*Plant Archives* Vol. 26, No. 2, 2026 pp. 2653-2663 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.364

# CLIMATE CHANGE AND TROPICAL FRUIT PRODUCTION: PHYSIOLOGICAL MECHANISMS, ADAPTIVE ORCHARD MANAGEMENT AND FUTURE BREEDING STRATEGIES: A COMPREHENSIVE REVIEW

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(Date of Receiving-18-08-2026; Date of Revision-17-10-2026; Date of Acceptance-21-10-2026)

**ABSTRACT**

Climate change is reshaping tropical fruit production through rising temperatures, irregular rainfall, atmospheric drying and increasingly damaging weather extremes. These stresses affect the photosynthetic rate, water relations in the plant, flowering, fertilization, fruit size and postharvest quality and results in loss even before the vegetative symptoms are seen. This narrative review combines recent advances in our understanding with well-established physiological mechanisms to analyse climate responses of mango, banana, papaya, pineapple, guava and avocado. Special focus is placed on reproductive sensitivity, combined heat and drought stress, genotypic variation and differentiating commercially useful resilience from plant survival. Adaptive orchard management, such as stage specific irrigation, soil conservation, balanced fertilization, canopy management, microclimate manipulation and enhanced pest monitoring is suggested. The success of such actions is influenced by local conditions, water availability, the cost of implementation and possible interactions between management options. Breeding windows for conservation of genetic diversity, use of suitable root stocks, reproductive phenotyping, genomic prediction and molecular breeding. Nonetheless, laboratory tolerance, a candidate gene's expression and genomic associations are needed to be validated by repeated field-based examinations. Future advances rely on integrating physiology, management, and breeding around well-defined production environments and quantifiable outcomes. Stability of marketable yield, quality at risk, post-stress function and sustainable resource utilization should be considered to evaluate resilience. There is a need for a concerted research, readily available advisory services and strengthening institutions that would help harnessing scientific breakthroughs for the benefit of a broad-based tropical fruit producer.

***Key words :*** Tropical fruits, Climate resilience, Heat stress, Drought physiology, Reproductive development, Orchard adaptation.

## Introduction

The production of tropical fruits is important to the livelihoods of farmers and to the food and nutritional security of consumers as it is rich in various vitamins, minerals and bioactive compounds. Commonly cultivated, commercially important tropical fruits such as mango, banana, papaya, pineapple, guava and avocado, have variable eco physiological characteristics and responses

to environmental stresses (Ollitrault *et al*., 2019). Climate change endangers their productivity as a result of higher temperatures, unseasonal rainfall, atmospheric drought, and other extreme weather patterns (Malhotra, 2017). These problems are especially challenging for perennial orchards, for which long establishment periods and low ability to replace cultivars result in greater exposure. Climatic stress can also interfere with flowering and fruit set, as well as fruit size and carbohydrate storage, and thus can potentially affect subsequent seasonal productivity, even if trees survive (DeJong, 2021; Raju *et al*., 2024). Hence, adaptation need to encompass short-term stress management, better orchard management, sustainable use of resources, as well as long-term investments in climate-resilient cultivars and infrastructure (Osorio-Marin *et al*., 2024; Medda *et al*., 2022).

Climate resilience in tropical fruit crops involves physiological responses, orchard management practices and genetic improvement strategies. Experimental evidence from studies examining reproductive performance, fruit development and field productivity provide important information, as do genomic analyses and climate change projections that can help identify potential adaptation strategies (Uffelmann *et al*., 2021). But results obtained from controlled environments or single species need to be validated across different production systems. Relevant adaptation measures must target crop-specific vulnerabilities, such as heat-related reproductive failure, water deficit, irregular bearing and reduced fruit quality. Likewise, improved irrigation techniques need to guarantee water sustainability, and molecular breeding methods need to provide reliable agronomic advantages. Combining plant physiology, precision horticulture, genetic improvement and economic assessment can enhance productivity and climate resilience. These integrated approaches are key to improving resilience and ensuring long-term productivity of tropical fruit production systems, maintaining yield stability, fruit quality and farmer income in a changing climate (Kushwaha *et al*., 2025; Ferguson *et al*., 2021).

**Climate exposure and Production risk**

Climate change affects tropical fruit production through increased temperatures, erratic rainfall, atmospheric dryness and extreme weather events. Heat stress, especially when it is prolonged and intense during flowering and early fruit development, is a major concern, as high night temperatures can lead to higher rates of respiration and lower yields (He, 2026; Giacalone *et al*., 2026). Thus, climate assessments need to account for crop developmental stages, consecutive dry days, heavy rainfall and locally validated temperature thresholds (Roussos, 2024). Vapour pressure deficit (VPD) also affects plant water relations by increasing atmospheric water demand, which can lead to stomatal closure, decreased photosynthesis and reproductive stress even when soil moisture is sufficient (Novick *et al*., 2024; Rashid *et al*., 2026). As a result, combining temperature, humidity, soil moisture and physiological measurements is necessary for accurate assessment of orchard vulnerability and effective adaptation strategies (Carella *et al*., 2023).

Climate suitability models provide an indication on how tropical fruit-growing areas might shift by taking into account temperature, rainfall, soil conditions and environmental limitation factors. Research on avocado, cashew and coffee highlights the need to consider both climatic and edaphic conditions when assessing future suitability for production (Gruter *et al*., 2022). Yet, projected suitability does not necessarily lead to productivity or profitability, as cultivar differences, groundwater availability, extreme events and management styles, among other factors, may influence realized performance (Parker *et al*., 2020). In a similar vein, the identification of adaptation options for banana production in Latin America and the Caribbean is largely influenced by social conditions, availability of infrastructure and land suitable for cultivation (Varma and Bebber, 2019; Varma *et al*., 2025). Hence, climate adaptation strategies should combine biophysical modeling with ground-truthing of economic viability, conservation of biodiversity and equitable distribution of resources to enhance sustainable tropical fruit production (Karunakaran *et al*., 2026).

**Photosynthesis, Heat injury and Carbon balance**

Heat stress is a major factor affecting tropical fruit crops, as it interferes with photosynthesis, cellular metabolism and carbon allocation. High leaf and fruit temperatures, especially under high light intensity, can exceed ambient air temperature and can lead to the damage of photosynthetic membranes, enzymes and protein complexes, which in turn can increase photoinhibition and oxidative stress (Bassi and Dall'Osto, 2021). Canopy temperature, chlorophyll fluorescence and gas exchange measurements are important indicators of physiological stress (Samat *et al*., 2025; Saglam *et al*., 2019). In addition, drought is an important stress that inhibits photosynthesis by closing stomata and restricting carbon dioxide uptake, while extended stress also induces biochemical impairment and reduced assimilate production (Wu *et al*., 2026). Elevated temperatures may

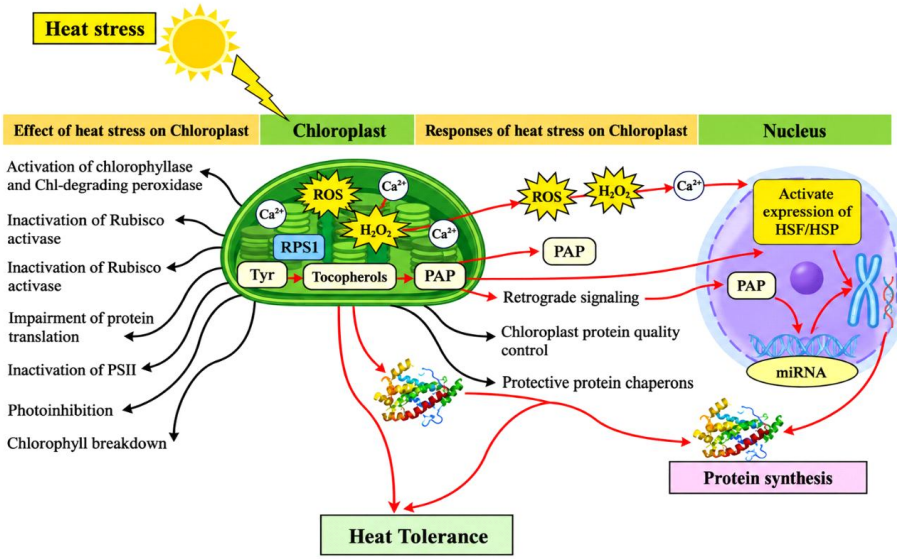



**Fig. 1 :** Chloroplast Responses and Protective Mechanisms under Heat stress. Source- Hu *et al.* (2020).

enhance respiratory carbon consumption, which increases competition among developing fruits, roots and shoots. Thus, recovery evaluation should be based on photosynthetic restoration, fruit retention and subsequent growth and not only on leaf appearance (Cosmulescu, 2026; Sato *et al.*, 2024).

Increased atmospheric $CO_2$ may promote photosynthesis and water use efficiency, but its effect varies with temperature, nutrient availability, developmental stage, and environmental conditions. Studies with mango cv Alphonso also reveal interaction between carbon dioxide enrichment and temperature on vegetative growth and flowering, highlighting the need for validation at the field level (Shivashankara *et al.*, 2024). Tropical fruit species also vary in their photosynthetic and water use systems. While pineapple use of crassulacean acid metabolism (CAM) allows a high level of nighttime carbon dioxide absorption coupled with effective water conservation, mango, banana, papaya, and guava are largely $C_3$ plants. But heat and drought responses differ as a result of variation in canopy architecture, stomatal regulation, and physiological adaptation. These crop-specific processes need to be elucidated to enhance carbon fixation, reproductive stability and stress recovery as the climate continues to change (Wang *et al.*, 2026).

**Water relations and Cellular Stress responses**

Water dynamics in tropical fruit crops rely on a coordinated system involving hydraulic pipelines between soil, roots, stems, and leaves. Soil water supply is lower during drought, restricting root uptake and creating hydroelectric resistance, while the atmospheric demand for water escalates combined water loss. Stomatal closure reduces transpiration yet *al*so lowers photosynthesis and carbon uptake (Affortit *et al.*, 2024). Drought responses are regulated by abscisic acid, calcium signalling and reactive oxygen species (ROS) whereas antioxidant enzymes and protective metabolites ameliorate cellular injury. Nevertheless, higher antioxidant activity is not always related to stress tolerance where physiological performance, membrane stability and recovery (ali *et al.*, 2025). Cellular hydration is supported by osmotic adjustment via compatible solutes and structural changes. Sweet leaf pectin properties and thickness of epidermal cells in drought resistant leaf of diploid and autotetraploid mango genotypes are strongly associated with drought adaptation, yet their practical importance calls for orchard-level research (Fonolla *et al.*, 2023).

Combined environmental stresses add on top of the existing challenges because the plant's physiological response to drought requires water conservation, while the response to heat requires evaporative cooling. These two plant physiological demands that go against each other can combine to further damage cells, reduce photosynthesis and reproductive output. Research on papaya genotypes has revealed differences in the capacity to withstand water deficit, heat shock, and combined stress, with heat shock transcription factor expression associated with encouraging responses to wild genetic material (Jain *et al.*, 2025; Bautista-Bautista *et al.*, 2025). But high tolerance in the lab may not translate into consistent field performance. Root architecture, canopy spread, hydraulic efficiency, osmotic regulation and antioxidant protection should all be accounted for in effective selection as well as flowering, fruit retention and yield. Repeated stress exposure, recovery assessment and multi-environment trials are required to identify genuinely resilient genotypes. Physiological characterization combined with genetic improvement and orchard management may enhance plant adaptation to drought, high temperatures, and other interacting environmental stresses (Cosmulescu, 2026).

**Flowering, Pollination and Fruit set**

Reproductive development in tropical fruit crops is highly sensitive to climatic variations, particularly during

flower initiation, pollen development, fertilization and early fruit growth (Banjare *et al*., 2023). In mango, reproductive processes are shaped by factors including genotype, shoot maturity, temperature and water availability, thus reproductive response is highly environment dependent (Cavalcante, 2022). Increased temperatures can affect flavour quality without affecting vegetative health (Clonan *et al*., 2021). Notably, these studies have found considerable genotypic variation in mango pollen germination and pollen tube growth across varying temperatures (Huang *et al*., 2023). But laboratory temperature may not be ideal to represent orchard temperature as other environmental inputs influence fertilisation such as humidity, stigma receptivity along with exposure time. Thus, reproductive breeding should integrate traditional laboratory screening with field evaluation of overlap of flowering, pollen performance and fruit retention to provide data of cool resilient cultivars (Lillo *et al*., 2024; Mehmood *et al*., 2025).

Metabolomic studies have revealed more information about the biochemical pathways involved in reproductive heat tolerance. Differences in temperature-related metabolites were observed in pollen responses among mango cultivars Renong No.1 and Jinhuang, indicating that reproductive resilience is a consequence of coordinated biochemical regulation rather than individual protective compounds (Liu *et al*., 2024). But causal mechanisms need to be functionally validated and tested across a range of genetic backgrounds (Rane *et al*., 2026). In addition, successful pollination is also influenced by environmental factors and pollinator activity, which can be hampered by excessive rainfall, strong winds and extreme temperatures. Using appropriate flowering cultivars, improving pollinator habitats and using pollinator-friendly pesticide practices can enhance reproductive stability. In addition, flower abundance, pollinator visits, disease incidence and early fruit abortion are also used as indicators to differentiate the impact of climatic stress from other factors contributing to poor fruit set. Combining reproductive physiology, pollination management and molecular breeding can enhance fruit yield resilience to climate change (Marcacci *et al*., 2023).

## Fruit Growth, Quality and Postharvest consequences

Tropical crops require cell division, assimilate supply, and water availability for early fruit development. A reduction in fruit retention, cell expansion and final fruit size which is induced by adverse environmental conditions, ultimately impacts marketable yield (Panigrahi *et al*., 2026). Sunburn and tissue damage might result from excessive solar radiation and temperatures, notably in exposed fruits. Prevention of these effects may be achieved by healthy canopy cover, efficient irrigation and reflective materials. On the other hand, shading might limit photosynthesis and fruit colour development. Therefore, effective orchard management and productivity improvement require monitoring fruit temperature, crop load, fruit growth and retention (Bellitti *et al*., 2025).

Climate variability in fruit quality can influence sugar accumulation, acidity, pigmentation, aroma, texture and ripening behaviour. Water stress can increase total soluble solids power through water loss, and heightened temperatures can hasten development and alter nutritional content (Bacelar *et al*., 2024). Postharvest quality and storage performance may be decreased by preharvest stress, uneven irrigation and nutritional deficiencies nutritional imbalance. Sufficient shade, careful handling, and appropriate crop-specific cooling practices reduce degradation, even while cooling sensitivity differs between tropical fruits. Therefore, pre and postharvest management are integral to maintaining fruit quality, lessening losses, and boosting marketable yield and growers profitability throughout the changing climate (Korumilli *et al*., 2026).

## Crop Specific priorities and Multiple hazards

The production of banana is extremely sensitive to the condition of irrigation, especially to water deficit, drought, strong winds and cyclical water availability which influence leaf development, bunch formation and yield stability. Adaptation strategies like efficient irrigation, drainage and wind protection for healthy planting materials through genetic improvement (Thingnam *et al*., 2023). Mango and guava can survive on a supply of water that is temporarily limited, but the success of flowering, fruit development and productivity are especially susceptible to climatic variations where cultivar selection then alone is not robust enough to preserve fruit quality and equip productive consistency (Abdel-Sattar *et al*., 2024).

Papaya and pineapple exhibit distinct responses to environmental stress. Papaya sustains continuous production which emphasises its sensitivity to water stress, compared to the PAW conserved by CAM in pineapple, though both are sensitive at the time of root development and sowing (Santos *et al*., 2021). Flooding, salinity and storms further threaten tropical fruit production by restricting root oxygen supply, disrupting nutrient uptake and causing physical damage. Beneficial adaptation strategies such as more effective irrigation management, enhanced drainage, suitable planting

schedules and multi-hazard assessment are crucial for improving the resilience of crops against climate change and maintain their sustainable productivity (Ananth *et al*., 2025).

**Irrigation and Sustainable water allocation**

Tropical fruit orchard irrigation management requires the synthesis of data from weather-based evapotranspiration estimates, monitoring of soil moisture, and plant physiological measurements. Due to the age of the orchard, canopy development, soil characteristics and irrigation techniques crop specific schedules must be recommended (da Silva *et al*., 2024). Water productivity may be increased by means of deficit irrigation with partial root-zone drying, by limiting excessive water use but at acceptable physiological performance. However, this depends on the species of crop, its developmental stage and environmental conditions. In papaya, climate studies have highlighted the need to assess gas exchange, yield, and water productivity prior to their use (Mahouachi and Marrero-Diaz, 2022).

Irrigation management must be sensitive to developmental stages, with attention to timing of plant establishment, flowering, fruit set, and rapid fruit expansion. Under water supplemented conditions, decisions on where to allocate will have to take into account crop stage, tree condition and water stored in soil for the rest of the season keeping in mind also avoiding below free nor re saturation (Nel *et al*., 2024). In terms of marketable yield, fruit quality long term resource sustainability must be considered along with water efficiency impact on overall water usage. An irrigation efficiency upgrade has never led to reduced overall water usage as water savings are going to be used towards the expansion of their production. Research on avocado' helps create the importance of integrated Part of irrigation practice and soil management and wider ecosystem dynamics, thus global and regional monitoring of groundwater availability, water-use efficiency, and potential competing demands is vital for informing climate resilient systems for tropical fruit areas (Lilli *et al*., 2024).

**Soil management, Nutrition and Root health**

Healthy soil improving conditions of water infiltration, drainage, root development and nutrient availability helps adapt to climate change. Physical blockage due to soil compaction limits root development and increases runoff, however appropriately applied organic amendments can improve soil structure and water holding capacity (Visconti *et al*., 2024). Mulching can also lower evaporation, ameliorate soil temperatures and out-compete weed growth, although, if used improperly, it

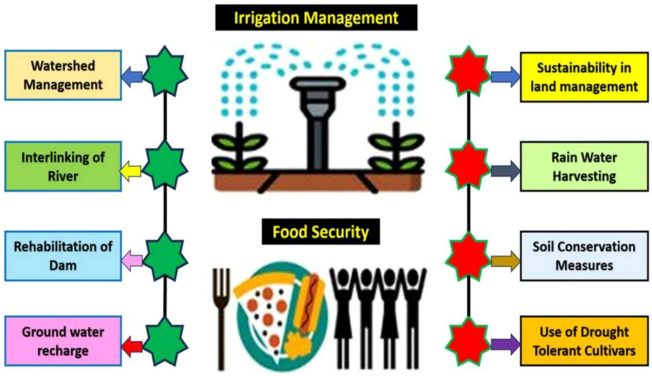



**Fig. 2 :** Effective water management strategies to support irrigation and food security. Source- Das and Mishra (2025)

can increase moisture around the base of the trunk or interfere with irrigation. Living ground covers will mitigate erosion but water stress in periods of dry periods could also affect them. Thus, soil management practices should take into account local rainfall, soil characteristics, amendment quality and orchard needs to increase resource-use efficiency and climate resilience (Giorgi *et al*., 2026).

Balanced nutrient management is one of the most important issues for tropical fruit productivity under environmental stresses. Restricting the transport and absorption of nutrients by drought, while waterlogging leads to a decrease in root function and nutrient acquisition. Excessive nitrogen application may stimulate vegetative growth and increase water demand, making soil testing, leaf analysis and precision fertigation important for efficient nutrient management (Thirupathaiah *et al*., 2025). Calcium, potassium, biochar, microbial inoculants and biostimulants may help plant performance; how well they work depends on soil fertility, formulations, and hard environmental conditions. Because of this, nutritional supplementation should be aligned to proven deficiencies and ground-truthing and economic analysis underpin recommendations. It is the foundation of climate resilient tropical fruit production to integrate balanced fertilisation with improved drainage, soil physical and root health (Zulfiqar *et al*., 2024).

**Canopy architecture and Microclimate protection**

Canopy management is an essential component of climate adaptation by influencing light interception, air flow, crop load, and exposure of plants to environmental stresses. The right pruning improves the canopy structure and makes the orchard more accessible, whereas excessive foliage trimming tends to lead to sunburn and heat injury. In theory, orchard management is facilitated by very close spacing between plants but it can result in greater competition for water and nutrients (Jodie *et al*.,

2025). The impact of a protective net on temperature, radiation and wind damage will depend on its material properties, installation and seasonal conditions. Winter shading nets for young Hass avocado trees minimized frost damage without markedly changing the min air temperature (Lahak *et al*., 2024). Canopy architecture and protective structures need to be assessed for photosynthesis, fruit quality, yield and economies of scale.

Evaporative canopy cooling is an alternative approach to mitigating heat stress as it reduces canopy temperature and improves plant water status at the same time. A study of sprinkler-based cooling methods used in avocado orchards shows that they have positive effects, subject to their water use, irrigation design, operating pressure and water quality (Dag *et al*., 2026). Drainage issues and salt build-up on leaves may be caused by over-application, and this should be carefully managed. Moreover, plant physical damage can further be reduced, the microclimate can be improved and ecological functions can be aided through windbreaks and diversified plantings. The result is greater competition and less fruit yield caused by incorrect spacing and excessive shade. Which is why the addition of canopy cooling, porous windbreaks, agroforestry arrangement, and orchard infrastructure management may enhance recovery of tropical fruit production from extreme heat, strong winds and storms (Bhandari *et al*., 2025).

**Biological protection and Decision support**

Climate variability affects pest development, disease incidence and host susceptibility, with variations dependent on temperature and moisture. Integrated pest management (IPM) should rely on sound plant material, orchard sanitation, up-to-date monitoring, and locally relevant forecasting systems (Kriticos *et al*., 2024). Conservation of biodiversity through the use of appropriate groundcovers, flowering resources and proper habitat management strategies can also foster pollinators and natural enemies. However, these practices cannot be implemented without taking into account water competition, alternative pest hosts and considerations for orchard needs. They also need to be evaluated by improvements pollination, lower pest damage and superior performance (Howard *et al*., 2024).

Digital technologies such as soil moisture sensors, weather stations and thermal imaging can contribute to climate smart orchard management drivers, by enabling early stress detection and enabling rapid response (Bonet *et al*., 2026). Climate advisory services should turn weather forecasts into specific recommendations for crops in specific areas with regard to irrigation, pesticide use, fruit protection and harvests. To make informed decisions, reliable data, local calibration and a very strong economic justification are essential. The integration of digital monitoring, farmer participation and extension support can promote adaptive management, decrease climate-related losses and support sustainable tropical fruit production (Baylis *et al*., 2025).

**Genetic resources and Conventional improvement**

Raising climate resilience in tropical fruit crops through breeding means protecting the genetic diversity available in landraces, locally grown cultivars, and wild relatives. Accurate genetic identification, analysis and evaluation of plant genetic resources in the face of relevant environmental stresses are key for effective germplasm preservation (Roy *et al*., 2025). Breeding should aim to keep the desirable fruit quality and marketability, while placing emphasis on stable yield, drought tolerance, stress recovery and reproductive heat resilience (Prado *et al*., 2025). Rootstock selection also has the potential to enhance water acquisition and ion exclusion, reduce vigour, and for adaptation to local soils. However, rootstock performance is a conjunction of scion compatibility and environmental conditions, needing evaluation of yield, fruit quality and disease resistance across multiple seasons (Modica *et al*., 2024).

Conventional breeding is still indispensable for breeding climate resilient tropical fruit cultivars in view of the advances in molecular technologies. The long juvenile periods, expansive heterozygosity and limited cross-compatibility that hinder genetic improvement of perennials fruit crops, together with the issues related to sterility and polyploidy in banana (Arshad *et al*., 2025). Consequently, the breeding efficiency can be increased by mixing parent assessments with controlled hybridization, clonal selection and systematic germplasm screening. While polyploid genotypes offer unique stress tolerance characteristics, there is need to evaluate the trade-offs of reducing fertility, vegetative growth, and fruit quality before claiming benefits (Gora *et al*., 2022; Ramakrishnan *et al*., 2025). Combining conventional selection with molecular approaches and multi-environment field testing can accelerate the development of productive, climate-resilient cultivars while retaining genetic diversity that is important to industry (Arshad *et al*., 2025).

**Genomics, Multiomics and Gene editing**

Genomic resources illuminate genetic diversity and complex traits that are not possible through conventional phenotyping alone. 224 mango accessions from 22 countries whole-genome re-sequenced and population

structure and genetic associations with key agronomic traits were identified for parental selection and candidate gene identification (Ma *et al*., 2024). These rules apply to genomic selection which predicts complex trait breeding values from an abundance of genome-wide markers (Liang *et al*., 2024). Studies in mango have indicated its robustness for fruit and growth traits, though predictions accuracy is affected by population structure, the other variability, and validation methods (Munyengwa *et al*., 2025). Consequently, genomic predictions for climate-resilient fruit breeding require independently testing across different genetic backgrounds, seasons and locations.

Multi-omics approaches combine genomics, transcriptomics, proteomics, metabolomics and physiological measurements to delineate the molecular bases of stress adaptation processes. Time-course studies throughout stress and recovery periods can separate defence responses from damage caused by stress, however (Hou *et al*., 2024). Finally numerical and functional confirmation bolster the detection of breeding targets of practical use (Hou *et al*., 2024). Gene editing technologies provide an opportunity to manipulate confident regulatory pathways, but retain cultivar performance characteristics. However, complex stress tolerance involves multiple interacting genes, and challenges related to transformation, regeneration, heterozygosity and ploidy remain significant in tropical fruit crops. Consequently, edited plants require molecular characterisation, physiological assessment and multi-environment field validation. Regulation, propagation success, consumer acceptance and economic affordability are to be factored in before any commercialization (Chavhan *et al*., 2025).

**Research design, Economics and implementation**

Future research on climate-resistant tropical fruit crops, should prioritize realistic experimental conditions using drought, heat, combined stresses and recovery periods. Soil properties, crop load and stress duration standardisation improve research reliability (Moshelion *et al*., 2024). Assaying physiological parameters, including gas exchange, chlorophyll fluorescence, and water potential, with fruit quality, marketable yield, and reproductive performance. Perennial crops should be monitored for long-term effects, as stress may carry over across successive seasons. The rational selection of developmental escape mechanisms over true stress tolerance can ultimately increase varietal selection and the efficiency and speed of cultivar breeding (Yao *et al*., 2024).

Economic feasibility and collaboration with institutions

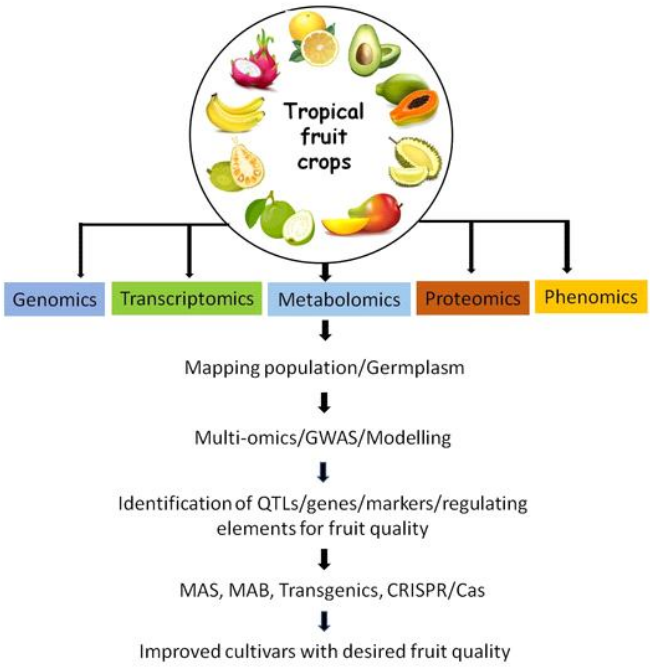



**Fig. 3 :** Multi-Omics Approaches for Genetic improvement of Tropical Fruit crops. Source- Mathiazhagan *et al*. (2021).

are required for climate adaptation activities. Smallholder adoption of technology might be enhanced by measuring return on investment, labour, water needs and profitability (Comincioli *et al*., 2025). Collaboration among breeding institutions, nurseries and extension agencies can contribute to the development of cultivar and sustainable orchard management (Babaeian *et al*., 2023). Adaptation also needs to address the reduction of greenhouse gas emissions and conserve biodiversity (Breure *et al*., 2024). Addressing immediate priorities, such as improved irrigation, drainage and postharvest handling. In the long-term, a focus should be on rootstock improvement, genomic selection and gene editing. It is important to evaluate yield stability, efficiency of use of resources and farmer profitability to promote sustainable tropical fruit production (Bounajra *et al*., 2024).

## Conclusion

Climatic change reduces tropical fruit production by affecting photosynthesis, water relations, flowering, fruit development and quality. For an effective adaption the crop-specific strategy is required and needs integration of physiological knowledge, sustainable orchard management and genetic improvement research more than mango, papaya, avocado and banana contribute to an understanding of a wide range of environmental stress responses. Future priorities should focus on reproductive resilience, stress recovery, efficient resource use and steady, marketable yields. Irrigation improvement, climate

resilient varieties, overcoming genetic erosion and postharvest management have the potential to bring about sustainable production practices. But success relies on economic viability, efficient water governance, institutional collaboration and farmer participation. In the end, integrated adaptation strategies can preserve fruit quality, environmental sustainability and the livelihood of farmers.

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