Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2023-s1-048

Review Article

Open Access

Physiological and Biochemical Responses of Fruit Crops Under Stress

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Received: October 06, 2023
Accepted: November 02, 2023
Published: November 06, 2023

Citation: Kondle R, Kapoor H. 2023. Physiological and Biochemical Responses of Fruit Crops Under Stress. *J Food Chem Nanotechnol* 9(S1): S381-S389.

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Abstract

Fruit crops are susceptible to various environmental adversities such as heat, salinity, drought, low temperature, and moreover pests, which affect their maturation, development, and yield. These stresses also induce physiologic and metabolic changes in fruit crops, which can have negative impacts on their quality and nutritional value. Altered water relations under stress conditions can lead to water stress, resulting in reduced fruit size and weight. Biochemical changes in fruit crops under stress conditions include changes in primary and secondary metabolites. For instance, under drought stress, fruit crops accumulate osmo-protective disintegrating solute compounds like proline to maintain turgor pressure and protect cellular membranes. Under high-temperature stress, fruit crops undergo changes in carotenoid and anthocyanin content, which affect fruit color and antioxidant capacity. To prevent cellular damage, numerous antioxidant systems can be triggered at the biochemical level, and many enzymes may create stress-related metabolites, such as glycine betaine, amino acids, proline, etc. This causes both biochemical and physiological changes such as melatonin stimulation and disorder in fruit crops. The main objectives of studying these alterations are to comprehend how fruit crops respond to stress and to develop strategies to reduce or modify these stressors. Understanding these physiological and biochemical changes in stressed fruit crops is essential for crop management, stress resistance breeding, and developing countermeasures. Fruit crops may become more prolific and robust even in the face of challenging environmental circumstances by putting this learning into practice. In this review, we identify stress-causing elements and talk about the causes, behaviours, and responses to situations.

Keywords

Stress, Physiological disorders, Biochemical, Melatonin, Proline, Betaine, Osmo-protectant, Salinity stress

Introduction

Understanding how fruit crops adapt to difficult surroundings and unfavorable circumstances requires a comprehension of the physiology and biochemical changes these plants undergo in response to different stresses. Drought, extremely high or low temperatures, salt, pests, illnesses, and other conditions can all cause stress. This area of research is crucial to maintaining the productivity and resilience of fruit crops in agriculture, which impacts sustainable crop production and global food security. The primary determinants of plant stress responses are the duration of the stress, its severity, and the stage of plant growth [1]. Stress is the primary key factor that restricts the growth and development of plants. Stresses that are experienced throughout pivotal growth phases have an inimical impact on their production [2]. Since fruit crops are typically perennial, stress poses a greater threat to them. Different abiotic and biotic stresses, have a sig-

nificant impact on fruit plants' development and productivity throughout their lives [3]. Physiological and metabolic processes and transcription control networks that lead to biotic stress tolerance have been investigated in higher plants [4]. Stressful conditions cause different physiological diseases and chemical changes. Physiological changes may include alterations in the plant's water balance, photosynthesis, respiration, and nutrient consumption. For instance, under drought stress, fruit crops close their stomata to reduce water loss, which results in reduced photosynthesis and limited nutrient uptake. Similarly, under high temperatures, fruit crops may experience heat stress, leading to reduced photosynthesis and increased respiration, which can negatively affect fruit quality and yield.

Biochemical changes may include the accumulation of various osmo-protectants, antioxidants, and secondary metabolites, such as phenolics, flavonoids, and carotenoids, which play an important role in protecting fruit crops from oxidative damage and pathogen attack. For example, under salt stress, fruit crops may accumulate osmo-protectants like glycine betaine and proline to maintain their water balance and protect against oxidative stress. In summary, the physiology, and the biological changes (Figure 1) that take place in fruit crops under stress scenarios are complex and multifaceted and depend on various factors, including the type of stress, the time frame and intensity of the stress, and the specific fruit crop. Understanding these changes is crucial for developing strategies to improve the resilience and efficiency of fruit crops pursuant to stress conditions. We will discuss the importance of researching fruit crops' physiological and biochemical stress responses in this introduction, as well as the consequences for agriculture.

Abiotic and Biotic Stress

Abiotic stress is defined as effects caused by different outside stimuli such as oxidative stress, chemical toxicity, dehydration, salinity, and extremely high temperatures causing several effects on fruit crops (Figure 2). Abiotic stress creates adverse effects on multiple procedures of morphology, biochemistry, and physiology that are directly connected with growth and yield of the plant [5]. The most important abiotic stresses limiting agricultural productivity, almost all over the world, are drought, salinity, non-optimal temperatures, and low soil fertility [6]. Biologic stress is the term used to describe the harm that other living organisms, such as bacteria, fungi, nematodes, protists, insects, viruses, and viroid's, cause to plants. Plants

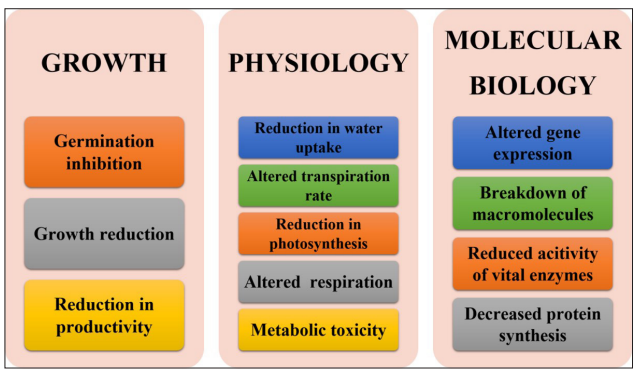

Figure 1: Effects of stress on fruit crops.

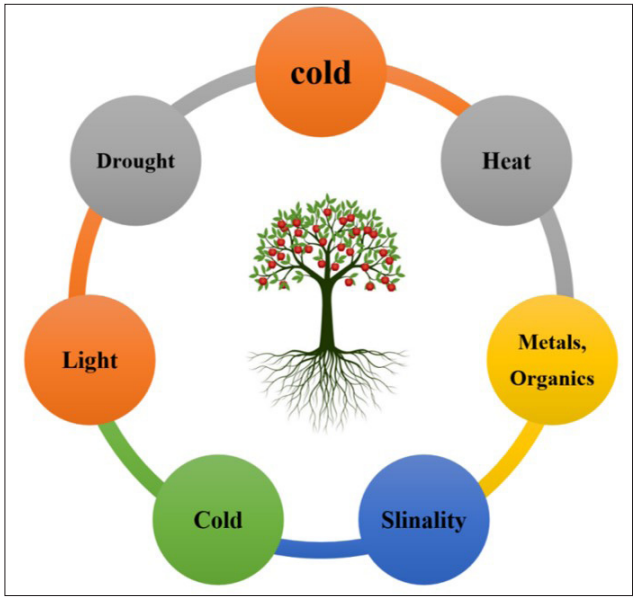

Figure 2: Stress factors.

have evolved defence systems to withstand and adapt to environmental biotic and abiotic stressors. Many signalling pathways with interconnections or crosstalk are activated in response to every given environmental event. Plant hormones, salicylic acid, jasmonic acid, and ethylene play crucial roles in biotic stress signalling. The signalling of numerous hormones is regulated by many transcription factors. Polyunsaturated fatty acids are oxidised to fatty acid hydroperoxides by LOXs. The biosynthesis of jasmonic acid begins with linolenic acid, which is transformed into 12-oxo-phytodienoic acid by oxygenation with LOX, allene oxide synthase, and allene oxide cyclase. Additionally, LOXs are essential for defence reactions against abiotic stressors [7].

Combinations of biotic and abiotic stressors influence plant response favourably. Either biotic or abiotic stress will cause the defense response genes to become active. Plants use a variety of signal transduction mechanisms to defend themselves against biotic stresses. A few biotic resistance verities of different fruit crops are viewed in table 1. By controlling the stomatal aperture and boosting the production of genes linked to defence against pathogen attack, abscisic acid (ABA) starts the plant's defence mechanism. By adjusting guard cells' ion fluxes of stomata in both Ca^{+}-independent and Ca^{+}-dependent pathways, ABA significantly reduces the amount of water that plants lose through transpiration [8].

Table 1: Biotic stress-resistant fruit varieties.

S. No.	Fruit crop	Variety	Tolerant towards
1	Strawberry	Catskill, Blackmore	Drought tolerant
2	Grape (Rootstock)	Dogridge	Salinity tolerant
3	Pomegranate	Ruby	Drought tolerant
5	Citrus	Swingle, Orlando	Drought tolerant
6	Apple	Golden Delicious	Drought tolerant
7	Plum	Early, Bluefri	Drought tolerant
8	Annona	Arka Sahan	Drought tolerant
9	Mango	Bappakai	Salinity tolerant
10	Fig	Excel, Deanna	Salinity tolerant

Climate Change

Abiotic and biotic challenges that have had a negative impact on crop production are mostly caused by climate change [9]. Since the entire global ecosystem, including agriculture, is strongly correlated with climate change in numerous aspects, climate change poses serious hazards to agricultural and horticultural productivity as well as to global food security. According to reports, productivity is negatively impacted by destructive environmental changes, including rising temperatures, and altered precipitation patterns brought on by recent climate change [10]. Climate change (Figure 1) has a significant impact on photosynthesis, the core physiological mechanism of plants. Extreme temperatures and a lack of water are two factors that affect a plant's reproductive phase of growth because of climate change. It was reported that water stress in wheat had a negative impact on flower initiation and inflorescence [11].

Physiological Responses

Environmental considerations significantly restrict the expansion and productivity of agriculture. For instance, an increase in atmospheric carbon dioxide (CO_2) can alter the pace at which plants photosynthesize, resulting in variations in growth rate that typically have a beneficial effect on biomass overall but a negative influence on nutritional quality [12]. Plants make their own food by fixing CO_2 through the photosynthetic process, and it is generally accepted that increasing atmospheric CO_2 levels will boost agricultural harvests. On the other hand, the distribution and production of plants are already being severely impacted by the growing atmospheric CO_2 levels (Food and Agriculture Organization). In temperate fruits, temperature, particularly low temperatures, significantly affects the induction of flowers; nevertheless, genotype, photoperiod, and temperature interact heavily to control flowering.

High-temperature Stress

Calculations indicate that even a slight rise in air temperature might significantly reduce the output of several crops that are now grown in typical crop-producing regions. Heat stress disrupts redox equilibrium, which results in the generation of reactive oxygen species (ROS) and damages the processes that remove these harmful forms of oxygen from various cell compartments, ultimately leading to oxidative stress. Increased ROS causes alterations in gene expression, membrane breakdown, molecular oxidation, and enzyme deactivation [13]. Additionally, Heat stress can seriously harm protein structure and the cell membrane, which can result in the creation of ROS and oxidative stress it reduces the synthesis of heat shock proteins, their transcription and translation, the generation of phytohormones and antioxidants, and modifications to cell structure that affected hormonal equilibrium [14] (Figure 3). Numerous physiological systems are impacted by the high temperatures encountered at different phases of crop growth and development. While the air temperature remains constant, increased radiation absorption and decreased transpiration (stomatal closure) heat up the canopy, which further affects the meristem temperature. Plants undergo physiological changes because of heat stress. Plant development is impeded

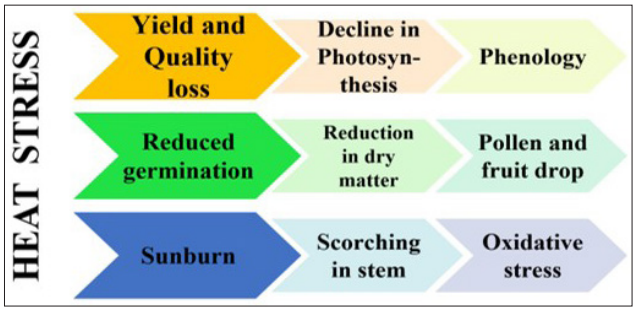

Figure 3: Impact of heat stress on fruit trees.

when the photosynthetic machinery is damaged, which lowers transpiration because of stomatal closure and CO_2 content, inhibits the rates of photosynthetic enzymes and ATP synthases, reduces leaf expansion, and speeds up senescence [15]. The metabolism of carbon absorption is changed to counteract the effects of heat stress, re-mobilizing the starch stored in chloroplasts of plants and enabling them to withstand stress periods and avoid additional damage by releasing energy, carbohydrates, and derived metabolites [16]. To control the responses to stress, plants under heat stress also boost the biosynthesis of many hormones. Auxins, salicylic acid, ABA, brassinosteroids, cytokinin, jasmonate, and ethylene are among the hormones that are stimulated by temperature rise and accumulate more in plant cells as a defence against heat stress [14].

Impact on Patterns of Blooming and Fruit Quality

Under the Western Himalayan conditions of India, climate variations modify the rhythm of blossoming and bearing, resulting in decreased fruit output, and declining apple quality. There is still a chance that apple blossoms will be damaged by frost because of the earlier flowering caused by the higher winter and springtime (January to March) temperature increases. In regions with moderate climates, frost may also be the primary factor causing weather-related crop damage [17]. Transport protein modulation resulting in ion extrusion and sequestration, phytohormones, ROS detoxification, and compatible osmolyte production is one of the biochemical responses while upregulating gene expression for protective functions, signal transduction, ion transport, osmolyte biosynthesis, cell wall and membrane remodelling, photosynthesis, and energy metabolism are among the molecular responses [18]. Therefore, the use of paclobutrazol is helpful in overcoming the decreased flowering and blooming brought on by stress [19]. If soil moisture is permissible, climate change results in high light intensity for extended periods, more CO_2 is reduced, and more carbohydrates are created, which can be used to fill out and enhance the taste of fruits. Mandarin grown in the heat of the sun (35 °C) are 2.5 times firmer than those grown in the shade (20 °C). The ripening process is delayed by decreased cell wall enzyme activity at higher temperatures during growth and development [17].

Water Stress

Water stress has a significant impact on how mango flowers are induced, particularly in relation to the floral stimulus

that matured leaves provide. Crop improvement depends critically on agricultural water consumption, water use efficiency, and the creation of drought-tolerant plants. Water use efficiency is the amount of carbon taken in by the crop as grain or biomass per unit of water utilized [20]. It is a key component of plant survival under drought stress since it establishes the plant's capacity to withstand mild to severe soil water deficits [21].

ABA is first produced by plants when their root cells detect a water deficit in the soil. Then, through vascular bundles, ABA sends signals to other organs and tissues, resulting in morphological and anatomical changes like senescence of the leaves, stomatal closure, reduction of the leaf surface, induction of the root-to-shoot ratio, and an increase in the amount of water that plants take up from the soil by osmotic adjustments that lower the water potential in contrast to the water-limiting environment [22]. One short-term, rapid reaction to water scarcity is stomatal closure mediated by ABA. But ROS, NO, and Ca^{2+} are recognized as secondary messengers in ABA-signalling, and they can trigger processes that help plants adapt to biotic and abiotic stress over the long term [15].

Mechanical Stress

During handling and harvest, horticultural goods are subject to mechanical stress. This strain results in bruises from cuts, punctures, and collisions. Temporary increases in respiration, wound-induced ethylene production, the creation of phenolics, and the degrading of plant tissue are potential outcomes of cuts [23]. Cut wounds develop during the harvesting process and are more severe in products that have been gathered by machines. The extent and severity of bruises are influenced by a variety of factors, such as the horticulture product's temperature, maturity, water potential, tissue, or cellular orientation at the point of injury, form of the object that caused the bruising, energy, and angle of impact. Freshly cut things tend to have the most cuts. Abiotic stress from freshly cut tissue results in tissue rupture and subsequent oxidative reactions that discolour, particularly the browning of cut surfaces. Additionally, it results in increased respiration and ethylene evolution, flavour and texture loss, dehydration and weight loss, a reduction in nutrient content, the emergence of foul odours, membrane disintegration, and tissue softening. Fresh-cut products' increased production of respiratory pathway enzymes and momentary increase in aerobic respiration have both been connected to cut-induced respiration. Phenol levels are increased by wound-stimulating PAL, a key enzyme in phenolic biosynthesis.

Mineral Stress

Mineral nutrients have a variety of effects on horticultural goods' quality, but physiological diseases have the biggest impact. A mineral nutrient imbalance might cause some postharvest issues with horticultural products. The mineral most frequently linked to postharvest illnesses is calcium. Plants have internal resistance, but resistance to abiotic stressors is conferred by a balanced nutrition supply. More and more data show that plants decreased mineral nutritional quality has negatively impacted their ability to respond to resistance [24]. It is crucial for maintaining the functional and structural integrity of plant membranes. It also helps to stabilize cell wall structures, govern ion exchange behaviour, and regulate ion transport and selectivity. Mineral imbalances are the cause of plants that are salt stressed. These imbalances are caused by salinity's effects on nutrient availability, competitive absorption, transport, or partitioning inside the plant. They can also be the result of a nutrient's physiological inactivation, which increases the plant's need for the key element internally. In addition to mineral imbalances, salinity has an impact on the physiological reactions of plants to osmotic stress and toxic ion stress. Increased salt causes significant physiological and metabolic changes in tomato fruit. It increases the sugar content of the fully grown fruit. Smaller fruit is produced when tomatoes are grown in high salinity. Due to their larger surface area to volume ratios, smaller fruit is more vulnerable to water stress.

Salt Stress

India has 6.74 M ha of salt-affected soils, with 2.95 M ha and 3.79 M ha, respectively, of sodic soils and saline soils. When there is a climate shift, the crops will also experience salinity stress because of a higher salt accumulation from high evaporation. Numerous crops suffer significant harm because of the greater concentrations of chlorides and sulfates of magnesium, calcium, and sodium that are present in the soils. Osmotic and ionic stressors brought on by salt stress in the soil can impede photosynthesis by limiting carbon fixation either non-diffusional (photochemical and biochemical) or diffusional (stomatal, mesophyll, and boundary layer resistance to CO_2 [25]. In the root zone these dissolved salts damage plant roots through osmotic stress or make plants poisonous when they are ingested. Nutrient imbalance and decreased absorption of essential nutrients is caused by the buildup of harmful ions in leaves. Due to the damage to the leaves, growth inhibition, and lack of fruit production, yields are therefore decreased. According to studies, mango cultivation is not successful under saline circumstances. Without influencing the P and S contents, the increased salinity of irrigation water resulted in decreases in N, K, Ca, and Mg contents in leaves. In banana, salt stress-induced necrosis first appears in the leaf margins before spreading to the leaf's interior. Salt stress results in reduced pseudo-stem thickness, delayed blooming, smaller fingers, and low-quality bunches [26]. Salinity stress affects numerous physiological parameters, growth, and nutrient uptake in grapes. Fruit crops, therefore, react variably to salinity stress and are impacted to varying degrees at different salinity levels.

Plant response to salinity

Fruit plants use a variety of tactics to deal with salt stress. They include osmotic adjustment, salt exclusion, maintenance of photosynthesis, preferential accumulation of K^+, accumulation of hormones like ABA, maintenance of osmotic balance, and osmotic adjustment. Most of the time, these reactions are genotype- and crop-specific and are impacted by elements like growth stage, substrate, and agro-climatic variables [27]. One of the primary biological processes impacted by salinity and drought is photosynthesis. The two primary roles of stomata in plants are to control CO_2 entry into the leaf and to

regulate transpiration, which provides nutrients and controls leaf temperature. Plants respond to drought by reducing their stomatal aperture as one of their initial actions. If the stress event persists, however, changes in leaf photochemistry and/or carbon metabolism are also hindered, which further impairs photosynthesis [28].

Salinity's impact on plant growth

Three independent but related stresses "osmotic", "salt-specific", and "oxidative" affect plants growing on saline substrates. Depending on the species, these stresses contribute differently to the severity of salt-induced damage. The rate of salt accumulation in the shoots and leaves varies between annual and perennial species.

In annual fruit crops that are salt-stressed, salt concentrations in leaves can reach deadly levels in as little as a few days or weeks. In contrast, the signs of salt harm in perennials typically develop months or years after salt exposure. Salinity decreased both leaf water potential and osmotic potential, which increased leaf turgor in Carrizo citrange seedlings, resulting in salt-induced (50 mM NaCl) decreases in growth and net gas exchange. This suggests that ion toxicity in leaves rather than a loss of leaf turgor is to blame [27].

The osmotic effect of salinity

High salt concentrations first cause a water shortage in the soil, which hinders plant roots' capacity to collect enough water for metabolism. The water deficiency stress could get severe because of the leaves gradually losing water. The pattern of salt accumulation has the most influence on the harmful consequences of osmotic stress on citrus. Even though the abscised leaves may still be deficient in Na^+ and Cl^-, a fast surge in salinity causes the levels of ethylene and leaf ABA to rise, speeding up the pace of leaf fall. In contrast, progressive salinization helps the plants to effectively alter the osmotic pressure to reduce osmotic stress [29].

Plants under water stress tend to increase endogenous ABA levels to prevent leaf dryness by closing stomata. Yet, oxidative stress is ultimately brought on by ABA-regulated stomatal closure. Decreased stomatal conductance causes chloroplast CO_2 deficit, which disturbs the electron transport chain because molecular oxygen works as a potent electron receptor in these conditions, the chloroplast produces highly oxidizing ROS like singlet oxygen ($^-O_2$), hydroxyl radical (OH), superoxide radical (O^{-2}) and hydrogen peroxide (H_2O_2). Ion compartmentation polymerizes extra salts from the cytoplasm into the cell vacuole to protect the metabolic enzymes from ionic harm. The enzymatic activities are hindered by Na^+ and Cl^- at values of 100 mM and higher. To balance the osmotic pressure of the ions in the vacuole, various solute types accumulate in the cytoplasm after being partitioned in the vacuole (also known as osmotic adjustment).

Hormonal changes

By inhibiting both photosynthesis in the source organs and the growth of sink (assimilate-consuming) organs, salinity slows the growth of plants. Hormonal signals such cytokinin's, ABA, 1-aminocyclopropane-1-carboxylic acid (ACC), and auxin indole-3-acetic acid regulate the synthesis, partitioning, and utilization of assimilate in plants under salt stress. Hormonal regulation of source-sink interactions during osmotic stress may increase the amount of energy available for growth, root function, and ion homeostasis while delaying the harmful accumulation of Na^+ and Cl [30].

Ethylene builds up in response to salt stress, which is consistent with other stress hormones and suggests that ethylene is essential to the salt response. Additional data revealed that salt stress phosphorylated and stabilized ACS2/6 at the protein level via inducing MAPK cascades, in addition to activating ACS7 at the transcriptional level [31]. At different developmental stages, Arabidopsis treated with ACC showed improved salt tolerance. Additionally, it was discovered that the ethylene-producing mutants eto1 and eto2 also conferred soil salinity tolerance. In conclusion, ethylene buildup brought on by salt stress is crucial to plants' ability to adapt to salt.

Melatonin

During development, plants are subject to a variety of environmental pressures (both abiotic and biotic). Lerner and colleagues discovered melatonin, which is produced from the essential amino acid tryptophan, in the pineal glands of cows [32]. The basic metabolism of the affected plants is changed by circumstances of stress. For plants to efficiently complete their life cycle, they must adapt to the environmental limitations phase of the life cycle [33]. To adapt to challenging environmental conditions, plants create and control a variety of biomolecules [34, 35]. Melatonin, a well-researched chemical that serves as a potent stress-relieving medication, is one of the most investigated compounds (Figure 4) [36]. Melatonin (N-acetyl-5-methoxytryptamine) is a widely distributed chemical that is found in all living things, including plants, animals, and microbes. By altering the production of endogenous melatonin and antioxidant systems, exogenously applied melatonin improves plant resistance to abiotic conditions such as drought, waterlogging, extremely high temperatures, salinity, and heavy metal toxicity [37] (Figure 5).

Factors that Influence Stress

Drought

Plant development and growth are significantly slowed down by drought stress [38]. Drought stress affects a plant's morphological, physiological, biochemical, and molecular

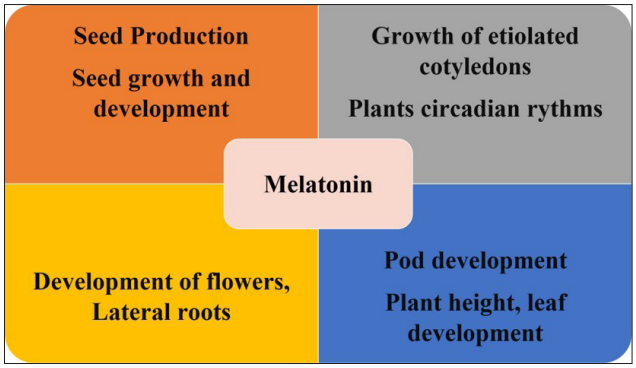

Figure 4: Function of melatonin.

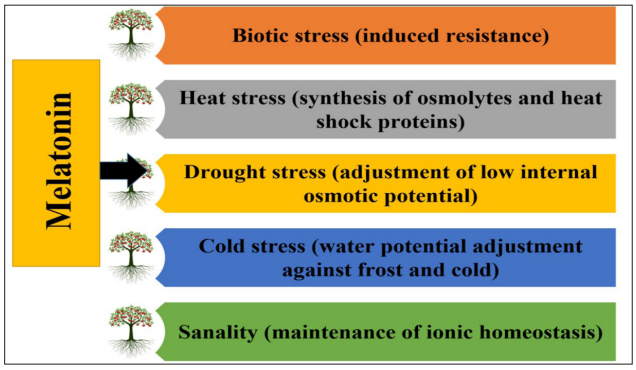

Figure 5: Various functions of melatonin.

characteristics, which poses a serious threat to the productivity and quality of agriculture [39].

Temperature and salt stress

Plant development and survival are significantly affected by cold stress. Redox imbalance and excessive ROS accumulation could result. To protect plants from fatal injury, melatonin prefers to assemble in extremely cold climates. Globally, salt stress has become a serious problem that limits agricultural productivity and causes significant economic losses. According to recent studies, melatonin has been linked to an improvement in plants' resistance to salt stress. Several plant species, including apples, showed enhanced salt tolerance after melatonin therapy [24].

Heavy metals

All forms of living creatures, particularly plants, are seriously at risk from heavy metal pollution [40]. The plant's resistance to the stress caused by heavy metal's was greatly increased by exogenous melatonin treatment [41]. Melatonin controls antioxidant levels as well as the uptake and sequestration of heavy metals, which helps control the tolerance to heavy metals.

Photosynthesis change

A decrease in stomatal conductance is one of the initial responses in plants under salt stress to reduce the water loss from leaves. Additionally, the closure of the stomata reduces the amount of CO_2 that diffuses into the leaves, hence lowering internal CO_2 partial pressure and, eventually, photosynthetic rates. Numerous animals' photosynthetic processes are impacted by non-stomatal biochemical constraints. Stomatal closure, Na^+ toxicity, and chlorophyll degradation were responsible for the salt-induced (75 mM NaCl) reduction in photosynthesis in the Valencia orange, Taylor lemon, and Ellendale tangor scions grafted on Cleopatra mandarin rootstock. Na^+ ions restrict transpiration and photosynthesis more strongly than Cl^-. Vine vigour, maintenance of photosynthetic capacity, and retention of Na^+ in the shoots were all factors in "Séjnène" grapevines' tolerance to salinity. Reduced photosynthetic efficiency under salt stress is caused by stomatal (e.g., diffusional resistance to CO_2 transport) and non-stomatal (physical and metabolic factors) constraints [27].

Salt exclusion

The term "salt exclusion" refers to a plant's ability to filter salts at the root level. Although water can pass through, the dissolved salts are not taken in. Complete salt exclusion is only truly demonstrated by salt-resistant halophytes. The relative salt tolerance of various rootstocks may be influenced by genetic characteristics like ploidy level. Tetraploid citrus seedlings, for instance, frequently exhibit stronger salt tolerance than diploid genotypes. Genome duplication improves oranges' ability to exclude salt, probably by changing its physiological and morphological characteristics. Tetraploid seedlings of Citrus macrophylla acquired much less Na^+ and Cl^- in leaves than diploid seedlings at salinities of 40 and 80 mM NaCl. Moreover, only salinized diploid seedlings' leaf K^+ contents decreased, demonstrating the intrinsic variations in mineral uptake [42].

Stress-related physiological disorders

The various physiological disorders under stress are viewed in figure 6 and figure 7.

Sunburn

Fruits of a variety of crops grown in warm climes can develop sunburn, a physiological disease caused by photodamage from excessive heat and/or light irradiance (visible and ultraviolet radiation). It is believed that the primary cause is an increase in the generation of reactive oxygen species, which results in oxidative damage since the fruit is unable to recover from stress. This may lead to an undesirable morphological and structural phenotype [43].

Alternative bearing

Fruit crops can experience problematic alternating bear-

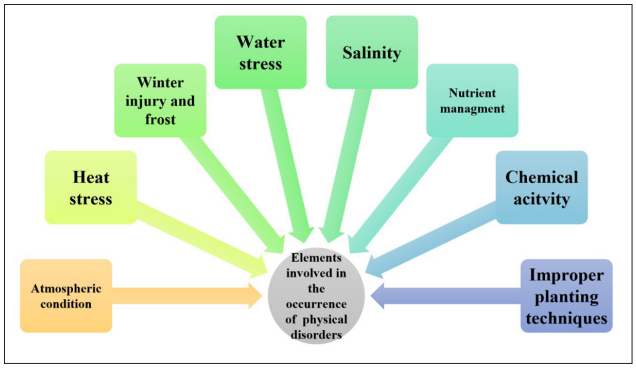

Figure 6: Various physiological disorders under stress.

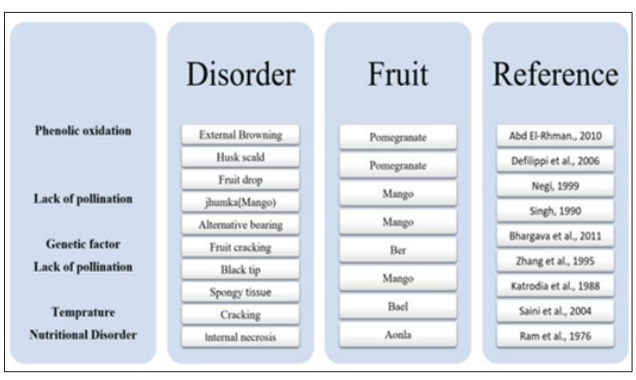

Figure 7: Various research findings on the physiological disorder in fruits.

ing. The "on" harvest of citrus is distinguished by an abundance of tiny fruit in a single season. Different tropical and subtropical fruit crops' bearing habits are observed to be impacted by both internal and extrinsic influences on the blossom and vegetative buds. For the same fruit species, formation in the tropics and subtropics differs, and this implies that shoot age and cold inductive temperatures are regulated by the congruence of internal and external signals in higher plants. Typically, environmental signals cause tropical trees to bloom. In addition to these, there are several endogenous and external elements that contribute to this rhythm. Exogenous variables can be divided into: Environmental factors including temperature, atmospheric humidity, rain, edaphic stress, and spring frost [44].

Oleocellosis

Oleocellosis, also known as postharvest oleocellosis and on-tree oleocellosis, is a disease that affects citrus fruit and is particularly sensitive to both postharvest storage and on-tree ripening. After the oil gland in the peel bursts, a physiological condition known as oleocellosis (or oil spotting) results in the pitting of the oil that is generated [45]. Additionally, the symptoms were somewhat variable across the stages. On-tree oleocellosis results in light green (dark grey in print form) and smaller than 0.8 cm due to the low fruit maturity at this stage of fruit expansion, whereas postharvest oleocellosis frequently appears >1.0 cm in oleocellosis lesions with yellow patches.

Granulation

Granulation, also known as crystallization or section drying, is a hazardous physiological issue in most citrus-growing countries. This disorder causes the citrus fruit juice sacs to swell, and become hard, dry, and grey, making it difficult to extract the juice. In contrast to sweet orange cultivars like pineapple, Washington Navel, Hamlin, blood red, Mosambi, and Valencia late, mandarin cultivars like Kaula, Nagpur, and Dancy, and citrus hybrids like Huangguogan in China, grapefruit, pummelo, lemons, limes, tangerines, and tangelos are less prone to granulation [46].

Strategies for Overcoming

The application of plant growth regulators, particularly brassinosteroids, has proven to be extremely useful. The development of chemical synthesis technology and the practical use of brassinosteroids in horticulture crops, particularly fruit crops, for enhancing output, quality, and stress tolerance offer great prospects. Acknowledging the production, metabolism, routes, and roles of brassinosteroids in economically significant plant species, especially perennial fruit crops, has advanced significantly. The development and architecture of plants, photosynthesis, the transition to blooming, and the setting of fruit in fruit crops are all regulated by brassinosteroids [47]. A class of naturally occurring plant steroidal chemicals with a variety of biological functions is known as brassinosteroids. Several crucial pomological characteristics, including the start and end of flowering, the structure of the plant canopy, micropropagation, cell division and elongation, vegetative development, blooming, fruit set, fruit ripening, quality, and yield, are regulated by brassinosteroids. Moreover, brassinosteroids can enhance tolerance and resistance to biotic and abiotic stressors (Table 2). Brassinosteroids have been generally described as "pleiotropic phytohormones" due to their numerous and varied physiological effects on development and plant growth [48]. Plant hormones are crucial in regulating a plant's development and growth. While a plant's metabolism provides energy and building materials, hormones coordinate the growth of various portions into the shape of a plant and regulate the growth of each individual plant part.

Table 2: The occurrence of brassinosteroids in fruit tree species.

Fruit family/species	Plant part	Brassinosteroids type
Bael (*Aegle marmelos*)	Leaves	24-EBL
Satsuma mandarin (*Citrus unshiu*)	Pollen	BL
Sweet orange (*Citrus sinensis*)	Pollen	BS, CS
Chestnut (*Castanea crenata*)	Galls	CS, BL, 6-deoxo CS
Loquat (*Eriobotrya japonica*)	Flower buds	CS
Date palm (*Phoenix dactylifera*)	Pollen	24-epiCS

Note: BL - brassinolide, CS - castasterone, 24-EBL - 24-epibrassinolide.

Effect of Other Plant Growth Regulators in Fruit Retention due to Stress

Other than nutrients, plant growth regulators or plant regulators are organic substances that, when applied in trace amounts, alter, or regulate physiological processes in a significant way in plants. When these compounds are administered to various sections of the plant, they are quickly absorbed and flow through the tissues. While phytohormones, also known as plant hormones, are likewise regulators, they are created by plants in small amounts and are transported from the site of production to the site of action [49]. Important phytohormones such as cytokinins, auxins, gibberellins, ethylene, and ABA are known to be generated by plant growth regulators. These phytohormones not only support root expansion but also cell division and enlargement in plants as well as plant hormone homeostasis [50].

Conclusion and Future Aspects

Fruit crops naturally undergo physiological and biochemical changes during both normal growth and development and stressful situations. The quality and nutritional value of fruit crops may be greatly impacted by these changes. Therefore, understanding these changes is crucial for developing strategies to enhance fruit quality and yield, reduce losses, and ensure sustainable production. Under stress conditions, fruit crops undergo various physiological and biochemical changes that can have negative impacts on their quality and nutritional value. However, several tactics can lessen these consequences. Examples of crop management techniques that can lessen the impacts of stress on fruit crops include irrigation, fertilizer management, and pest control. Additionally, fruit crop cultivars with increased stress tolerance can be created using genetic engineering approaches. Moreover, it is essential to consider the postharvest management of fruit crops to maintain their quality and nutritional value. Postharvest management practices such as proper storage, handling, and packaging can help prevent further physiological and biochemical changes in fruit

crops after harvest, leading to longer shelf life and better quality. In conclusion, physiological and biochemical alterations in fruit crops are essential for their growth, development, and ability to adapt to stressful situations. Understanding these changes can aid in enhancing crop management techniques, increasing the nutritional value and quality of fruits, and ensuring sustainable production. To minimize the detrimental impacts of stress on fruit crops and improve their postharvest management, additional study is required**.** Future studies on stressed fruit crops will concentrate on biotechnological developments that create stress-tolerant cultivars through breeding and genetic modification. Through the identification of important genes, proteins, and metabolites for resilience, omics technologies-genomics, transcriptomics, proteomics, and metabolomics-will provide insights into stress responses. Targeted stress management will be made possible by precision agriculture that makes use of sensor-based technology and data analytics. We will investigate natural chemicals and elicitors for ecologically friendly stress reduction. It will be essential to implement climate-smart measures and satisfy consumer demand for premium, stress-tolerant food. The projects are designed to fulfill global food demands, improve crop resilience, and assure sustainable fruit production in the face of environmental changes. To ensure a resilient future in the production of fruit crops, collaborative research and innovation in these areas are essential.

Acknowledgements

We are greatly in debt to Dr. Ab Waheed Wani for their kind support. We are also very grateful to Lovely Professional University, Phagwara, India for their assistance.

Conflict of Interest

The authors report no potential conflict of interest..

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