutrients such as potassium and nitrogen-biochar could mitigate...
water stress’s effects on crop yields, allowing water savings in potato and tomato crops. The irrigation deficit suggested significant water savings in cucumber, garlic, and carrot crops; however, it could negatively affect crop yields. Regarding the application of hormones or osmoprotectants, their beneficial effect on accumulating antioxidant compounds has been reported, but their impact on performance and water management is unclear.

3.2. Plant Breeding Approaches

Plant breeding refers to the improvement of genetic patterns of crops by human intervention for their benefit [214–216]. Plant breeding has been applied to produce tolerant plants under different abiotic stress conditions, and has great potential to improve the productivity of crops subjected to drought in arid and semi-arid environments [179]. Due to severe and moderate drought conditions for dryland crops in the global south and the increasing demand for food, plant breeding is emerging as a technique to improve crop yields under drought conditions and has received particular attention in South and East Asia, including India, where drought already provokes yield losses of 30% [217].

A conventional strategy for crop improvement is to consider productivity as the main indicator in plant selection; nevertheless, this strategy is considered slow and expensive, and it has shown limited performance against drought effects [147]. Due to the above, it is currently suggested that the combined effects of plant physiology with genomics should be studied to develop drought-resistant plants. Using molecular and cytological techniques allow plant biotechnology to increase crop yields, improve the product’s quality, and prevent damage caused by abiotic stress [218].

Drought tolerance is a quantitative variable controlled by genes; therefore, genetic manipulation to produce drought-tolerant crops is complex. Genes associated with water stress tolerance can be identified, edited, silenced, and overexpressed to generate tolerance to water stress conditions [219]. Thus, some strategies have been developed such as identification of quantitative traits to improve water use efficiency by introducing wild relatives to select drought-tolerant germplasm. Drought adaptation refers to drought-tolerant plants with many genes associated with stress and can help reproduce varieties of tolerant plants [220]. Due to the above, it is essential to identify the loci of quantitative traits that control water use efficiency to improve crop productivity under stress conditions [199]. Quantitative trait locus analysis is a statistical method that integrates phenotypic (such as trait measurements) and genotypic data (such as primary molecular markers) to associate specific phenotypes with chromosomal regions [221]. The marker-assisted QTL technique has been used to identify traits related to drought tolerance in triticale [222], rapeseed [223], okra [224], rice, wheat, maize, pigeon pea, and tomato [225,226].

4. Trends in the Use of Physical Eustressors (Biostimulants/Elicitors) to Promote Drought Tolerance

Abiotic and biotic stress factors promote negative plant responses that affect their growth, quality, and yield. However, it has been reported that these effects are related to the dose, its intensity, the duration of the stress factor, and the plant response. It is known that administering small doses of stress factors can stimulate responses in plants that improve agricultural production, while high doses can negatively affect crop productivity [30]. According to the dose and the effects they generate in plants, stress factors are divided into eustressors and distressors; while the former, applied in low to moderate doses, positively stimulate plants and can improve growth and productivity, the latter impair their development at high doses [227]. According to their nature of origin, Vázquez-Hernández et al. (2019) [30] classify eustressors as physical, chemical, and biological stress factors (Figure 9).
Their use positively affects plant performance by promoting plant growth and quality, proline), in addition to reversing the insufficiency of nutrients such as N, P, Mg, Zn, and Cu. In contrast, some research has reported that acclimatization induced by UV radiation does not mitigate the adverse effects of drought on biomass accumulation and growth, so it has been proposed that the combination of UV and water stress could have an additive response, which requires further exploration to understand, from a multidimensional approach, the tolerance and adaptation of plants to stress [229,231].

Both biological and non-biological eustressors (chemical and physical) have been proven to help improve agricultural production and promote resistance to stress factors. Their use positively affects plant performance by promoting plant growth and quality, helping improve the absorption of nutrients and water, and promoting tolerance to abiotic and biotic stress. According to Vázquez-Hernández et al. (2019) [30], the favourable effects of applying biological products and chemical eustressors have been widely reported in the literature; however, physical eustressors have not been exhaustively studied. Therefore, this section brings together some of the physical eustressors and their effects on crops of commercial interest.

Recently, the induction of drought tolerance using physical eustressors has been evaluated. According to Romero-Galindo et al. (2021) [228], the most reported physical eustressors are UV-B radiation and the application of magnetic fields in vegetables, cereals, legumes, trees, and medicinal plants, in addition to the use of helium–neon and CO₂ lasers, gamma radiation, and plasma on cereal seeds and medicinal plants prior to sowing. UV-B radiation has been proposed as a potential eustressor to provide resilience to drought stress since UV-B rays promote positive regulation in plants of metabolites related to defense against abiotic stress (proline, flavonoids, anthocyanins, and antioxidants), whose biosynthesis is modulated by signalling molecules such as ethylene, hydrogen peroxide, and abscisic, jasmonic, and salicylic acid [229]. On the other hand, Luo et al. (2023) [230] observed that UV-B solar radiation alleviated the adverse impact caused by drought in chestnut rose, improving total biomass, possibly by activating the enzymatic antioxidant system (increased SOD activity and CAT) and the non-enzymatic (increased flavonoids and proline), in addition to reversing the insufficiency of nutrients such as N, P, Mg, Zn, and Cu. In contrast, some research has reported that acclimatization induced by UV radiation does not mitigate the adverse effects of drought on biomass accumulation and growth, so it has been proposed that the combination of UV and water stress could have an additive response, which requires further exploration to understand, from a multidimensional approach, the tolerance and adaptation of plants to stress [229,231].

Figure 9. Hormetic curve and classification of eustressors based on their natural origin.
For its part, the application of magnetic fields has also been proposed as a physical eustressor that can be used to modulate the resistance of plants to various stress factors, especially drought [232]. Magnetic fields are known to mitigate the effects of stress by increasing antioxidant compounds in plants and reducing oxidative stress [233]. However, their effects differ according to intensity, exposure time, and type of crop. The use of magnetic fields of 0.3–1.1 T for 5 min in seeds is recommended to increase drought tolerance in pepper seedlings because during 12 days of irrigation suspension, the melatonin content increased, which is an antioxidant phytohormone that causes the elimination of the harmful effects of stress, along with increased CAT activity [234]. Mshenskaya et al. (2023) suggested the use of low-frequency magnetic fields (14.3 Hz) in wheat plants subjected to drought conditions, finding that they had a protective effect on plants that were subjected to water restriction for 12 days, based on the delay in the appearance of harmful changes in the processes of photosynthesis and transpiration; however, significant differences in dry weight, plant length, or leaf area were not observed between plants under drought stress conditions and those treated with magnetic fields and drought stress.

On the other hand, the application of helium–neon laser (He-Ne laser) as a pretreatment in seeds has gained significant interest in improving the stress tolerance of crops. Aslam et al. (2022) [235] found that He-Ne laser priming (630 nm, 2 min) improved drought tolerance in wheat (50% FC for 21 days) through differential modification of photosynthetic pigments (chlorophyll a and b, total chlorophyll, carotenoids, and anthocyanins) and antioxidant enzymes (SOD, CAT, POD, and APX). Qiu et al. (2017) [236] studied the transcriptome changes induced by He-Ne laser irradiation (632.8 nm, 5.43 mW mm$^{-2}$, 3 min) in wheat seedlings under drought stress (5 days without irrigation), and found that in pretreated wheat plants, 820 transcripts were differentially expressed related to photosynthesis, nutrient absorption and transport, and the control of ROS homeostasis, which may have contributed to improving the tolerance of this crop to drought. The application of He-Ne laser has also been reported in sunflowers, where it caused an improvement in biomass production, the accumulation of phenolic compounds and proline, and more significant CAT enzymatic activity, which is why it was proposed as a strategy to improve the yield and nutritional value of sunflowers subjected to drought conditions [237].

Regarding gamma rays’ potential to induce tolerance in plants against abiotic stress, their use at low doses (50 to 100 Gy) has been reported [238]. Suhesti et al. (2015) [239] found that sugarcane calli irradiated with doses of 10 and 20 Gy were more tolerant to drought (10% PEG), increasing their ability to survive and regenerate. El-Sallami et al. (2019) [240] found that under the evaluated drought conditions (40, 60, 80 and 100% FC), irradiation of Jericho flower seeds with gamma rays at higher doses (50–250 Gy) promoted an increase in plant growth, which may have been due to the apparently direct relationship between drought tolerance and concentrations of phenolic compounds, proline, and abscisic acid, as well as increased CAT and POD activity. For their part, Suharjo and Pamekas (2023) [241] observed that exposure of potato seeds to gamma radiation (30 Gy) and growth under exposure to chemically induced water stress with PEG8000 (0, 2, 4, and 8%) improved growth and crop performance under drought conditions.

Other physical eustressors that can potentially improve drought tolerance in crops are sound vibrations, which modify the behaviour of plant cells through Ca$^{2+}$ and ROS signals associated with signalling processes in the stressed plants, causing changes in their biochemical activity or regulation of gene expression to cope with stress conditions [242]. In this context, López-Ribera and Vicent (2017) [243] observed that white noise (100 dB) applied for 10 h to adult Arabidopsis plants with irrigation deprivation for 2 weeks improved drought tolerance and increased survival rates up to 24.8% compared with untreated plants. Furthermore, noise caused the upregulation of 86 genes, including 32 genes associated with abiotic stress responses, and 2 genes involved in the response to mechanical stimulation. The above suggests that sound’s impact on plants probably occurs through a perception mechanism similar to that of mechanical stimuli [243]. For their part, Caicedo-Lopez et al. (2021) [244] proposed that the application of acoustic waves similar to the acoustic vibra-
tion to jalapeno pepper plants subjected to low (LHS), medium (MHS), and high (HHS) water stress could positively impact the performance of the plants at a biochemical and genetic level. They found that acoustic treatments positively regulated POD, MHS and HHS positively regulated Mn-SOD and PAL, and the medium level regulated Chs gene expression and induced a higher capsaicin content, which could suggest an alternative for the management of tolerance in this crop.

In general, physical eustressors improve the tolerance of plants to water stress \[228\] through positive regulation of osmolites, phytohormones, and secondary metabolites, activation of enzymatic and non-enzymatic antioxidant systems, gene upregulation, and stimulation of growth parameters (Figure 10); however, their effects are variable and depend on various factors, such as the type of eustressor and application conditions, drought induction methods, type of crop, and phenological stage at which the stress is applied, so this is a field that should continue to be explored. It is necessary to continue evaluating physical eustressors as stress factors that improve the quality of agricultural production in other plant species such as vegetables. Furthermore, it is necessary to evaluate whether drought tolerance promoted by these physical eustressors is inherited.

Figure 10. General effects of biostimulants and elicitors of physical origin on mitigating water stress.

5. Combination between Agronomic Approaches and Physical Stressors to Alleviate the Effects of Water Stress and Develop Tolerance to Drought

The relation between physical eustressors and agronomic approaches in crops can be explored for improving drought stress tolerance and alleviating the negative effects of stress according to common morphological, physiological, biochemical, and molecular responses. Table 3 shows agronomic strategies for drought stress management and physical eustressors recently proposed for improving drought tolerance in diverse crops, mainly vegetables, and their common effects associated with morphological changes, improvement in secondary metabolites content, enzymatic and non-enzymatic defense, and upregulation of genes associated with the drought stress factor.

**Table 3. Possible combination between agronomic strategies and physical eustressors for improving drought tolerance according to plant responses.**

<table>
<thead>
<tr>
<th>Improved Drought Response Management Strategy</th>
<th>Plant/References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomic strategies</td>
<td>Physical eustressors</td>
</tr>
</tbody>
</table>

**Biostimulant effects**
- \(\uparrow\) Growth plant.
- \(\uparrow\) Total biomass.

**Elicitor effects**
- \(\uparrow\) Photosynthetic pigments.
- Positive regulation of osmolites such as proline.
- \(\uparrow\) Phytohormones (melatonin and ABA).
- Non-enzymatic antioxidant defense system activation (phenols, flavonoids, carotenoids, anthocyanins).
- Enzymatic antioxidant system activation (CAT, SOD, POD, APX).
- Up-regulation of genes associated with water stress.
Table 3. Possible combination between agronomic strategies and physical eustressors for improving drought tolerance according to plant responses.

<table>
<thead>
<tr>
<th>Improved Drought Response</th>
<th>Management Strategy</th>
<th>Plant/References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morphological traits</strong></td>
<td>Tillage</td>
<td>Maize [157]</td>
</tr>
<tr>
<td>(root length and diameter, leaf area, plant height, stem diameter)</td>
<td>Mulching</td>
<td>Lentil [158]</td>
</tr>
<tr>
<td></td>
<td>Intercropping</td>
<td>Tomato [14,27]</td>
</tr>
<tr>
<td></td>
<td>Nutrient handling</td>
<td>Chili [16]</td>
</tr>
</tbody>
</table>
|                           | Exogenous hormones and osmoprotectants | Lettuce [15] 
|                           | Gamma rays          | Broccoli [17]    |
|                           |                     | Potato [20,241]  |
| **Chlorophyll**           | Tillage             | Lentil [158]     |
|                           | Exogenous osmoprotectants | Eggplant [18] |
|                           | He-Ne laser         | Wheat [235]      |
| **Osmolytes** (proline, glycine betaine) | Exogenous hormones and osmoprotectants | Chili [21] |
|                           | UV-B                | Eggplant [18]    |
|                           | He-Ne laser         | Chestnut rose [230] |
|                           | Gamma rays          | Sunflower [237]  |
|                           |                     | Jericho flower [240] |
| **Antioxidant enzymes**  | Tillage             | Wheat [213]      |
| (CAT, POD, SOD, APX)      | Nutrient handling   | Potato [20]      |
|                           | UV-B                | Eggplant [18]    |
|                           | Magnetic fields     | Chestnut rose [230] |
|                           | Gamma rays          | Chili [232]      |
|                           | He-Ne laser         | Sunflower [237]  |
|                           |                     | Jericho flower [240] |
|                           | Exogenous hormones  | Tomato [14]      |
| **Antioxidant compounds** | Mulching            | Eggplant [18,23] |
| (ascorbic acid, carotenoids, anthocyanins, phenolic compounds, capsaicin) | UV-B                | Chestnut rose [230] |
|                           | He-Ne laser         | Wheat [235]      |
|                           | Sound vibrations    | Sunflower [237]  |
|                           |                     | Chili [245]      |
| **Secondary metabolites** | Mulching            | Eggplant [23]    |
| (MDA, soluble sugars, and protein) | Exogenous hormones | Chili [21]      |
|                           | He-Ne laser         | Wheat [236]      |
| **Up or downregulation genes, and expression of genes associated with drought stress** | He-Ne laser | Wheat [236] |
|                           | Sound vibrations    | Arabidopsis [243] |
|                           |                     | Chili [245]      |
| **Biomass and yield increase** | Tillage             | Maize [157]     |
|                           | Intercropping       | Lentil [158]     |
|                           | UV-B                | Lettuce [15]     |
|                           | He-Ne laser         | Chestnut rose [230] |
|                           | Mulching            | Sunflower [237]  |
|                           |                     | Wheat [236]      |
|                           |                     | Chili [16]       |
|                           |                     | Jericho flower [240] |

Tillage, mulching, intercropping, nutrient handling, exogenous hormones and osmoprotectants, and gamma ray application can alleviate morphological drought effects
in maize, lentils, tomatoes, chili, lettuce, broccoli, and potatoes, acting as biostimulants. In lentils, eggplant and wheat, crosstalk between strategies such as tillage, exogenous osmoprotectants (α-Tocopherol), and He-Ne laser could be relevant to improve chlorophyll content, increasing the leaves’ photosynthetic capacity, contrasting physiological drought stress effects [235], and improving plant growth [18]. Proline and glycine betaine content, relevant osmolytes for osmotic adjustment during drought conditions, could improve with use of exogenous osmoprotectants such as melatonin, in cross talking with UV-B, He-Ne laser or Gamma rays in chili, eggplant, chestnut rose, sunflower, and Jerico flower (acting as elicitors). According to the increase in antioxidant enzyme activities and antioxidant compounds for drought stress alleviation and improved drought tolerance in wheat, potato, eggplant, chili, sunflower, and Jerico flower, diverse strategies (tillage, nutrient handling, or exogenous hormones) could be combined with physical eustressors (UV-B, magnetic fields, gamma rays, sound vibrations, or He-Ne laser). Also, it is important to know the crosstalk between He-Ne laser or sound vibrations and up or downregulation genes and the expression of genes associated with drought stress. Finally, it is necessary to study the implementation of tillage, intercropping, or mulching with UV-B or He-Ne laser in maize, lentil, lettuce, chestnut rose, sunflower, wheat, and chili to improve biomass and crop yield.

6. Conclusions

Water stress reduces crop yield and tends to increase because of climate change. Plants adopt different strategies to avoid drought conditions and to adapt to water stress, which causes a series of morphological, physiological, biochemical, and molecular changes that have been widely studied for different crops. The physiological and biochemical responses to water stress are contrasting; these depend on factors such as the severity and duration of the water deficit imposed, vegetable species, and the phenological stage of the plants.

Several strategies have been proposed for mitigating water stress in vegetables. These include agricultural practices such as tillage, mulching, and intercropping, as well as the exogenous application of phytohormones, osmoprotectants, and specific nutrients. These substances, depending on the dose evaluated and the vegetable responses, have been considered as biostimulants or elicitors, which are compounds that stimulate plant growth and development or induce defense responses, respectively. The literature highlights the interest in using physical eustressors to mitigate water stress in vegetables. Considerable research shows various relief and tolerance responses to water stress; however, the mechanisms are still poorly elucidated.

Finally, it was observed that various strategies for managing water stress show similar responses in plants both at a physiological level and in biochemical responses of an antioxidant nature and in the presence of osmolytes, as well as in the regulation or expression of genes related to stress response. Therefore, we propose that a combination of these strategies could be used to help improve water stress mitigation. For example, agronomic practices such as tillage and mulching with the application of phytohormones and osmoprotectants, as well as treatment with gamma rays to alleviate the effects of drought on morphology, could increase biomass and crop yield. Also, we propose using hormones and physical eustressors such as He-Ne laser, UV-B, and gamma rays to increase the antioxidant response and osmotic adjustment of plants in response to drought or promote genetic regulation with sound vibrations and He-Ne laser. Further exploration is required to establish doses, application conditions, and effects on water stress mitigation and vegetable yield, and to evaluate the possibility of implementing these strategies in agriculture production, underscoring the importance and ongoing nature of this research.

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References
4. Parkash, V.; Singh, S. A Review on Potential Plant-Based Water Stress Indicators for Vegetable Crops. Sustainability 2020, 12, 3945. [CrossRef]
17. Sakr, M.T.; Ibrahim, H.M.; ElAwady, A.E.; AbouELMakarm, A.A. Growth, Yield and Biochemical Constituents as Well as Post-Harvest Quality of Water-Stressed Broccoli (Brassica oleracea L. Var. Italica) as Affected by Certain Biomodulators. Sci. Hortic. 2021, 275, 109605. [CrossRef]
18. Akram, N.A.; Bashir, R.; Ashraf, G.; Bashir, S.; Ashraf, M.; Alyemeni, M.N.; Bajguz, A.; Ahmad, P. Exogenous α-Tocopherol Regulates the Growth and Metabolism of Eggplant (Solanum melongena L.) under Drought Stress. Plants 2023, 12, 237. [CrossRef]


34. Wang, J.Q.; Li, H.; Liu, Q.; Xiang, D. Effects of Drought Stress on Root Development and Physiological Characteristics of Sweet Potato at Seedling Stage. *Ying Yong Sheng Tai Xue Bao-The J. Appl. Ecol.* 2019, 10, 100004. [CrossRef]


42. Wang, J.Q.; Li, H.; Liu, Q.; Xiang, D. Effects of Drought Stress on Root Development and Physiological Characteristics of Sweet Potato at Seedling Stage. *Ying Yong Sheng Tai Xue Bao-The J. Appl. Ecol.* 2019, 10, 100004. [CrossRef]


44. Wang, J.Q.; Li, H.; Liu, Q.; Xiang, D. Effects of Drought Stress on Root Development and Physiological Characteristics of Sweet Potato at Seedling Stage. *Ying Yong Sheng Tai Xue Bao-The J. Appl. Ecol.* 2019, 10, 100004. [CrossRef]


176. Assadi, N.M.; Bijanzadeh, E. Influence of Relay Intercropping of Barley with Chickpea on Biochemical Characteristics and Yield under Water Stress. *PloS ONE* 2023, 18, e0273272. [CrossRef]


230. Luo, D.; Li, J.; Luo, J.; Ma, Y.; Wang, Y.; Liu, W.; Rodriguez, L.G.; Yao, Y. Responses to Solar UV-B Exclusion and Drought Stress in Two Cultivars of Chestnut Rose with Different Leaf Thickness. Forests 2023, 14, 50. [CrossRef]


234. Yakupoglu, G. Effects of Magnetic Field and Ultrasound Applications on Endogenous Melatonin Content and Drought Stress Tolerance of Pepper Seedlings. *Horticulturae* 2023, 9, 704. [CrossRef]


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