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Editorial

The Impact of Temperature on Cotton Seed Germination

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Abstract

Cotton (*Gossypium hirsutum* L.) is primarily cultivated across the globe for its natural fiber, which is a vital raw material in the textile industry. One of the most critical early stages in the cotton growth cycle is seed germination, which significantly influences crop establishment, seedling vigor, and final yield. Among the various environmental factors affecting this process, temperature plays a fundamental role. It regulates essential physiological and biochemical mechanisms such as water absorption, hormonal activity, and enzyme function. This paper reviews and synthesizes findings from multiple international studies examining the effects of temperature on cotton seed germination. It highlights the optimum temperature ranges, the plant's physiological responses to thermal stress, and the implications of fluctuating temperatures under climate change scenarios. Research indicates that cotton seeds generally germinate best within a temperature range of 25 ℃ to 35 ℃. Germination is notably hindered at temperatures below 15 ℃ and above 40 ℃. At lower temperatures, enzymatic activities responsible for energy production and starch breakdown are suppressed, slowing down the germination rate. Conversely, exposure to higher temperatures can lead to oxidative damage, protein denaturation, and cellular injury, ultimately compromising seed viability. Understanding these temperature thresholds is essential for improving sowing strategies, especially in regions experiencing increasing climate variability.

Keywords

Temperature, Cotton Seed Germination, Physiological Responses, Climate Change

1. Introduction

Cotton plays a major role in the feed, oil, and textile industries, making it an essential crop for the world economy. The earliest and most important stage of the cotton life cycle, seed germination determines the success of crop establishment and production. Temperature is a crucial environmental component that affects germination since it controls the seed's enzyme activity, water absorption, and hormonal balance. Given that climate change is increasing temperature unpredictability, it is critical to comprehend how temperature affects cotton seed germination in order to develop measures to lessen its negative consequences. Global research on the topic is compiled in this review, which offers a thorough examination of how temperature affects cotton seed germination.

Temperature is one of the most critical environmental factors influencing seed germination, especially in temperature-sensitive crops like cotton (*Gossypium hirsutum* L.). Germination is a complex physiological process governed by enzymatic activity, water uptake, and metabolic function, all of which are heavily temperature-dependent [16]. Understanding the relationship between temperature and cotton germination is essential for optimizing sowing time and improving crop establishment, particularly in regions with fluctuating or marginal temperatures.

Cotton seeds require a specific thermal range to achieve

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successful and uniform germination. According to the literature, the optimal temperature for cotton seed germination is typically between 28 ℃ and 30 ℃, with a base temperature of 15 ℃ and an upper threshold of 40 ℃ [10]. Within the optimal range, enzymatic and cellular activities proceed efficiently, resulting in higher germination percentages, faster emergence, and more vigorous seedlings. For example, [15] found that cotton germination peaked at 30 ℃, with over 90% emergence within five days, while germination declined sharply below 20 ℃ and above 35 ℃.

Low temperatures delay the initiation of germination and increase the risk of seed rot and seedling diseases. Seedling emergence is significantly reduced at temperatures below 16 ℃ due to restricted metabolic activity and slower cell division [21]. Moreover, extended exposure to suboptimal temperatures can result in non-uniform stands and poor root development, particularly in cold-prone soils or early planting scenarios. A study by [18] confirmed that cotton varieties exposed to 15 ℃ germinated slowly and unevenly, with only 35–40% success rates.

Conversely, high temperatures especially those exceeding 35 ℃ can also inhibit germination by denaturing proteins and disrupting membrane integrity. Excessive heat accelerates water uptake too rapidly, causing imbibitional damage, particularly in dry or poorly hydrated seeds [14]. In hot climates or under late planting conditions, seedling mortality often increases due to such stress, despite adequate soil moisture.

To mitigate temperature-related germination issues, several studies have examined seed priming and coating techniques [17]. Study demonstrated that primed cotton seeds showed improved germination at suboptimal temperatures (18–20 ℃) compared to untreated seeds [22]. Additionally, breeding efforts have focused on developing cotton cultivars with improved low- and high-temperature germination tolerances, with promising results under controlled environments [20].

Climate change has further intensified interest in this topic. Rising global temperatures and erratic weather patterns are expected to affect cotton sowing windows and increase the frequency of temperature extremes during germination. Researchers advocate for adaptive strategies including early warning systems, precision agriculture, and selection of thermo-tolerant genotypes [19].

In conclusion, the relationship between temperature and cotton germination is both direct and profound. An optimal thermal range ensures uniform and vigorous seedling emergence, while deviations in either direction significantly impair crop establishment. Future research should focus on improving thermal stress resilience through breeding, seed enhancement technologies, and adaptive agronomic practices.

2. Optimal Temperature Ranges for Cotton Seed Germination

According to [1], cotton seeds have a limited ideal temperature range for germination, usually falling between 25 ℃ and 35 ℃. Temperatures below 15 ℃ or above 40 ℃ might significantly hinder germination, according to studies. For instance, extreme heat above 38 ℃ caused seed dormancy and decreased seedling vigor, while [2] reported a 50% decrease in germination rates at temperatures below 20 ℃. Similarly, [4] showed that temperatures outside of the ideal range decrease total germination percentages and delay radicle emergence. These results highlight how sensitive cotton seeds are to temperature changes and how crucial it is to maintain ideal planting temperatures.

3. Physiological and Biochemical Responses to Temperature Stress

The physiological and biochemical mechanisms necessary for seed germination are disrupted by temperature stress, regardless of whether it is cold or hot. The rate of starch hydrolysis and energy production is slowed down by cold temperatures, which also slow down enzyme activity [3]. As a result, seedling establishment is weak and germination is delayed. However, high temperatures can cause oxidative stress, denature proteins, and harm cellular structures, which inhibits germination and seedling growth [1]. Cotton seeds have developed coping strategies to handle temperature stress. For example, heat shock proteins (HSPs) and antioxidants build up and assist reduce the harm that high temperatures can do [5]. Similarly, cold stress triggers the production of cryoprotectants and Osmo protectants, which stabilize cellular structures and maintain metabolic functions [6]. However, these mechanisms are often insufficient under extreme temperature conditions, highlighting the need for further research into enhancing temperature resilience in cotton seeds.

4. Impact of Climate Change on Cotton Seed Germination

Temperature variability is predicted to worsen due to climate change, which will provide serious difficulties for cotton production [13]. Cotton seed germination and crop establishment are projected to be hampered by rising global temperatures and an increase in the frequency of extreme weather events like heatwaves and cold snaps [7]. Research has indicated that little variations from the ideal temperature range can have a substantial impact on germination rates and jeopardize the health of seedlings [8]. Temperature variations are already influencing crop yield in cotton-growing regions like China, India, and the southern United States. For example, a study by [9] in India found that higher nighttime temperatures during the planting season reduced germination rates by 30%. Similarly, research in the United States highlighted the adverse effects of early-season cold stress on cotton establishment [10]. These findings emphasize the urgent need for adaptive strategies to mitigate the impact of climate change on cotton seed germination.

5. Strategies to Mitigate Temperature Stress

Several strategies have been proposed to enhance cotton seed germination under suboptimal temperature conditions. These include:

1) Seed Priming: To enhance germination under temperature stress, seeds can be pre-treated with growth regulators or osmotic solutions [1]. For instance, it has been demonstrated that Osmo priming and hydropriming improve enzyme activity and water uptake, resulting in quicker and more consistent germination [11].
2) Breeding for Temperature Resilience: Conventional breeding and genetic engineering are promising methods for creating cotton types that can withstand both heat and cold. To increase temperature resilience, characteristics such increased HSP generation and higher antioxidant capacity can be addressed [5].
3) Agronomic Practices: Using mulch, modifying planting dates, and maximizing irrigation can all help reduce temperature stress. For example, germination rates can be increased by postponing planting in areas vulnerable to early-season cold stress [10].
4) Biotechnological Approaches: Advances in molecular biology, such as CRISPR/Cas9 gene editing, give new options to enhance temperature tolerance in cotton seeds [12].

Table 1. *Effects of Temperature on Germination.*

Temperature Range	Germination Effect
< 15 ℃ (Too low)	Poor or delayed germination; risk of seedling disease and decay
15–20 ℃ (Suboptimal	Slow and uneven germination; reduced seedling vigor
28–30 ℃ (Optimal	Fast and uniform germination; best seedling development
> 35 ℃ (Too high)	Reduced germination percentage; heat stress can damage seed enzymes

Table 2. *Germination Rate vs. Temperature (Hypothetical Data Example).*

Temperature (℃)	Germination Rate (%)	Time to Germinate (days)
15	30	12
20	60	8
25	85	5
30	95	4
35	70	3
40	40	3

6. Conclusion

As tables 1 and 2 shows Cotton seed germination is greatly influenced by temperature, with ideal values usually being between 25 ℃ and 35 ℃. Variations from this range, whether brought on by heat or cold stress, can lower overall crop establishment, delay seedling emergence, and severely diminish germination rates. While high temperatures result in oxidative stress, protein denaturation, and cellular damage, cold temperatures slow down enzyme activity and energy production. Even while cotton seeds have defense mechanisms like the buildup of antioxidants and heat shock proteins (HSPs), these are frequently insufficient in extremely hot or cold temperatures. These issues are made worse by climate change, since rising global temperatures and an increase in the frequency of extreme weather events pose a threat to global cotton output. Adaptive techniques including seed priming, breeding for temperature-resilient cultivars, and improving agronomic methods are crucial to resolving these problems. Novel approaches to improving cotton seed temperature tolerance include CRISPR/Cas9 gene editing and other technical developments. This review emphasizes how important it is to carry out more research on how cotton seeds react physiologically and biochemically to temperature stress and to come up with creative ways to lessen its effects. We can guarantee sustainable cotton production and protect the livelihoods of

millions of farmers worldwide by comprehending and resolving the impacts of temperature on cotton seed germination.

Abbreviations

CRISPR/Cas9	Clustered Regularly Interspaced Short Palindromic Repeats / CRISPR-associated Protein 9
HSPs	Heat Shock Proteins

Author Contributions

Tesfaye Worku is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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