

Abiotic stresses effect on plants physical and chemical events, and role of melatonin against abiotic stresses in regulating plant growth, biochemical traits, antioxidant activities and plant Metabolic System.

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Abstract

Abiotic stress like drought, salinity, high and low temperature, flood, radiation, heavy metals, oxidative stress, and nutrient shortage harmfully disturb growth rate, quality and productivity of plants. Melatonin as a plant growth regulator was discovered in 1995 in plants and holdup a strong position due to its affect in plants environment. Melatonin shown a considerable character in plant growth response, development, re-production and various biotic stresses. Moreover, melatonin performs a resistive character against stresses like drought, salinity, metal toxicity. Melatonin important character in plant system is to lighten the harmful effect of abiotic stresses. In this evaluation we have investigate the effect of melatonin on growth, physiology, photosynthesis behavior, metabolic response, and bio-chemistry of plant under stresses (abiotic and abiotic) environment.

Keywords: melatonin, drought stress, oxidative stress, heavy metal stress, hot and cold stress, salinity stress, plant development, physiology.

Introduction

Inferable from environmental change and outrageous climatic conditions, it is informed that the terrible effect regarding environmental biotic and abiotic stress on plant production will increment in numerous part of the world (Denby and Gehring 2005). Stress factors can concurrently show their effects on plants (kalefetoglu and Ekmekei 2005). About 71% of agricultural product effected by abiotic stresses, while the remaining 29% cause by other stresses. (Boyer 1982). About 10% of area throughout the world is far from stresses. It has been described that more than 50% of yield reduction taking place worldwide due to abiotic stress factors (Mahajan et al., 2005). In the last decade, altered field water supply methods, soil improvement, and the practice of appropriate fertilizers have been introduced so that decrease the influence of stress. As a different tactic, the application of some outside regulator during plant growth has been practiced in recent period, and it has been detected that the application of melatonin (MEL) increasing tolerance in plant against stresses. Melatonin (N – Acetyl – 5 – Methoxytiprimamine) was identified in the year 1958 in the pineal gland of cattle (lerner 1958). Melatonin is one of the most inspected bio- molecules, which is widely discovered in animals. In plant as an indole amine neurohormones MEL was discovered in the year 1995 (Dubbels et al., 1995; Hattori et al., 1995). Due to performing role in in specific plants physiological pigments MEL considered by many investigator as plant growth regulator (PGR). The natural antioxidant ability of MEL can be described by its aptitude to improve tolerance in plants visible to biotic and abiotic stresses (Amao 2014). Melatonin work as plant bio stimulator for stresses, regulate

plant growth and perform a probable supervisory character in plant, flowering, production and maturity of fruit. (Reiter et al., 2015; Amao 2014; Nawaz et al., 2016). On the basis of previous research work Table 1 and Table 2, indicates response of melatonin in various plants against stresses and in regulation of various plants antioxidants

Table 1. Role of MEL in oxidative stress and antioxidants regulation in different crop plants subjected to stresses.

Crop Plant	Stress Condition	Exo-Melatonin Based Up-Regulated Antioxidant	Exo-Melatonin Based Down-Regulated Antioxidants	Exo Melatonin Based Variable Antioxidants	Reference
Zea mays L.	Salinity	POD, APX			Jiang et al., 2016
Cucumis sativus L.	Salinity	SOD, CAT, ASA, GSH	POD, APX,		Wang et al., 2016
Malus hupehensis Rehd	Salinity	APX, POD	CAT,		Li et al., 2012
Cucumis sativus L	Salinity	APX, POD	CAT,		Zhang et al., 2014
Citrullus lanatus L.	Salinity	GSH, CAT, DHAR, MDHAR	ASA, APX,	GSSG, DHA	Li et al., 2017
Zea mays L.	Salinity	APX, POD, SOD, GR	CAT, GPX,	GSSG, DHA	Chen et al., 2018
Solanum lycopersicum L.	Salinity	SOD, GR, GSH, ASA	CAT, APX,	GSSG, DHA	Sidiqui et al., 2019
Avena nuda L	Salinity	SOD, CAT, APX	POD,		Gao et al., 2019
Coffea arabica L	Drought	CAT, SOD	APX	SOD	Campos et al., 2019
Zea mays L.	Drought	SOD, APX, POD	CAT,		Ye et al., 2016
Malus domestica Borkh	Drought	SOD, APX, GSH	POD,		Wang et al., 2013
Festuca arundinacea Schreb	Drought	CAT, POD			Alam et al., 2018
Brassica	Drought	POD, CAT,			Li et al.,

napus L		APX			2018
Solanum lycopersicum L	Drought	SOD, APX, ASA	CAT, GR, POD		Liu et al., 2015
Zea mays L	Drought	CAT, SOD, APX, GPX, AsA, DHA, GSH		GR, GSSG	Huang et al., 2019
Triticum aestivum	Cold Stress	SOD, APX, GR	GPX, CAT	GR, GSSG	Turk et al., 2014
Camellia sinensis L	Cold Stress	APX, SOD	CAT	GR, GSSG	Li et al., 2018
Oryza sativa L	Cold Stress	SOD, POD, GSH	CAT		Li et al., 2017
Cucumis sativus L		SOD, CAT, POX			Marta et al., 2016
Solanum lycopersicum L		SOD, APX, POD	CAT	ASA, GSH	Ding et al., 2017
Zea mays L	Heat stress	GPX, CAT	GR	ASA, GSH	Li et al., 2019
Actinidia deliciosa	Heat stress	SOD, GR, GSH	POD, ASA	CAT	Liang et al., 2018
Triticum aestivum	Heavy metals	SOD, GSH	APX, CAT, POD		Ni et al., 2018
Nicotiana tabacum L	Heavy metals	SOD, CAT	APX		Wang et al., 2019
Melissa officinalis L	Heavy metals			SOD	Hodzi et al., 2019
Valeriana officinalis L	Heavy metals			SOD	Hodzi et al., 2019
Cynodon dactylon L	. Heavy metals	SOD, CAT, APX	POD, GR		Xie et al., 2018
Solanum lycopersicum L	Acid rain stress	SOD, CAT	POD, APX		Debnath et al., 2018
Cucumis sativus L	Water stress	SOD, CAT	POD		Zhang et al., 2013
Malus baccata L	Waterlogging	SOD, CAT	POD		Zheng et al., 2017
Pisum sativum L	Oxidative stress	SOD			Szafr et al., 2016
Malus	Alkaline	SOD	POD		Gong et

hupehensis Rehd	stress	CAT		al., 2017
Citrullus lanatus	stress	SOD, CAT		Nawaz et al., 2018
Arabidopsis thaliana	High light stress	APX		Lee and Back 2018
Trigonella foenum graecum L	Lead and acid rain stress	SOD, CAT		Xalxo and keshavkant 2019
Solanum lycopersicon	Salinity and heat stress	CAT, APX, GR, GST, GPX MDHAR	SOD	Martinez et al., 2018
Cynodon dactylon L	Salinity, drought and cold stress	POD, SOD, CAT, GSH		Das and Roy Choudhury 2014

Table 2. research investigation List confirming the effect of MEL on altered antioxidant enzymes at the mRNA level in different crop plants. Upward arrow ↑ shows the up-regulation, while downward arrow ↓ shows down-regulation of genes for enzymes corresponding's, ± shows variable regulation, and = shows no effect.

Plant Name	Genes Name	Stress Condition	Expression	References
Solanum lycopersicon L	CAT, DHAR Cu / ZnSOD, FeSOD, GR, GPX GST, APX, MDHAR, DHAR	Salinity and Heat Stress	↓ ↑	Martinez et al., 2018
Cucumis sativus L	Cu/ZnSOD, CAT, POD FeSOD	Salinity-Stress	↑ ±	Zhang et al., 2014
Camellia Sinensis L	APX, CAT, SOD, GR	Cold-Stress	↑	Li et al., 2018
Avena Nuda L	NAC, WRKYI, MYB, DREB1 DREB2	Salt-Stress	↑ ±	Gao et al., 2019
Citrullus Lanatus	SOD, APX, GPX, GST, CAT	Vanadium-Stress	↑	Nawaz et al., 2018

Malus Domestica	APX	Oxidative-Stress	$\pm$	Ni et al., 2018
	GR		$\pm$	
	POD, MDHAR, DHAR, CAT		$\uparrow$	
Prunus Persica	SOD,CAT,APX,DHAR	Oxidative-Stress	$\uparrow$	jiang et al., 2016
	APX		$=$	
	GR		$\pm$	

Melatonin function in plant growth and physiology

MEL regulate different metabolic processes in plants and animals. Shape of MEL molecules is endogenous in all plant species. In plant organs attentiveness of MEL are varies in different tissues (Reiter et al., 2015). Melatonin are structural biogenic indole-amine tryptophan, tryptamine, and serotonin) and also linked to indole-3acetic-acid (IAA) as well as indole compounds, which are very imperative in physiology of plant (common auxin. Metabolic ways of tryptophan in mammals and plants) as deliberate by (Murch et al., 2000) and are shown in Figure 1. Melatonin are present in various plants seeds, roots, leaves, fruits, Table 3, shows the presence of melatonin in various plants. MEL work as auxin to promote plant vegetative growth in many plant species (Paredes et al., 2009). (Murch et al. 1997) disclosed that MEL concentration improve root growth in Hypericum perforatum L plant, as compared to the use of auxin, serotonin.

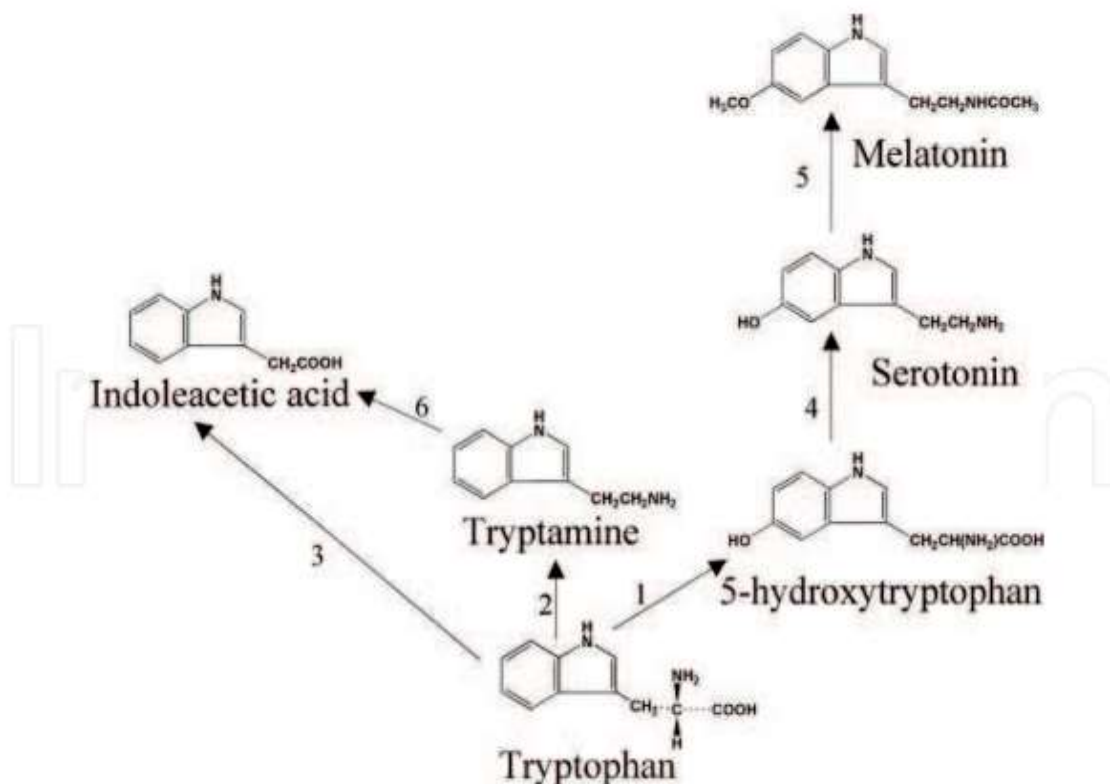


Figure 1. Metabolic pathways of tryptophan in mammals and plants as proposed by (Murch et al. 200)

In metabolic processes MEL plays an important role and normalize Proline (Antoniou et al., 2017). MEL keeps plant chlorophyll and membrane integrity by donating plant water balance and root formation (Wang et al., 2013; Wei et al., 2014; Arnao and Hernandez 2009; Chen et al., 2009). MEL work as scavenging agent for ROS, auxins as plant growth promotor and signal molecules Paredes et al., 2009. MEL turns in numerous plant biological, metabolic, rooting, catabolism of chlorophyll, and stress tolerance (Park and back. 2012; Arnao and Hernandez 2009; Liang et al., 2015; Zhang et al., 2017). MEL synthesized by plants and perform as antioxidant or a modulator of plant growth and improvement in plants (Fleta et al., 2005). Soybean coating with melatonin also enhanced plant growth and yield (wei et al., 2014). Similar to the effect of IAA, melatonin affects formation of lateral roots, increases root and shoot biomass in lupin (Arnao and Hernandez 2007. Melatonin also germination rate under adverse condition, and refine plant production quality (Arnao et al., 2014; Tan et al., 2012). Exogenous melatonin lower concentrations raised the content of endogenous IAA in plant roots, however melatonin concentration higher levels had no effect on IAA content (Chen et al., 2009). Melatonin work as scavenger and antioxidant to detoxify the OH^- , H_2O_2 , Nitric oxide, ONOO^- , HNO_3 , and HClO , which are biosynthesized under stress environments. Furthermore, treatment with melatonin promote antioxidant enzyme events under abiotic stress circumstances. About 10 free radicals hunt by one molecule of melatonin (Tan et al., 2007). Nitrogen and carbohydrate metabolism could be improved with melatonin treatment, it also has good impact on readjustment of transcription (Shi et al., 2015). Signal transduction is affected by MEL

application; it also plays main role to regulate plant bio-physical practices. The use of MEL is therefore, recommended.

Table3. Reported Melatonin in some edible Plants.

Crop	Used Methodology	Melatonin Content(pg/g FW(DW) Tissue	References
Apple	GC-MS	0.16	Badria 2002
Asparagus	RIA	9.5	Hattori et al., 1995
Barley	LC	500-12000 R;82,300S	Hernandez et al., 2005; Arnao and Hernandez 2009
Cucumber fruit seed	RIA	24.6, 11,000	Hattori et al., 1995; Posmyke et al., 2009
chilies	UHPLC-MS/MS	31-93	Riga et al., 2014
Kiwi	RIA	0.02	Hattori et al., 1995
Kidney bean	ELISA	529DW	Aguilera et al., 2016
Rice	HPLC	100L; 500S; 200R; 400F1	Park and back 2012; Park et al., 2013
Sunflower	HPLC	29,000DW	Manchester et al., 2000
Tea	HOLC	2.12 μ gg ⁻¹	Chen et al., 2003
Tomato	LC	15,000 – 142000L	Arnao and Hernandez et al., 2013
Wheat	LC	124,700S	Hernandez 2005

Abbreviation; L, stands for leaf, R, stand for root, FL, stands for flower, GC-MS, stands for gas chromatographic-mass spectroscopy, RIA stands for radioimmunoassay, LC, stands for liquid chromatography, UHPLC-MS/MS, stands for ultra-high performance liquid chromatography coupled to mass spectrometry in tandem mode, ELISA, stands for enzyme linked immunosorbent assay, HPLC, stands for High performance liquid chromatography.

Melatonin function in mitigating abiotic stresses

i) Melatonin function under Drought Condition.

Water shortage is one of the main issue throughout the world and more than 100 countries worldwide face water deficit problem. It has been estimated that about two thirds population of the world population will face water deficit by 2025 (Zhang et al., 2017). Research work shows that drought problem will increase in coming years which will not only creative problem for human being but will also effect s agriculture productivity severely (Kijne 2006). Research indicates that due to climatic change and increase in arid and semi-arid zones in the world leads to increase drought, soil erosion, and salinization. (turkes and Artan 1994). Drought also effect plant traits, productivity, defensive system and photosynthetic activities (Farooq et al., 2009; Bajaj et al., 1999; Arora et al., 2002; Escuredo et al., 1998). Drought restricts plants photochemical movement and declines enzymes activities in Calvin circle (Monakhova and Chernyadev 2002). Research indicates that plant treated with melatonin under drought condition, improve plant antioxidant (Li et al., 2016). Brassica napus L treated with MEL 0.05 mmol/L

reduced the toxic effect of drought on plant growth. Moreover, MEL treatment reduced hydrogen peroxide (H_2O_2) and augmented plant antioxidant activity and osmotic solutes (Li et al., 2018). Application of endogenous MEL also improve plant photosynthetic ability and stress related phyto-hormones under drought conditions. (Fleta-Soriano et al., 2005) exposed that MEL treatment improved photosystem II resulting in a protective factor in maize crop under drought. MEL treatment improve Fv/Fm ratio in plant, which reinstate plant after drought effect. (Gui et al., 2017) investigate that wheat effected by drought reinstated with melatonin treatment. MEL improved wheat antioxidant, reactive oxygen species scavenging behavior and reduced damages in membrane. MEL also caused a thicker epidermal cell, intact grana lamella of chloroplast and leaf structure, and greater photosynthetic act. They revealed that wheat treated with MEL improved genes expression and enzymes activities. Likewise, (Wang et al. 2013; Meng et al., 2014) pointed out that melatonin treatment reduces drought created toxic effect, improves photosynthesis activities and uplift antioxidant enzymes behavior and limit ROS harmful effect. (Ma et al., 2018) pointed out that melatonin treatment increased ME bio-synthesis genes expression in *Agrostis stolonifera*. Melatonin application reduce synthetic gene expression of ABA (MdNCED3) and raise catabolic genes expression like MdCYP707A1 and MdCYP707A2 (Li et al., 2015). Melatonin application reduce the level of H_2O_2 and aminocyclopropane-1-carboxylic acid (ACC) creation, raise indole acetic acid (IAA) and zeatin due to which water use efficiency and ability of photosynthetic increase (Li et al., 2017). Drought also reduce the production of abscisic acid (ABA), which cause stomata closer (Seki et al., 2007). Use of MEL is useful to reinstate the plant after drought has happened and plants are re-watered (Meng et al. 2014; Seki et al. 2007; Wang et al. 2014).

ii) Melatonin and Heavy metal stress.

Heavy metals presence in soil prevents growth rate and cause plant death. (Prasad 1995; Salt 2001). Up to certain amount plant related metal are required However, in plant root some metal presence has harmful on the plants. Some metals (Cd, Cr, Zn, Cu, Pb, Ni), have harmful effect on plant growth and yield (Prasad & Strazalka 2002). Theses metals collect in plants system and break plant growth and plant nutrient promise (Brune et al. 1995). Due the entrance of these metals, uptake capacity of plants for essential minerals damaged by producing a poisonous effect and by substituting the like iron for the plants. Plant photosynthesis rate also effected by heavy metals, by stimulating ROS in plants. Presence of metal presence in plant caused raised in ethylene which limit the plant growth, CO_2 fixation and compact sugar pathway (Buchanan et al., 2000). The presence of metals in plant support ROS, which cause plants oxidative stress (Loureiro et al., 2006; Hu et al., 2007; Gupta et al., 2009). The exposers of plants to metals like (Pb, zn, Cd, etc.) have been shown to persuade melatonin bio-synthesis for refining effects of metal stress (Tal et al., 2011). (Tan et al., 2007) examine that melatonin treatment raised pea ability of phytoremediation under copper stress. Several work revealed that treatment with exogenous MEL compact the toxicity of heavy metals such as cadmium (Cd), copper (Cu), nickel (Ni) etc. (Posmyk et al., 2008; Nawaz et al., 2018). (Tang et al. 2015) investigated that as foliar melatonin concentration $150 \mu\text{mol} \cdot \text{L}^{-1}$ was best for eggplant under cadmium stress. They further revealed that melatonin application improved photosynthesis activities in eggplant under Cd stress. MEL treatment increase removal rate of cadmium and cadmium transfer from cytosol to the vacuole and cell wall (Hasan et al., 2015). (Gu et al. 2017) pointed out that cadmium stress condition in alfalfa improved by endogenous MEL treatment and correct expression of ion channel genes in plant against cadmium stress. They revealed that MEL treatment re-establishing micro RNA redox hormones in plant by decreasing toxic effect of cadmium (Cd). Additionally,

(Safari et al., 2017) showed that presence of boron (B) in excess amount restrict pepper dry mass and also decrease photosynthesis rate. However, they pointed out that MEL treatment of 1 μ M, increase photosynthesis rate, nutrient up taking capacity, antioxidant and sugar accumulation and reduced ROS in plant. (Zhang et al., 2017) verified that application of exogenous melatonin in Glycine max could improve aluminum prompted phyto toxicity. Although melatonin treatment with 0.1mM and 1 mM improved root growth and reduced H₂O₂. MEL root application at rate of 1 mM increased plant antioxidant activity under stress (A1). (Ni et al., 2018) showed that melatonin treatment reduced cadmium (Cd) toxic effect in wheat and improved plant APX and SOD activities. They concluded that MEL reduced the effect of ROS by improving plant antioxidant pigment. (Moussa and Algamal 2017) investigated that application of MEL in spinach enhancing plant antioxidant character and reducing level of ROS.

iii) Melatonin and Salinity Stress.

Extreme salinity in soil severely reduce crop yield throughout the world. Salinity affects about 110 million hectors land (arid and semi arid) areas of the world. According to foods and agriculture organization (FAO) report, 20 to 30 million hectors areas is badly damage due to extreme salt presence (shi et al., 2015). Salt accumulation in soil is due to natural phenomena as well as due increased in water table (Leyva et al., 2011). Due to over population and misuse of water clean water availability for agriculture practice becoming inadequate, so treated and untreated water introduced for agricultural activities which cause salt accumulation in soil. Salt presence in soil create osmotic stress in plants by water potential sinking and raising the energy required for the water and nutrient intake. Ionic stress in plant tissues taking place due to accumulation of chlorine (Cl), and Sodium (Na) ions (Munns and tester 2008; Flowers et al., 2010; Yildirim et al., 2006). It has been reported that disturbance in plant morphological and physiological behavior and growth restriction is due to the presence of salt (NaCl) in soil or in water (Cirillo et al., 2015). Plant nutrients variation and shortage also cause by salinity (Parida and Das 2005). Plant oxidative stress and ROS formation promoted by salts (Gao et al., 2008), which create significant membranes damage and other cellular structures (Arora et al., 2008). Presence of salt affect plant growth related traits as well as plant chemical traits, which leads to low quality yield and yield loss (Yu et al., 2018). MEL application improved plant salt resistance by either use MEL as exogenous or by enzymes genetic reform intricate in synthesis of melatonin (Kanwar et al., 2018). Use of MEL improved growth parameters, antioxidant enzymes, chlorophyll content and decrease the level of ROS and oxidative stress in cucumber grown under salinity condition (Wang et al., 2016). (Dawood et al., 2015) revealed that MEL application in fava bean (grown under salt stress environment) reduced the harmful effect of salts (Na, Cl), improved water related traits, plant chemical pigments, biomass, phenolic matter, and plant nutrient uptake capacity. Melatonin concentration of 500 mM was more operative than that of 100 mM concentration. (Zhou et al., 2016) studied the impacts of MEL conducts on tomato photosynthetic activity in salty environments. They concluded that melatonin treatment reduced the toxic effect of salt on plant growth parameters and photosynthesis process. MEL application recover electron transport chain of protein biosynthesis photosynthetic. MEL application reduced the ROS levels. Likewise, watermelon roots treated with MEL reduced salt-stress harmfully effect in photosynthetic capacity reduced oxidative stress, improved plant antioxidant behavior and redox homeostasis (Li et al., 2017). Melatonin treatment increased salt tolerance and K⁺ /Na⁺ in potato, decreasing sodium chloride (NaCl) absorption and swelling K⁺ (Yu et al., 2018). MEL treatment enhance nutrient up taking capacity, seedling growth, and nitrogen metabolism detection in Cucumis sativus, grown under salty environment (Zhang et al., 2017). (Ke

et al.,2018) Investigate that MEL treatment with 10–500 μM could improve germination and seed growth rate in rice grown under salty condition. they further concluded that MEL treatment reduced the harmful effect of salt stress in wheat by promoting poly-amine metabolism, improving antioxidant and ROS scavenging behavior This perfection was documented to dipping sodium (Na^+) and chloride (Cl^-) ions content in leaves and roots (Li et al., 2017). (Jiang et al. 2016) revealed that exogenous MEL application on maize sown in salt effected environment, produced good impact on growth parameters, photosynthesis processes, antioxidant activities, and. It was established that melatonin concentration in roots raised because of stress environments, swelling to 6 times the melatonin levels likened to the control. This increase can show a major part in the enhancement of stress environments (Arnao and harnandez 2009). Treatment with exogenous MEL exhibited a melatonin main effect linked to lipid metabolism with K^+ / Na^+ homeostasis in potato which grown in salt effected environment (Yu et al., 2018). Root MEL application improved antioxidant role in watermelon and reduced the toxic behavior of salt on photosynthetic activity by controlling oxidative stress. This effect regulates stomatal function and hence improved transport of electrons in photo system II (Li et al., 2018). (Liang et al.,2015) use melatonin for treatment of rice grown in salt effected area and determined that application of melatonin control damage in chlorophyll and senescence genes transcripts, therefore refining salt tolerance in plant. They also noted that use of melatonin protects leaf senescence and cells from death caused by ROS.

vi) Melatonin under Cold and Hot Environment.

temperature is essential for plants every stage of growth, and this requisite may differ between plant varieties and species. Variation in temperature from optimum requirement of plant effect plant germination, growth rate and yield and also result into various plant diseases (Pierce 1987). Species of hot climatic environment are sensitive to low temperatures (Decoteau 2000). Research work revealed that low temperature effect plant cells metabolic system and cause water stress, also damages cell membranes, sugars, phenolic, phospholipids, protein, and ATP (Kratsch & wise 2000; Lyons 1973). Cold environment result into extreme production of reactive oxygen species (O_2^- , H_2O_2 , OH^-) in plant cells. Reactive oxygen species may cause lipid peroxidation and oxidative alterations in proteins and nucleic acids (Liu et al., 2010; Fan et al., 2014). However, the plants have developed a defensive system and non-enzymatic acetyl-salicylic-acid and gluta-thione (GSH) to improve and overhaul damage produced due to oxidative stress (Almeselmani et al., 2006; Yin and Chen 2008). Low temperature tolerance in plants related to stimulation of ROS scrubbing systems. Plants that grown in cooled climate harmfully effected by high temperature. High temperature damagingly affect plant germination development period, declines photosynthetic ability, assimilation of carbon dioxide (CO_2), and plant metabolic practices (Alkhetab and Paulsen 1999; Sam et al., 2000). High temperatures also cause into weaken constancy of membrane, resultant in necrotic spots same indication like water stress in leaves and hence causing to deaths (Hall 2001). Plants food intakes also affected by high temperature stress (Rosa et al., 2003). Increase in temperature also had bad impact on plant. High temperature create oxidative stress which cause yield reduction, damage in membrane, degrade proteins and slow down plants pigments, and deprivation of DNA elements in plants (Suzuki and Mittler 2006). Many researchers investigated that use of melatonin as exogenous defend plants from harmful effect of excesses temperature. (Tan et al., 2000). Research work also investigated that MEL antioxidant capacity could reinforce plants exposed heat and cold stresses (Arnao and Hernandez 2018; Janas and Posmyke 2013). Several studies revealed that biosynthesis of MEL and upregulated genes induced by MEL supplementation under low temperature stress

conditions (Bajwa et al. 2014; Shi & Chen 2014). The harmful effect of low and high temperature on plants by down or upregulating genes and proteins, polyamine metabolism modulating, removal of ROS, chlorophyll-a, b and heat shock protein synthesis been improved with MEL treatment (Tan et al., 2007, Shi and Chen 2014; Turk et al., 2014; Xu et al., 2016; Zhang et al., 2017). (Balabusta et al. 2016,) showed that cucumber seeds treated with melatonin had improved SOD activities and reduce ROS under chilling stress. Research conducted on tomato under chilling stress also indicates that MEL treatment compact photo inhibition by improving non-photochemical reducing through introduction of violaxanthin de-epoxidase activity (Ding et al., 2017). (Alam et al.,2018) determined that tall fescue plant with melatonin treatment under high temperature stress had higher value of proteins, chlorophyll, and antioxidants activities, while lower malondial-dehyde and ROS, as compared to non-treated plants. Their result also revealed that plants thermos-tolerance improved with MEL treatment. another research work indicates that, maize seeds priming under chilling stress with MEL (50 and 500 μM) regulated melatonin-associated visible proteins in seeds to low temperature and improved tolerance in plant to chilling (kolodziejczyk et al., 2016). *Lolium perenne* plants treated with MEL as foliar application, result into higher chlorophyll content, photo synthesis capacity and biomass as compared to non-treated *lolium perenne* under heat stress. Plants treatment endogenous melatonin and condensed ABA content and downregulate genes related to ABA (Zhang et al., 2017). Under chilling condition MEL applications improved antioxidant enzymes superoxide dismutases (SOD) and catalase (CAT), but compact hydrogen peroxide (H_2O_2) and malondialdehyde (MDA) content of pepper seedlings. Lipid peroxide decreasing in tissues result to promote antioxidant activities in plant., therefore pepper seed emergence and germination rate increased. (Korkamaz et al., 2017). (Xu et al.,2010) also investigate that treatment with MEL significantly increase antioxidants superoxide dismutases (SOD), catalase (CAT), ascorbate peroxidase (APX), peroxidase (POD), and Ascorbic acid (AA), vitamin E (non-enzymatic antioxidant), reduced reactive oxygen species (ROS) levels and lipid per-oxidation in cucumber under stress created by higher temperature. (Posmyk et al.,2009) examined that melatonin osmo and hydro priming application on germination in cucumber to increase rate of germination under low temperature creative stress. They revealed that cucumber seed germination amplified to 50%–60% at 15°C and further additional MEL 25 μM to 100 μM amplified the germination ratio of cucumber seeds. From this result they reported that application of MEL protected cell membranes beside peroxidation in cucumber seeds during chilling stress but increase in melatonin level is responsible for oxidative changes in proteins.

v). Melatonin role in Oxidative Stress.

As an antioxidant and signaling molecule MEL develop strong reaction to plant stress, particularly abiotic stresses. MEL along with other plant hormones control the effect of drought. In plants cell membranes permeability change by MEL, facilitated by ion transporters, which control plant stomata closing and opening during transpiration. Therefore, MEL antioxidant behavior make it effort as an endogenous plant bio-stimulator for biotic and abiotic stresses (Amao & Hernandez 2019). Melatonin also increase plant tolerance against heavy metals like zinc, cadmium, copper and vanadium. vanadium, is present in the Earth's crust. Watermelon have been investigated to check its response against vanadium as well as the effect of MEL on vanadium. Watermelon seeds were exposed to vanadium and treated with 50mg/L MEL. Result indicated that MEL treated seeds appeared with improved chlorophyll content and photosynthetic response of plant as compared to the non-melatonin-treated plants. MEL reduce transcript level of senescence-associated-genes (SAG) and the effect of pheide-a-oxygenase

(PAO). MEL also boost SOD and CAT antioxidant enzymes activities and reduce the vanadium presence in plant and hence decrease plant stress and improve plant growth (Nawaz et al., 2018). Iron level variation in plant reduce plant growth rate, secondary plant metabolic behavior and antioxidant enzymes activities. To overcome on these deficiencies MEL is used to change the genes expression and properly maintain iron level in plant. Plants antioxidant reduction related to flavonoids and phenolic. After melatonin treatment, plant antioxidant (ferric-reducing) activities increase SAR stressed, which also contains their antioxidant assets. MEL treatment also reduce lipid peroxide and hydrogen peroxide level inn plants, which decrease plant stress and finally improve photosynthesis and plant growth. Crop yield also effect with acid rain, which could be treated with MEL application (debnath et al., 2018). Plant defense system and antioxidant behavior could be improved with MEL treatment. *Carya cathayensis* Chinese hickory plant which is available on commercial base and known throughout due to its nuts. But this plant took more time to reach nut growing stage. This plant very sensitive to stresses (biotic and abiotic). In order to reduce *Carya cathayensis* plant, vegetative and reproductive phase grafting can be done. Therefore, MEL is used in the grafting of *Carya cathayensis* under drought stress, which enhanced efficiency of plant defense system and improve photosynthesis activities and reduce the effect of ROS and activating Proline content. This indicates that MEL treatment regulates biological routes at catalytic and molecular levels (sharma et al., 2020). Melatonin plays an important role against abiotic and biotic stresses, it is used to boost up plants defense mechanism against oxidative stress, some of which are discussed below in **Table 4**. While, **Fig 2** indicates a diagrammatic sketch of melatonin defense system.

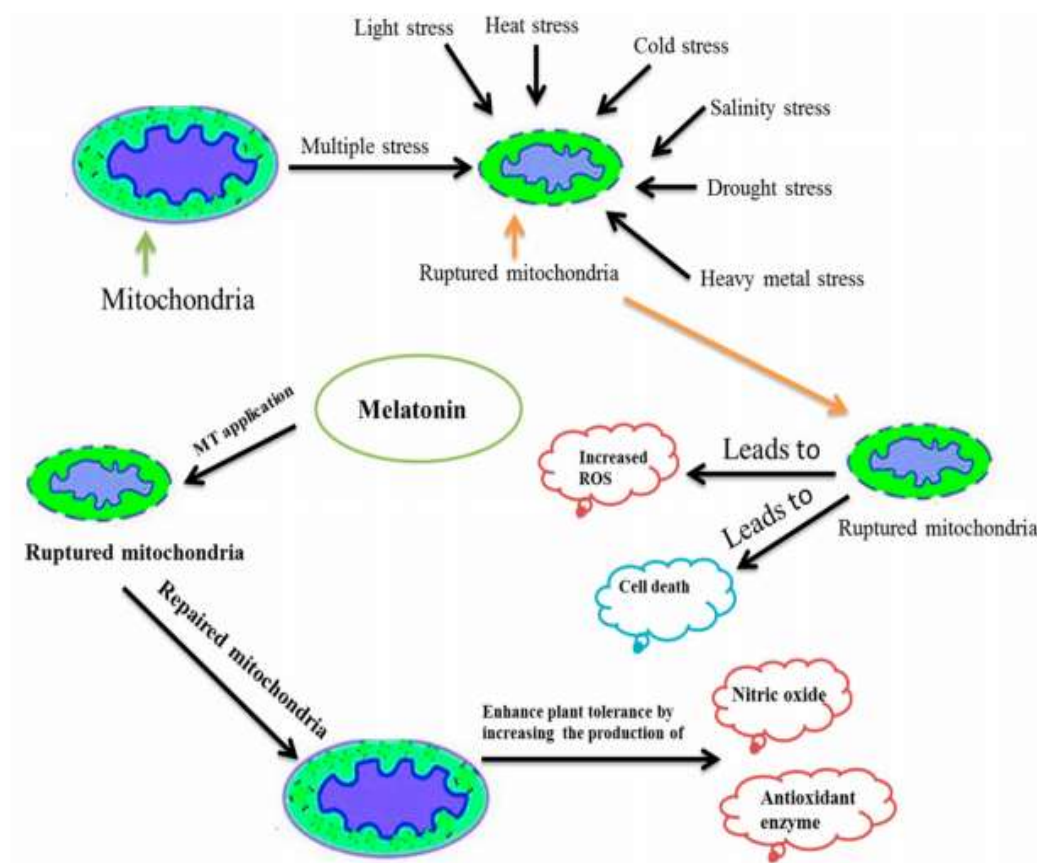


Figure 1. Schematic representation of melatonin defense mechanism pathway.

Table 4. Protective role of melatonin in various crops against different abiotic stresses.

crop	Stress condition	Concentration	Function	References
Arabidopsis	Heat	1000µM	Improved seed germination under heat stress	Harnandez et al., 2015
Apple	Drought	100 µM	Reduced ABA activity and radical scavenging	Li et al., 2014
Apple	waterlogging	200 µM	Reduced chlorosis and wilting of the seedlings	Zheng et al., 2017
Barley	senescence	1 µM	Boosted chlorophyll content	Arnao and Harnandez 2009
Brassica napus L.	Drought	0.05 mmol/L	Increased the overall growth indices of brassica seedlings	Li et al., 2018
Bermuda grass	Cold	100 µM	Induced photosynthetic activity under cold stress	Hu et al., 2018

Cucumber	salinity	100 μ M	Overall growth	Wang et al., 2016
Cucumber	Cinnamic acid	10 μ M	Rescued cucumber seedlings from Cinnamic acid stress and increased the allocation of dry weight in roots.	Li et al., 2017
Eggplant	Cadmium stress	150 μ mol/L	Enriched photosynthetic activity	Tang et al., 2015
Faba bean	salinity	500 μ M	Enriched photosynthetic activity and mineral accumulation	Dawood and Elawdi 2015
Graps	Water deficient	200 μ mol/L	Amended antioxidative enzymes activity	Meng et al., 2014
Maize	Drought	100 μ mol/L	Photosynthesis and growth	Ye et al., 2016
Melon	Cold	200 μ M	Improved proline and ascorbic acid content	Zhang et al., 2017
Medicago sativa	Drought	10 μ M	regulation of nitro-oxidative and osmoprotective homeostasis	Antoniou et al., 2017
Malus hupehensis	salinity	0.1mM	Improved photosynthetic activity and better plant growth	Li et al., 2012
Malus hupehensis	Alkaline	5 μ M	Significantly induced the tolerance against alkaline stress by increasing the antioxidant activity and biosynthesis of polyamines	Gong et al., 2017
Perennial ryegrass	High Temperature	20 μ M	Regulate abscisic acid and cytokinin biosynthesis	Zhang et al., 2017
Potato	Salinity	100 μ M	Better chlorophyll content, antioxidant activities and water content	Yu et al., 2018
Pisum sativum L.	Oxidative stress	50 μ M	Reduced $O_2^{\bullet-}$ accumulation in leaf tissues and preservation of photosynthetic pigments	Szafra et al., 2016
Rice	Salinity	20 μ M	Delay leaf senescence and cell death in rice	Liang et al., 2015
Red cabbage	Heavy metal	10 μ M	improved seed germination and reduced the toxic effect of metal on the	Posmyk et al., 2008

				seedling.	
Soybean	Multiple stress	100 μ M		Boost and maintain the overall plant growth	Wei et al., 2014
Soybean	Aluminum stress	50 μ M		Enhanced root growth and reduced aluminum toxicity	Zhang et al., 2017
Sunflower	salt	15 μ M		Regulate root growth and hypocotyl elongation under salt stress	Mukherjee et al., 2014
Tomato	Cold salinity and	100 μ M		Improved photosynthesis and regulation of photosynthetic electron transport	Yang et al., 2018; Zhou et al., 2016
Tomato	Heat salinity and	100 μ M		Induced antioxidant enzymes activity and better photosynthetic performance	Martinez et al., 2018
Tomato	Acid rain	100 μ M		Enhanced tolerance against simulated acid rain and increased the photosynthetic activity	Debnath et al., 2018
Tea	Cold	100 μ M		Triggered photosynthetic and antioxidant enzymes activities	Li et al., 2018
watermelon	Salinity	150 μ M		Redox homeostasis and improved photosynthetic activity	Li et al., 2017
Watermelon	Vanadium stress	0.1 μ M		Lower the concentration of vanadium in leaf, stem and better photosynthetic and antioxidants activity	Nawaz et al., 2018
watermelon	Cold	150 μ M and 1.5 μ M		Alleviate cold stress by inducing long-distance signaling in the untreated tissue.	Li et al., 2017
Wheat	Drought and nano-ZnO	500 μ M and 1nM		Augmented seedling percentage, growth, and antioxidant enzymes activities.	Cui et al., 2017;
wheat	Cadmium stress	50mM		Reduce the level of hydrogen peroxide which increases the wheat plants growth	Ni et al., 2018

Conclusion

Grounded on literature information, Melatonin under abiotic stress environment could work as a regulator to improve plant yield. MEL also consider tolerance to stress. Melatonin improves plant growth parameters, plant anti-oxidants response, plant water related traits, and photosynthesis activities of plant and hence improve yield under opposed environment. These improvements in plants caused by

- (i) refining plant photosynthetic capability.
- (ii) scavenging ROS.
- (iii) augmenting plant anti-oxidant capability.
- (iv) stress linked genes regulation, and
- (v) enrichment of osmotic metabolites.

There are as yet numerous unanswered inquiries regarding MEL and more areas for additional exploration. The systems by which MEL is delivered are still generally uncertain and should be explained by various plant cells in various circumstances.

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