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Review Article

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Biotic and Abiotic Stress Management under Climate Change in Sericulture

Kahkashan Qayoom, Shaista Manzoor, Aroos Rauf Rafiqui and Omais Bin Ayoub
College of Temperate Sericulture, Mirgund, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar190025, J&K-India
**Corresponding author e-mail: kehkashanqayoom@gmail.com*
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ABSTRACT
Climate change threatens sustainable agriculture with its rapid and unpredictable consequences, making it more challenging for agricultural researchers and farmers to adjust to biotic and abiotic stress challenges. The combined impacts of climate, including temperature, precipitation, humidity, and other factors including soil moisture, atmospheric CO_2, and tropospheric ozone (O_3), will determine the potential influence of global climate change on plant-pest populations. Variations in sericulture productivity can be caused by either direct consequences of these factors at the plant level or repercussions at the system level, such as variations in insect pest prevalence. In addition to the physiological response of the impacted mulberry plant, silkworm rearing, and post-cocoon technology, as well as variations in the frequency of droughts or floods, all these factors determine how vulnerable raw silk production is to climate change. A number of researchers in the field of sericulture predicted that climate change would have a major impact on the productivity of silk, which has a direct impact on the Indian economy, was predicted by a number of researchers in the field of sericulture. The development of genotypes suited for various agro-climatic situations is essential for ensuring the long-term sustainability of the sericulture sector amid global climatic change and the impending scarcity of land and water. Transgenic revolution, tissue culture, transcriptomics, proteomics, and metabolomics in mulberry will generate advanced biotechnological cultivation technologies that will improve sericulture industry's economy and the quality of life of those engaged in sericulture practices.
Keywords: Climate change, Abiotic, Biotic, Stress, Mulberry, Biotechnological, Sericulture.

INTRODUCTION

Climate change threatens sustainable agriculture with its rapid and unpredictable consequences, making it more challenging for agricultural researchers and farmers to adjust to biotic and abiotic stress challenges. The main abiotic stressors that have a significant impact on crop yield and food safety are drought and soil salinity. They demonstrate negative effects on many developing nations socio-economic frameworks.

Any combination of three or more ($n \geq 3$) stress elements that affect plants at once is referred to as a multifactorial stress combination. According to the model shown in Figure 1, the numerous stress factors that could affect plants at once can be biotic (such as viruses, bacteria, and insects), abiotic (such as flooding, drought, and heat), abiotic anthropogenic (such as pesticides, antibiotics, and heavy metals), or biotic/abiotic stresses associated with soil (such as nutrient deficiency, salinity, and decreased microbial diversity). (Zandalinas *et al.*, 2021).

Any plant's physiological development and growth are influenced by environmental factors such as soil fertility, temperature, moisture, and rainfall, with evapotranspiration being another key environmental factor. Collectively, these mechanisms have an impact on the photosynthesis-related stages of a plant's life cycle. Global warming is expected to have an impact on the areas used for growing different crops, including mulberry trees. Warmer temperatures will shorten the growing season and lower yields in cereals and seed crops, but water stress conditions may cause yield reductions in a variety of crops. Since mulberry is a C3 plant, it has a completely different physiology than C4 plants. The photosynthetic machinery of C3 plants is located on the outer mesophyll cells, and they are relatively inefficient at utilising CO_2. In order to make up for this, the stomata must remain open for a longer period of time, potentially increasing evapotranspiration rates. Long *et al.* (2006) and Polley (2002) reported the effect of rising CO_2 on plant yield via photosynthesis and the stomatal conductance, with evidence indicating that C3 crops may respond positively to increased atmospheric CO_2 in the absence of other stressful conditions (Long *et al.*, 2004), but the beneficial direct impact of elevated CO_2 can be offset by other effects of climate change, such as increased temperature, higher tropospheric ozone concentrations, and altered patterns of precipitation.

The IPCC (2001) also reported climate change's direct and indirect effects:

i) Direct effects arise out of alterations in temperature, rainfall patterns, or carbon dioxide concentrations; and

ii) Indirect effects arise from alterations in the moisture content of soil and its distribution, along with the frequency of pest and disease infestations.

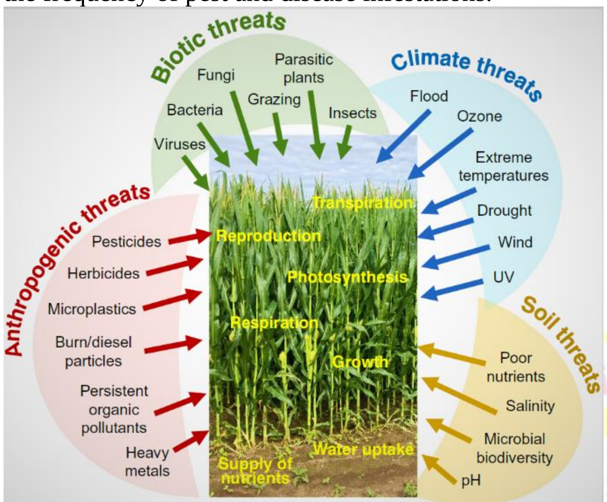

Fig. 1. Multifactorial Stress Combination (Zandalinas *et al.*, 2021)

Climate change and mulberry diseases

The combined impacts of climate (such as temperature, precipitation, humidity, etc.) and other elements (like soil moisture, atmospheric CO_2, and tropospheric ozone), can have a significant impact on plant-pest populations. Variations in sericulture productivity can be caused by either direct consequences of these factors at the plant level or repercussions at the system level, such as variations in insect pest prevalence. A rise in temperature may cause changes in the geographic distribution of populations, increased overwintering, altered population growth rates, additional generations, a prolongation of the growing period, altered crop-pest synchrony of phenology, modified interspecific interactions, and an elevated risk of migrant pest invasion (Parmesan, 2007). Due to intensive cultivation methods and indiscriminate use of nitrogenous fertilisers and pesticides, several pests and diseases have been reported to be the primary challenges restricting the production and productivity of mulberry leaves in recent years. Due to changes in the climate and agroecosystem, the insect pest situation in mulberry has also changed, and these pests are Bihar hairy caterpillar (*Diacrisia oblique*), Pink mealy bug (*Maconellicoccus hirsutus*,), Thrips (*Pseudodendrothrips mori*), Leaf webber (*Diaphania pulverulentalis*), Mites and diseases are Root-knot disease (*Meloidogyne incognita*), Powdery mildew (*Phyllactinia corylea*), Leaf rust (*Peridiospora mori*) and Leaf spot (*Cercospora moricola*), etc. It has been reported that the pink mealy bug, *Maconellicoccus hirsutus* has 346 host plants, and in mulberry, it causes leaf yield loss of 4500 kg/ha/year, thus depriving the farmer of a brushing of about 450 dfls/ha/year, leading to a decline in cocoon production of 150 kg/ha/year (Ravikumar *et al*., 2010). Since 1995, the leaf webber *Diaphania pulverulentalis*, which attacks native M5, MR2, S36, and V1 cultivars, has been identified as a major pest in Karnataka. D. *pulverulentalis* infestation levels are greater in the areas of Salem (between October and December) and Krishnagiri (between October and February). Similarly, Rajadurai *et al.* (2000) reported that the leaf yield loss due to diseases and pests is 12.8% with an average incidence of 21.77%.

In the global scenario, one of the most significant effects of climate change in the temperate zone could be a change in pest or pathogens winter survival. Due to the individualised reactions that some insect and host plant species have to temperature, CO_2, and photoperiod, it may throw off the synchronisation between temperature and photoperiod. Increases in pathogen growth and infection within specific temperature ranges are the foundation of several mathematical models that have proven beneficial for predicting epidemics of plant diseases.

According to Coakley *et al*. (1999), rising temperatures make plants more vulnerable to rust diseases, and the optimal conditions for fungi to grow are those with moderate temperature ranges. He further reported that due to the rising temperature, temperate climatic zones—which have seasons with cool average temperatures—are likely to suffer more prolonged periods of high temperatures that are conducive to pathogen growth and reproduction. Additionally, he mentioned that increased precipitation frequency and intensity, elevated CO_2 levels, and dense canopies with higher humidity all favour disease growth.

Many researchers have reported on the impact of climate change on the pathogens of various crops. For instance, higher CO_2 may change the pathogen's aggressiveness and/or host susceptibility and interfere with the pathogen's early establishment on the host, particularly fungus (Matros *et al*., 2006). Greater plant canopy area, particularly in conjunction with humidity and higher host abundance, increased fertility, and the growth of several fungal diseases, can enhance pathogen load under increasing CO_2 concentrations (Chakraborty *et al*., 2000).

Climate change and the sericulture industry's economy

Sericulture is an agro-based industry, and the susceptibility of raw silk production to climate change is dependent upon many factors, including changes in the frequency of droughts and floods as well as the physiological response of the affected silkworm host plants. Many scientists who study sericulture foresaw the considerable impact that climate change will have on mulberry leaf productivity, silkworm rearing, and post-cocoon technologies, all of which have a potential impact on the Indian economy. With a 2ºC increase in the average world temperature, climatic variability is predicted to cause crop losses of 10% to

40% and a loss of agricultural revenue in the hundreds of billions of rupees. If other effects are considered, such as loss of land and livelihoods owing to coastal erosion and sea level rise, increased disease incidence and morbidity, forced evictions, and property loss through flooding and landslides, the repercussions are likely to be larger. There is no estimated data available for the net revenue loss of the sericulture industry, but the loss in net revenue at the farm level is likewise anticipated to vary between 9% and 25% with a temperature rise of 2-4°C. According to Kumar and Parikh (1998), even after accounting for farm-level adaptation, the financial consequences will still be substantial. According to Sanghi *et al.* (1998) estimations, the country's overall net profits would decrease by 12.3% as a result of a 2°C rise in average temperatures and a 7% increase in average precipitation. Global warming is expected to affect mulberry leaf yield and raw silk production, silk content, silk thread breakage through reeling or spinning, water stress, drought, soil acidification and salinization, organic matter decomposition, N fixation, soil erosion, longer growing season insect pests, a shorter silkworm growth period, and an increased risk of viral, bacterial, and fungal infections. It is also predicted that sericulture practises in tropical regions such as Karnataka, Tamil Nadu, Andhra Pradesh, West Bengal, Madhya Pradesh, Bihar, Jharkhand, Assam, etc. will be severely impacted due to a 2°C or greater average annual temperature rise; however, small to marginal losses can be observed in Jammu & Kashmir and the Sub-Himalayan region of North Eastern India. Researchers in agriculture estimate that in temperate locations, sericulture may experience a net revenue loss of between 10% and 20%.

Management strategy under climate change

Global climatic changes and shortages of land and water in the coming decades make it necessary to develop genotypes that can survive varied agro-climatic conditions for the sericulture industry's sustainable growth. Transgenic revolution, tissue culture, transcriptomics, proteomics, and metabolomics in mulberry will generate advanced biotechnological cultivation technologies that will improve the sericulture industry's economy and the quality of life of those engaged in sericulture practices. The information flow in multiple aspects of mulberry genomics research is illustrated in Figure 2.

There are indigenous and exotic mulberry germplasm accessions available in many countries. Mulberry germplasm exhibits genotypic and phenotypic diversity because diverse environmental factors elicit various physiological, biochemical, and morpho-anatomical responses in plants. A comprehensive evaluation of particular traits is required for breeding programs in order to effectively utilise these genetic resources. Numerous factors have a negative impact on mulberry plantations, yet salt and drought are the worst because roughly 50% of mulberry land is in arid or semi-arid climates. In addition, high yielding mulberry cultivars require a lot of water because of their rapid growth rates, huge cumulative leaf areas, and extensive canopies; therefore, a water shortage can arrest the growth and yield performance of mulberry genotypes (Guha *et al.*, 2010a). In Table 1, a list of important reports on the characterization of mulberry germplasm for stress tolerance has been provided.

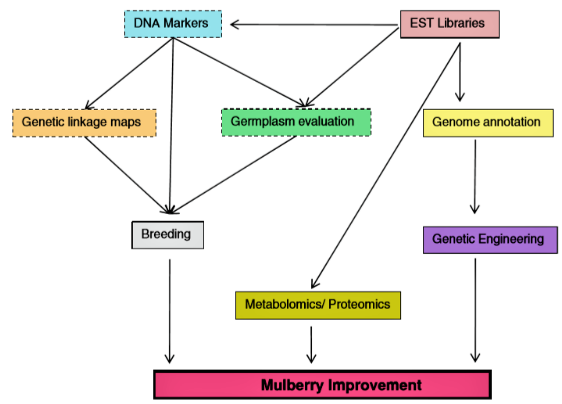

Fig. 2. Information Flow in Already-Researched (Dashes) and Under-Represented (Boxes) Sections of Mulberry Genomic Approaches (Khurana and Checker, 2011)

The purpose of developing a new mulberry variety is to combine all desirable traits into a single genotype that will be fed to the silkworm (*Bombyx mori*) in order to produce cocoons of superior quality. Despite significant attempts being made to produce mulberry genotypes that are salt-resistant (Vijayan *et al.*, 2009), it is necessary to develop mulberry genotypes for vertical expansion of sericulture, appropriate to distinct agro-climatic areas, and suitable mulberry varieties for alkaline, saline, acidic, and inundated soil conditions are currently unavailable (Tikader and Kamble, 2007). Advances in genomics and molecular biology approaches offer the ability to overcome issues associated with conventional breeding and open new horizons for improving mulberry yield under adverse conditions, revolutionizing sericulture practices (Vijayan, 2010).

Tissue Culture and Transgenic Revolution

Plant regeneration from tissue culture is extremely valuable since it may be used to enhance cultivars directly and is required for genetic modification and transformation studies. The most typical explants for mulberry in vitro propagation are axillary and apical buds; however, leaf, cotyledon, and hypocotyl explants have also proven successful in regenerating mulberry plants. The lack of notable advancements in traditional plant breeding for abiotic stress resistance and the recent economic losses brought on by abiotic challenges have paved the road for molecularly customizing crops via transgenic methods. Targeted gene-based transgenic techniques for the introduction of beneficial genes providing stress tolerance in mulberry are based on genomic technologies, which generate useful information on the molecular basis of stress tolerance (Table 2).

Table 1. List of Important Reports on the Characterisation of Mulberry Germplasm for Stress Tolerance

Stressor	No. of varieties	Parameters studied	References
NaCl	2	Phy, Biochem	Giridara Kumar *et al*. (2000)
NaCl	5	Morpho	Tewary *et al*. (2000)
High temperature	1	Biochem	Chaitanya *et al*. (2001)
Water withholding	1	Biochem	Barathi *et al*. (2001)
NaCl	63	Morpho	Vijayan *et al*. (2003)
Water withholding	5	Phy, Biochem	Ramachandra Reddy *et al*. (2004)
NaCl	4	Phy, Biochem	Lal *et al*. (2006)
NaCl	5	Morpho, Biochem, Anat	Vijayan *et al*. (2008)
NaCl	5	Phy, Biochem	Lal and Khurana (2009)
Drought	4	Phy, Biochem	Ren (2009)
Drought	5	Biochem	Chaitanya *et al*. (2009)
NaCl	11	Morpho, Biochem, Phy	Vijayan *et al*. (2010)
Drought	15	Morpho, Biochem, Phy	Guha *et al*. (2010a)
Drought	4	Morpho, Biochem, Phy, Anat	Guha *et al*. (2010b)
Drought	4	Morpho, Biochem, Phy	Guha *et al*. (2010c)
NaHCO3	2	Biochem, Phy	Ahmad and Sharma (2010)
Aerial drying and NaCl	10	Biochem, Phy, Mol	Das *et al*. (2011a)
Drought	1	Phy, Mol	Ackah *et al*. (2021)
Drought	1	Biochem, Phy, Mol	Li *et al*. (2022)

Morpho: morphological, Phy: physiological, Biochem: biochemical, Anat: anatomical, Mol: molecular.

Through several physiological and developmental processes, the plant hormone Abscisic acid (ABA) controls how plants respond adaptively to environmental challenges such as drought, salinity, and cold. As a result of extensive research on the ABA biosynthetic pathway, several essential enzymes involved in ABA production have been employed in transgenic plants to increase their ability to withstand abiotic stress. Increased resistance to salinity and drought stress was observed in transgenic plants that overexpressed the ABA production genes.

Table 2. Transgenesis in Mulberry for Abiotic Stress Tolerance.

Gene	Expression profile	Reference
WAP21	cold tolerance	Ukaji *et al.* (1999)
COR	cold tolerance	Ukaji *et al.* (2001)
OC	insect resistance	Wang *et al.* (2003)
SHN 1	drought tolerance	Ahroni *et al.* (2004)
HVA1	drought and salinity stress	Lal *et al*. (2008)
Bch	drought and salinity stress	Khurana (2010)
NHX	drought and salinity stress	Khurana (2010)
Osmotin	drought and salinity stress	Das *et al.* (2011b)
Bch1	UV, high temperature and high irradiance	Saeed *et al.* (2015)

(Source: modified from Vijayan *et al.*, 2011)

Mulberry Transcriptomics

Mulberry breeding is a tedious procedure; thus, it is necessary to add genetic and genomic technologies that could speed up the identification of functionally significant regions of the genome. The Mulberry Genomic Toolbox can be a valuable resource for understanding the roles of new genes and using them in genetic engineering. Due to the vastness of the mulberry genome and a shortage of adequate genetic and physical maps, the entire sequencing of the plant is not yet justifiable. The initial, relatively inexpensive phase in the functional genomics of mulberry allows for the direct identification of a broad range of genes by large-scale EST (Expressed Sequence Tags) sequencing. ESTs also include information on gene structure, alternative splicing, expression patterns, and transcript abundance, which is essential for correct genome annotation. The plant science community will value genomic analysis more and more as sequence and annotation data keep accumulating.

Mulberry Proteomics

Plants can adapt to biotic or abiotic stress conditions by undergoing profound changes in gene expression, which alter the transcriptome, proteome, and metabolome composition of the plant. Proteomics studies can considerably help to clarify the potential links between protein abundance and plant stress adaptation since proteins are directly involved in plant stress response. It has previously been established by several studies that changes in gene expression at the transcript level frequently do not coincide with changes at the protein level. The analysis of changes in the plant proteome is crucial because, unlike transcripts, proteins directly influence how plants respond to stress. Thus, proteomics research may help identify possible protein markers whose variations in abundance are quantitatively correlated with alterations in specific physiological characteristics associated with stress tolerance.

Kumari *et al*. (2007) investigated the effect of salinity on proteome alterations in two different mulberry cultivars, as identification of genes involved in salinity tolerance can provide essential evidence for improving salt tolerance in mulberry utilizing genetic modification techniques. The protein profiles of infected and healthy leaves were compared using two-dimensional electrophoresis to better understand the pathogen stress response of mulberry (*M. alba*). Quantitatively changed spots were then identified using mass spectrophotometry to reveal a complex array of proteins involved in the response to infection (Ji *et al*., 2009). These proteomic studies are extremely important because they reveal novel protein elements involved in developing stress tolerance.

Mulberry Metabolomics

A wide range of physiological plant processes may be better understood if an entire set of metabolites could be monitored. The goal of this methodical research, which is referred to as "metabolomics," is to present an integrated view of the biochemical functions of plant genes and the regulatory networks that control plant metabolism. Recent studies have shown that the fruits and leaves of the mulberry plant contain a variety of bioactive substances of great interest, including alkaloids, flavonoids, steroids, and anthocyanins, which have an impact on human health due to their antioxidant, antimicrobial, and anti-inflammatory properties. The examination of biochemical pathways of essential bioactive components and their response to environmental stresses showed their involvement in health advantages, thereby offering several new directions for research on various drugs and natural products. In order to examine gene activities and the metabolic status of the mulberry, metabolic profiling of the plant at the genome level will offer unambiguous findings.

CONCLUSIONS

Mulberry is one of the most economically important plants, with significant contributions to the Indian economy. Worldwide, biotic and abiotic stressors have a significant impact on mulberry productivity. A thorough analysis of genotypic variances offered fresh ideas for making the most use of the genetic resources available. Biotechnology has energized research and fostered a surge of new ideas for mulberry improvement. Standardized tissue culture experiments have been used to raise stable transgenic plants with various important traits. The development of enhanced stress-tolerant and disease-resistant plants by genetic engineering in response to changing climatic conditions was made possible by the abundance of unique candidate genes offered by the *Morus* genome resources. Although proteomics and metabolomics have untapped potential, combining transcriptome, proteomic, and metabolomic studies is anticipated to produce positive outcomes for knowing how to increase mulberry output. In order for the data to be helpful to everyone, the mulberry community needs an international mulberry consortium.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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