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Optimization of Thermal Regime Parameters in Cotton Seed Drying

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ABSTRACT

The optimization of thermal regime parameters during cotton seed drying is a crucial factor affecting seed quality, germination rate, and technological efficiency. Improper temperature and air velocity can cause protein denaturation, oil degradation, and loss of viability. This research investigates the optimal parameters of heat regime—temperature, air humidity, and airflow speed—necessary to ensure both effective moisture removal and biological preservation of cotton seeds. Through experimental analysis and simulation, the study identifies temperature intervals of 40–45°C and air velocity of 2–3 m/s as optimal for maintaining high germination potential while achieving economic energy efficiency. The results contribute to the design of modern drying systems for cotton processing plants and can be applied to large-scale agricultural production and seed storage facilities in arid regions.

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Introduction. Cotton is one of the most important industrial crops cultivated in arid and semi-arid regions. Its seeds are not only essential for textile fiber production but also serve as a major source of edible oil and livestock feed. The preservation of seed quality during post-harvest processing, particularly during the drying stage, is a determining factor in ensuring both agricultural productivity and technological efficiency.

Drying represents one of the most energy-intensive operations in cotton processing. The primary goal is to reduce seed moisture to safe storage levels (typically 8–10%) without impairing physiological activity or germination potential. However, excessive temperature or uneven air distribution may lead to thermal damage, reducing viability and oil content.

Therefore, determining the optimal thermal regime—a combination of air temperature, humidity, velocity, and exposure time—is essential for balancing drying efficiency with seed safety. This study investigates these interdependent parameters, focusing on the development of a scientifically justified drying process that preserves biological properties and enhances energy utilization efficiency.

Methodology. The problem of optimizing thermal regimes in seed drying has practical and scientific importance in Uzbekistan and other cotton-producing countries. Harsh climatic conditions and outdated drying technologies often result in over-drying or uneven moisture distribution, leading to significant seed losses.

Economic Relevance: Energy-efficient drying reduces fuel consumption and operational costs.

Biological Relevance: Proper heat treatment maintains enzymatic activity and ensures high germination rates.

Technological Relevance: Optimal parameters improve equipment performance, uniform drying, and product quality.

In the context of global climate change and resource scarcity, improving drying technology aligns with the principles of sustainable agriculture and green engineering.

Methodology

This research employed both experimental and theoretical approaches to determine the optimal drying parameters for cotton seeds.

3.1 Experimental Setup

The experiments were conducted using a laboratory-scale drying unit equipped with adjustable temperature, airflow rate, and humidity controls. The setup included:

Heat blower (kalorifer type) for controlled hot air supply

Thermocouple sensors for real-time temperature monitoring

Anemometer to measure air velocity

Digital moisture analyzer for seed moisture content measurement

3.2 Materials

Cotton seeds of the Gossypium hirsutum L. variety commonly grown in the Sirdaryo region were used. The initial moisture content averaged 22–24%, and the target final moisture content was 8–10%.

3.3 Experimental Design

The experiment followed a factorial design involving:

Independent Variables: Air temperature (35°C, 40°C, 45°C, 50°C, 55°C), Air velocity (1.5, 2.0, 2.5, 3.0 m/s)

Dependent Variables: Drying time, final moisture content, seed germination rate, and energy consumption

Each drying condition was repeated three times for statistical validity. Germination tests were conducted according to ISTA (International Seed Testing Association) standards, assessing viability 5 and 10 days post-drying.

3.4 Theoretical Model

A heat and mass transfer model was applied to describe moisture diffusion within the seed matrix. The model assumes constant air properties and uses the following relation:

$$\frac{dM}{dt} = -k (M - M_e)$$

where:

– seed moisture content (%),

– equilibrium moisture content (%),

– drying rate constant, dependent on air temperature and velocity.

The Arrhenius equation was employed to determine the temperature dependence of the drying constant:

$$k = k_0 \exp\left(-\frac{E_a}{RT}\right)$$

where is the activation energy (kJ/mol), is the universal gas constant, and is the air temperature (K).

3.5 Data Analysis

Data were analyzed using regression analysis and variance testing (ANOVA) to identify statistically significant effects. Graphical models were constructed to visualize relationships between drying conditions and seed quality indicators.

Results and Discussion

4.1 Effect of Temperature on Seed Viability

The experiments demonstrated that temperatures above 50°C caused noticeable reductions in germination rate, indicating thermal injury. Seeds dried at 40–45°C maintained 95–97% viability, while those exposed to 55°C dropped to 70–75%.

This confirms that moderate heat ensures sufficient moisture removal while preserving enzymatic and cellular integrity.

4.2 Air Velocity and Uniformity

Air velocity played a major role in ensuring uniform drying. Optimal airflow (2.5–3.0 m/s) achieved even moisture distribution across the seed layer. Lower velocities resulted in prolonged drying and localized moisture pockets, increasing mold risk.

4.3 Drying Duration

At optimal conditions (T = 45°C, v = 2.5 m/s), drying time was reduced by 22% compared to conventional open-air methods, without sacrificing quality.

4.4 Energy Efficiency

Energy consumption was minimized under the same conditions, with thermal efficiency reaching 68–72%, demonstrating a favorable balance between drying speed and fuel usage.

4.5 Comparison with Conventional Systems

The kalorifer drying system showed superior performance compared to traditional sun-drying and high-temperature convective dryers. It allowed precise temperature regulation and reduced mechanical stress, preventing seed coat cracking.

Significance of the Study

This study is significant for several reasons:

Scientific Contribution: Provides experimental evidence and mathematical modeling of the optimal heat regime for cotton seed drying.

Practical Application: Offers parameters for designing energy-efficient dryers for seed processing plants.

Agronomic Importance: Ensures high germination and viability, improving crop yield and sustainability.

Environmental Relevance: Reduces energy waste and supports eco-friendly post-harvest processing.

Thus, the research bridges the gap between engineering optimization and biological preservation in agricultural technology.

Problems and Solutions

Problem effect proposed solution overheating during drying reduces viability, protein denaturation implement automatic temperature control systems uneven airflow distribution causes non-uniform drying optimize air duct design and install diffusers high energy consumption increases operational costs use recuperative heating and insulation lack of local data for optimization reduces reliability of parameters conduct regional calibration and empirical testing.

Innovations of the Research

Determination of Optimal Temperature Range (40–45°C) ensuring maximum viability.

Mathematical Modeling of drying kinetics for predictive control.

Use of Kalorifer-Type Heat Systems for stable temperature maintenance.

Integration of Energy Efficiency Metrics in seed drying evaluation.

Experimental Validation specific to Uzbekistan's climatic conditions.

These innovations contribute to both scientific theory and practical technology in seed processing.

Recommendations and Conclusion

Recommendations

Implement automated control systems to maintain stable temperature and airflow.

Incorporate energy recovery mechanisms such as air recirculation to reduce heat loss.

Train operators and engineers in seed-specific thermal handling principles.

Establish regional research centers for continuous monitoring and calibration.

Promote industrial adoption through policy incentives and pilot demonstrations.

Conclusion

The optimal heat regime for cotton seed drying was identified as temperature range 40–45°C and air velocity 2.5–3.0 m/s, achieving high germination rate (>95%), efficient energy utilization, and reduced drying time. These parameters represent a balance between drying kinetics and seed physiology.

The findings can be directly applied in industrial dryers and seed storage facilities across Uzbekistan and other cotton-growing regions. By adopting this optimized process, producers can achieve higher seed quality, energy savings, and long-term sustainability.

This research thus contributes to the modernization of the cotton processing industry and supports the transition toward eco-efficient agricultural technologies.

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