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# Abiotic Stresses in Tomato (*Solanum lycopersicum*) Under Climate Change: Physiological Impacts and Emerging Mitigation Strategies, A Review

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## ABSTRACT

Tomato (*Solanum lycopersicum*) is a very important vegetable crop grown naturally in the tropical and subtropical ecologies of the world. Abiotic stresses exert substantial influence on the physiology, growth and yield of the plants. This review studies the physiological impact and emerging mitigation strategies of abiotic stress on tomato (*Solanum lycopersicum*) caused by climate change. The findings revealed that while some of these abiotic stress-induced effects on tomato plants are distinct, some do overlap. These abiotic stresses are induced by environmental factors such as heat and cold, water logging and drought, humidity and abnormal gasses on tomato plants. Furthermore, the appropriate and effective mitigation options such as the use of stress resistant varieties, watering or irrigation changing and integrated management procedures were shown to be important and effective strategies in mitigating abiotic stress. Conclusively, the potential use of volatile organic compounds (VOCs) in reducing abiotic stress in tomato plants, will enable all stakeholders to preserve natural resources while minimizing the negative impacts of abiotic stresses and ensuring long-term tomato yield in a changing global climate.

**Keywords:** Abiotic stress, Climate change, Mitigation strategies, Tomato, Volatile organic compounds.

## Introduction

Decrease in crop productivity is one of the problems mounted by abiotic stresses. These stresses are mostly attributed to changes in climatic conditions (Dhankher & Foyer, 2018). These changes are projected to induce more droughts that will be averagely more frequent and severe in years to come (IPCC, 2014). Therefore, there is a need to know those abiotic factors that are likely to change and suggest solutions to sustainable increase in plant yield, while preserving the environment, its resources and reduce human health risk. In recent times, several

attempts have been made to boost plant productivity through the introduction of mechanization, advancements in plant genetics together with the extensive chemical substances usage (Brilli et al., 2019). The use of synthetic chemicals which is now common, comes with its increased negative consequences which has a big impact on human health and on the environment (Conley et al., 2009).

Stress in plants generally involves all the changes in growth conditions that interrupts the metabolic

homeostasis of plants thereby requiring accumulation which is the metabolic pathways adjustment (Manghwar et al., 2024). It has been proven that plants retain stimulus of stress conditions when they are subjected to abiotic factors Charng et al. (2023), and this retained stimulus plays a pivotal role in determining the reaction of plants to similar stress conditions in the future. In plants, abiotic stresses constitute a major alteration in the environment which negatively effects the plant's primary and secondary metabolism. This effect on metabolic variations adversely impacts the plant overall productivity (Vickers et al., 2009). Plants in their constitutive make-up have an inbuilt mechanism against changes in abiotic factors in their micro and macro environments. However, when excessive production of reactive oxygen species (ROS) which are substances continuously synthesized by plants under normal situations occur, plants respond to these stress conditions.

The continuous production of these substances results to plant cell damage through oxidative stress, which initiates a stream of chain reactions. Apel & Hirt (2004) reported that this process leads to further buildup of more ROS and initiation of cell death.

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### Abiotic Stresses of Tomatoes

Globally, the main source of revenue is agriculture. Climate change is an essential factor which affects crop productivity and yield especially vegetables such as tomatoes (Tuomisto et al., 2017). Tomato is among the vegetable crops grown worldwide, but mostly in tropical and subtropical regions (Gemechu and Beyene, 2019). It has a lot of economic and nutritional benefits. Tomatoes generated a total world trade of 9.81 billion USD in 2020 which was about 8.01% increase from the previous year. Tomato is a good source of nutrients such as potassium, iron, vitamin C, lycopene as well as folates, and other useful antioxidants, such as beta-carotene and phenolic compounds (Chaudhary et al., 2018).

Various environmental factors induce abiotic stress such as high and low temperatures, precipitation, salinity, and humidity. Disproportionate changes in these environmental factors turn to be detrimental to tomato cultivation thereby leading to a substantial yield losses (He et al., 2018). Considering the complexity of most environmental stress

factors and their occurrences, most abiotic stress rarely happen in a single form in nature (Mittler, 2006).

The understanding of how changes of these abiotic factors affect tomato production in many regions of the world is critical for the crop improvement programs which may depend primarily on the genetic differences existing on the available tomato species genome done by conventional breeding. Irregular rainfall is an important abiotic factor that drives the general average growth and yields of plants. This often results to a key abiotic stress factor affecting global tomato crops production and has been reportedly linked to droughts globally. Although some earlier studies have highlighted the effects of environmental stresses on physiological growth changes and consequent yield of tomatoes, there is need for an inclusive study updating the current information on the effects of abiotic stress on tomatoes with special focus on novel mitigation strategies in this our continuously changing climate, for guaranteeing economic, nutritional and food safety of global ever-growing population.

### Various Abiotic Stresses and their Effects on Tomato Productivity

Recently agricultural crop production especially in the tropical and subtropical regions has been greatly impacted by abiotic stress such as climate change which include abnormalities in temperature, moisture, greenhouse gases, and humidity, which affects the productivity and yield of tomatoes.

#### Temperature

Heat stress has been identified to affect plants independently by affecting processes of the cells metabolism and physiology (Hasanuzzaman et al., 2013). Elevated temperatures effects on plants depends on the susceptibility and its developmental stage such as, vegetative or reproductive stages (Driedonks et al., 2016). Furthermore, high temperatures induce stunted growth of tomatoes through its effects on the photosynthetic pathway by causing abnormal changes in the chlorophyll biosynthesis (Nankishore and Farrell, 2016).

High temperatures adversely affect the pollen grain development in tomatoes Amuji et al. (2020), particularly at the onset of pollen germination and eventual pollen tube development (Raja et al., 2019). These abiotic stress of high temperatures generally impairs flowering in tomatoes, leading to consequent reduced fruit set. It most importantly reduces the ultimate aim of production which is the crop yield by upsetting the normal development and maturation of the tomato fruits (Alsamir et al., 2021).

According to various reports available in literature, low temperatures of 0 to 15° C affects all stages of tomato growth leading to yield losses. This effects ranges from causing serious stunted growth, affecting number of days needed for flowering, reduction in the number of flowers produced and eventual fruits formed. Low temperatures cause membrane damage in tomato plant growth especially at the early growth stages (Yang et al., 2020). When these abnormally low temperatures occur, the quality of the tomato fruits is affected. Reports by Xiaoa et al. (2018) suggest lowering of the vitamin C content as well as lycopene and other soluble solid contents of tomato fruits.

### Water

Tomato plant water stress may cause lower yields and possible total crop failure (Sibomana et al., 2013). However, this particular abiotic stress varies between tomato plant species involved and the extent of the influence. Lesser the magnitude in terms of duration and severity the possibility of recovering is always very high for the tomato plant (Amuji et al., 2020). Early control of the water stress can be very helpful to maintain the normal growth of the crop (Hao et al., 2019).

Climate change due more incidence and intensity of adverse occurrence of rainfall has caused events such as flooding, and rising of water tables (USEPA, 2016). In tomato production especially in an open field cultivation, excess water normally occurs due to excess rainfall or over-irrigation (Mukherjee et al., 2023). The condition consequently created increases potentials for tomato crop yield losses (Mukherjee et al., 2023). Some of the abnormal conditions that can be exist when water is in excess in tomato production include the following: (1) Creation of conditions toxic to the tomato plants. For example, formation of sulphides and butyric acids. (2) Leaching of nutrients and pesticides to the groundwater below the root zone. (3) Creation of conditions favorable for fungal, bacterial, and root rotting diseases and finally ultimately reduction in yield (Rajanna et al., 2018)

Tomatoes growth and development can be adversely affect by lack of water also known as drought through reduction in photosynthetic activities (Petrović et al., 2021). During drought, the stomata that control movement of water and gases in and out of the plants are closed to conserve water. This closure results in reduced photosynthesis. The impact of water lack on the plants are more visible on the leaves than roots. The most common symptom of drought for tomatoes just like all other plants

is wilting which is caused by decreasing water pressure inside the leaves (English-Loeb et al., 1997). When this wilting condition occurs, there will be reduced growth and even death for the plants experiencing it.

### Humidity

Relative humidity (RH) as a climatic factor which impacts a plant's pollen viability (Aronne, 1999; Iovane et al., 2022). For example, RH extended the pollen viability of *Cucurbita pepo*. Trials in tomato plants showed that the RH of 50-70% is the optimal while above 90% caused pollen vulnerability to heat stress (Harel et al., 2014). High RH when there is an elevated CO<sub>2</sub> causes nutrient deficiency due to reduced transpiration rate thereby affecting the tomato fruit yield (Yang et al., 2020). Low RH (high VPD) causes osmotic adjustment in tomato plants thereby inducing a water stress that could be of a negative effect, especially on photosynthetic processes (Du et al., 2018). There are accounts that tomato farmers are always careful for energy saving through working on decreasing the greenhouse production dehumidification. This technique employed by farmers help to maintain increased physiological activities making the tomato fruit yield to increase as a result of its consequence (Xu et al., 2006).

### Greenhouse Gases

Carbon dioxide (CO<sub>2</sub>) levels are considerably high in the atmosphere contributing as one of the major shares to global warming. It is believed that climate change occurrence globally is due to increase due to various human actions that intensifies the emission of greenhouse gases such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and Nitrous oxide (N<sub>2</sub>O) (Kumar et al., 2018). Furthermore, as reported by the Intergovernmental Panel on Climate Change in Arias et al., (2021) estimates with respect to the RCP 6.0 (Representative Concentration Pathway) that there will be continuous global warming which will result to CO<sub>2</sub> levels rising up to 670 ppm by 2100. These increased levels of CO<sub>2</sub> as known to elevated rate of the photosynthesis together with accumulation of biomass but at higher level of 500 and 700 ppm, it will lower the flavonoids, titrable acidity, total soluble solids, and phenols contained in the tomatoes (Rangaswamy et al., 2021). Other GHG impact of tomato production have not been widely reported in literature however, their relative contribution to growth and yield, is different between other environmental factors (Bhandari et al., 2021). This suggests that footprints are more consistent with climatic factors than between the GHG (Koide et al., 2021).

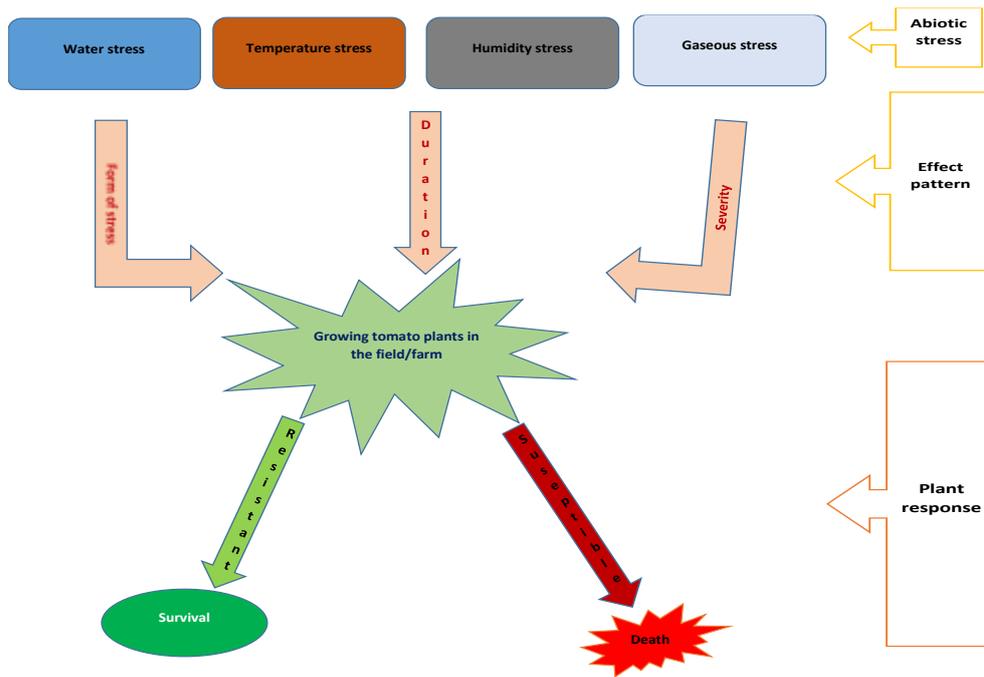


Figure 1: Abiotic stresses responses in growing tomato plants

### Concept of Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are simply organic chemicals that have low molecular weight and vapour pressures that are high even at normal room temperature (Parmar et al., 2008). The atmosphere constitutes a vast array of VOCs which are produced in form of secondary metabolites from various types of organisms, however plants constitute the dominant producer of it (Guenther et al., 1995). Also, plants are known to synthesize a large number of secondary metabolites as a reaction to specific needs, in addition the VOCs constitute one of the most essential secondary metabolites synthesized by growing plants (Pichersky and Gang, 2000). These VOCs are either produced constitutively by plants or in the induced state from their shoots or roots to the atmosphere and rhizosphere, respectively (Sharifi et al., 2022).

Plant VOCs are elusive chemicals that are important parts of how plants respond to their immediate environment, which goes on to affect the climatic condition of the environment (Dusan et al., 2015). These VOCs of plant origin have been recognized in diverse species ranging from angiosperms to gymnosperms of different families and orders (Knudsen et al., 2006). Principally, VOCs are released from plant floral parts (flower), however, other plant parts such as leaves, fruits, stems and roots also emit these chemical substances (Lo et al., 2024). VOCs have been found to enhance resistance to upcoming stress conditions by priming the defense system of plants (Conrath et al., 2015). Also, these plant VOCs are derived

within from different metabolic origins which include alkaloids, nitrogen-containing compounds, terpenoids, fatty acid gotten, and phenolics (Kutty et al., 2023). Plants in their ideal state usually release volatile compounds which are intended to attract pollinating agents for seed dispersal Raguso (2008), while under stress conditions (biotic and abiotic), they also release induced plant volatiles (Holopainen 2004). So far, the essential and most understood application of plant volatiles is the attraction of pollinators which guaranty continual reproductive success (Kessler et al., 2015).

### Abiotic Stresses Reduction Through the Use of Volatile Organic Compounds (VOC)

Plants abiotic stresses constitute a major alteration in the environment which can adversely impact the plant's primary and secondary metabolism. These impacts of the metabolic variation adversely impact plant overall growth and productivity, or may even lead to plant withering (Vickers et al., 2009). Plants in their constitutive make-up have an inbuilt mechanism against changes in abiotic factors in their environments. The production of reactive oxygen species (ROS) in excessive form by plants under normal conditions is the most common response to these stress conditions. Continuous production of these substances results to plant cell damage through oxidative stress, which initiates a stream of chain reactions, that results in ROS continuous accumulation programmed initiation of cells death (Apel & Hirt, 2004).

Furthermore, plants constitutive emission of VOCs has been reported to be of significant effect on the tolerance to abiotic stress (Loreto and Schnitzler, 2010). Also, many works, have revealed that isoprenoids emission- one of the most common VOCs groups' available (Guenther et al., 2006) as abiotic stresses induced. Isoprenoids have been found to protect cell membranes against the toxic accumulation of ROS, either by dousing their build-up directly, or through cell membranes stabilizing (Loreto and Velikova, 2001). The link between abiotic stress and plant volatile emissions are made apparent with the increased production of plant VOCs when there is abiotic stress, especially due to mechanical damage, intensive light, insufficient water and/or heat stresses (Vickers et al., 2009). Although, many plant species synthesize and store VOCs, others do not unless an environmental stimulus is sensed. Specific volatile compounds such as ethylene and nitric oxide also act as stress heralds that

help plants stimulate stress induced defenses (Calfapietra et al., 2009).

Nevertheless, it is essential to note that there is a difference existing between the constitutive VOCs and induced VOCs (IVOCs). The IVOCs are only produced after a stress condition which is advantageous due to the optimization of usage of carbon by the plants, does not impede of the plants (Dicke, 2000). Furthermore, the constitutive VOCs mostly emits inducible volatiles after foliar damage from formerly healthy plants (Vuorinen, 2004). Examples of already known IVOCs are: alcohols, alkanes, alkenes, nitrogen-containing compounds and carboxylic acids. Although, main compounds known are C6 green leaf volatiles (GLVs), terpenes and isoprene (Holopainen and Gershenzon, 2010). Plant's prevailing environmental conditions, species, developmental stages and organs involved tend to determine the type and quantity of VOC emission (Holopainen and Gershenzon, 2010)

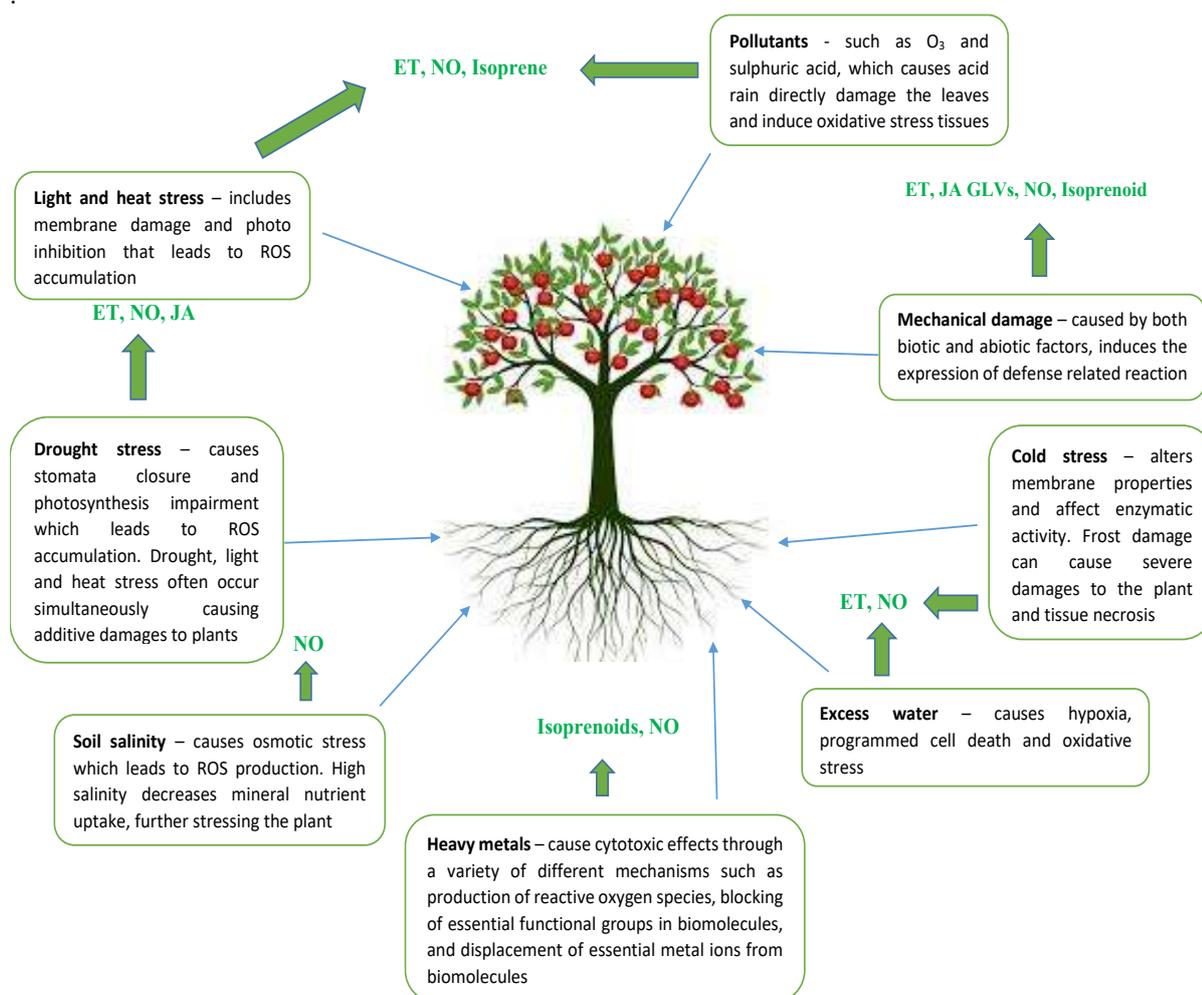


Figure 2: Abiotic stresses affecting plants with their effects on plant life and the resulting response through VOC emission. The VOCs are ethylene (ET), nitric oxide (NO), jasmonic acid (JA), green leaf volatiles (GLVs), and isoprenoids

## Conclusion

It is essential to state that with the possible changes in climate together with other factors such as increasing population there will be high production cost of tomatoes and other vegetable crops which will likely mount more stress on food security globally especially in the counties within the developing regions of the world that always lack the necessary mitigation and adaptive mechanisms for coping. In order to attain food security of the continuous growing world population, there is an urgent need to ensure that all parts of the world are able to lessen the negative impacts due to abiotic stresses as highlighted in this work. Therefore, the capacity of increasing the productivity of tomatoes and other similar vegetables through adaptive ability with suitable agronomic management practices such as sowing time adjusting, use of improve resistant varieties/genotypes, best planting methods and consideration of other better climatic and soil conditions peculiar to area that will be favorable should be implemented.

This review infers that plant volatiles have emerged as a vital as well as beneficial part of a plant's survival in its surrounding environment. In keeping with this fact, further advancements in study would identify different metabolic and signaling pathways of these VOCs emitted by plants in reaction to abnormal conditions imposed by abiotic stress, thereby, significantly improving on the agricultural output quantity and quality. We recommend that investigations can also be made by researchers done in vitro and in vivo experimentations to advance appreciate the role and impact of different plant emitted volatile compounds in achieving more eco-friendly and cost-effective agronomic practices for futuristic sustainable agricultural development.

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## Author contributions

CFA and BBO wrote the first draft. BOU and MOE reviewed the write up. All the authors read and accepted that the manuscript should be submitted.

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## Data availability

Not applicable.

## Ethical Clearance

Ethics not applicable.

## Competing interests

The authors declare no competing interests.

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