The Heat stress: How Genetic Advances Are Helping Crops Beat the Heat

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Abstract

High-temperature stress (HS) has become an alarming threat to the global food system. As our planet heats up, our crops face a growing challenge. With climate change causing more frequent and intense heatwaves, farmers are struggling to keep up. But there's good news: genetic advances are coming to the rescue. Scientists are now developing crops that can withstand higher temperatures, ensuring that we can continue to feed a growing global population even as the climate changes. Here we have discussed how these technologies are making a difference.

Introduction

Temperature is a primary factor affecting the rate of plant development. Warmer temperatures expected with climate change and the potential for more extreme temperature events will impact plant productivity. High-temperature stress (HS) has become an alarming threat to the global food system. Heat stress in plants occurs when temperatures exceed optimal growth conditions, leading to physiological and biochemical disruptions (Challinor *et al*. 2014). Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development. However, heat stress is a complex function of intensity (temperature in degrees), duration, and rate of increase in temperature. The extent to which it occurs in specific climatic zones depends on the probability and period of high temperatures occurring during the day and/or the night. Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperatures. However, while some researchers believe that night temperatures are major limiting factors others have argued that day and night temperatures do not affect the plant independently and that the diurnal mean temperature is a better predictor of plant response to high temperature with day temperature having a secondary role.

Climate change has affected the growth and development of major crops in the world and posed a great threat to agricultural production (Peng *et al*. 2014). Climate change has increased the frequency of heat damage events that affect crop yields (Lobell *et al*. 2011). The global average temperature is expected to rise by 2-3 °C in the next 30–50 years (Hatfield *et al*. 2015). For every 1 °C increase in the global average temperature, the average yield loss of major food crops may be as high as 7.4% (Zhao *et al*. 2017). In extremely high-temperature environments, HS can interfere with the normal growth, development, and metabolism of plants, and even lead to plant death in severe cases (Mittler *et al*. 2012).

Causes of heat stress in plants

- **High Temperatures**: Prolonged exposure to temperatures above the plant's tolerance threshold.
- **Low Soil Moisture**: Increased evaporation and transpiration can exacerbate heat stress.
- **Humidity Levels**: Low humidity can lead to excessive water loss through transpiration.

Symptoms

- **Wilting**: Leaves may droop due to loss of turgor pressure.
- **Leaf Scorch**: Margins and tips of leaves may turn brown and dry out.
- **Stunted Growth**: Reduced cell division and elongation can lead to smaller plants.
- **Abscission**: Premature shedding of leaves and flowers to conserve resources.

The Heat is on: Why Temperature Matters for Crops

Imagine working outside on a hot summer day. We'd likely find it hard to focus and get tired quickly. Crops, too, have their limits when it comes to heat. High temperatures can stress plants, affecting their growth, development, and yield. For instance, when plants experience heat stress during crucial stages like flowering, they may produce fewer seeds or have poor-quality fruit. The yield and quality of crops are affected by heat stress which in-turn effects the market. This can lead to reduced harvests and, ultimately, food shortages.

Genetics to the Rescue: how scientists are changing the game

High temperature is a major abiotic stress that limits the growth and production of plants. Therefore, the plant response to heat stress (HS) has been a focus of research. The good news is that scientists are using genetics to help crops better handle the heat. Identifying heat-tolerant genes, obtaining breeding intermediate materials, and cultivating heat-tolerant varieties are effective measures for crops to cope with Heat Stress. Here's a look at some of the key strategies:

1. Discovering Heat-Resilient Genes

Researchers start by finding plants that naturally handle heat well. By studying these "super plants," scientists identify specific genes that contribute to heat tolerance. For example, certain genes help plants produce proteins that protect them from heat damage. By understanding these genes, researchers can use them to breed new plant varieties that are more resilient to high temperatures.

2. Genetic Modification

One powerful tool in this effort is genetic modification. Scientists can insert genes from heat-tolerant plants into other crops, giving them the ability to withstand higher temperatures. For example, by introducing genes that boost a plant's heat-shock proteins—special proteins that help the plant cope with heat stress—scientists can create crop varieties that are more heat-resistant.

3. CRISPR-Cas9: The Gene Editing Revolution

CRISPR-Cas9 is a ground breaking technology that allows scientists to make precise changes to an organism's DNA. It's like having a highly accurate editing tool for genetic material. With CRISPR, researchers can directly alter the genes related to heat tolerance in crops. This can involve turning up the expression of beneficial genes or turning down the expression of those that make plants more vulnerable to heat.

4. Marker-Assisted Selection

Another technique is marker-assisted selection, which speeds up the breeding process. By identifying genetic markers—specific DNA sequences associated with heat tolerance—scientists can more quickly select and breed plants with the desired traits. This method combines traditional breeding with modern genetic insights, making it easier to develop new, heat-resistant varieties.

Success Stories: Heat-Resistant Crops

These genetic advances are not just theoretical—they're already making an impact. Here are some success stories:

1. Heat-Tolerant Rice: Rice is a staple food for billions of people, but it's also highly sensitive to heat. Researchers have developed rice varieties that can withstand higher temperatures, thanks to genetic modifications that enhance their heat tolerance. These varieties are showing promising results in field trials, with improved yields even under heat stress. The Indian Institute of Rice Research has developed, DRR Dhan 47 and DRR Dhan 52, which are high yielding varieties having heat tolerance. International Rice Research Institute- IRRI, in collaboration with Bangladesh Rice Research Institute- BRRI, has developed heat-tolerant rice varieties like IR18C IR1002, IR18C IR1004 and IR18C IR1005 to address the severe impact of rising temperatures on rice production in Bangladesh.

2. Drought and Heat-Resistant Wheat: Wheat is another crucial crop that benefits from genetic advances. Scientists have developed wheat varieties that can handle both heat and drought conditions. These new varieties use genes that help the plant manage water stress and maintain productivity, even in challenging climates. Examples for Drought and heat-resistant wheat varieties - DBW187, DBW222 and NW 1014.

3. Resilient Tomatoes: Tomatoes are a popular fruit, but they can suffer in extreme heat. Genetic modifications have led to the creation of tomato plants that are more resistant to high temperatures. These plants maintain better fruit quality and yield during hot weather, making them a valuable option for farmers facing hotter growing conditions.

The Benefits of Heat-Resistant Crops

Heat-resistant crops offer several key benefits as mentioned below.

1. Increased Food Security

By developing crops that can withstand higher temperatures, we're helping to ensure a stable food supply. This is crucial as climate change continues to affect weather patterns and growing conditions.

2. Improved Farmer Livelihoods

Farmers who grow heat-resistant crops can expect more reliable harvests, even during hot spells.

This translates to better income and reduced financial risk, which is particularly important in regions prone to heat stress.

3. Sustainable Agriculture

Heat-resistant crops can also support more sustainable farming practices. By reducing the need for additional water and inputs, these crops help conserve resources and minimize environmental impacts.

Looking Ahead: Challenges and Opportunities

While genetic advances offer great promise, there are still challenges to address:

1. Accessibility

Ensuring that heat-resistant crops are available and affordable for all farmers is crucial. Efforts must be made to distribute these varieties widely and support farmers in adopting new technologies.

2. Ongoing Research

Climate change is an ever-evolving challenge, so ongoing research is essential. Scientists need to continue developing crops that can adapt to new and unpredictable conditions.

3. Environmental Impact

Introducing new crop varieties into the environment requires careful consideration. Monitoring their impact on local ecosystems and biodiversity is important to ensure that they don't have unintended consequences.

Conclusion: A Brighter Future for Farming

Genetic advances are transforming agriculture, making it possible for crops to thrive in increasingly hot conditions. These innovations not only help secure food supplies but also support farmers and promote sustainable practices. As science continues to push the boundaries, we can look forward to a future where our crops are better equipped to handle the heat, ensuring that we can continue to feed the world, no matter what challenges come our way.

By harnessing the power of genetics, we're taking a crucial step towards adapting our food systems to a changing climate. With continued research and collaboration, we can build a more resilient agricultural future, one where heat stress is no longer a barrier to growing the crops we rely on every day.

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