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Analyzing the Role of Fiber Composition in Drying Behavior: A Comparative and Predictive Approach

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Abstract

This research presents a comprehensive analysis of the drying behavior and thermal response of three distinct fabric types: 100% Cotton, 100% Polyester, and a Polyester blend (65/35), under meticulously controlled environmental conditions. The Polyester blend (65/35) consists of 65% Polyester and 35% Cotton, combining characteristics of both fibers. The investigation focuses on understanding how fiber composition impacts drying time, moisture retention, and thermal characteristics. Experimental trials were conducted using standardized protocols, with environmental parameters such as temperature and humidity precisely regulated and monitored through calibrated sensors. A full-factorial experimental design was implemented to examine drying performance across 48 conditions, considering temperature ranges from 12°C to 34°C and relative humidity from 30% to 75%. Each condition was tested in triplicate, resulting in 144 experimental samples. A Random Forest regression model was employed to analyze the influence of key variables on drying time, trained on 100 experimental data points and validated with 10-fold cross-validation, yielding a mean absolute error of less than 5%. The model further generated 500 synthetic data points to explore extended scenarios. Findings reveal that Polyester exhibited the fastest drying and lowest heat retention due to its hydrophobic properties, while Cotton retained the most moisture and heat, resulting in significantly longer drying times. The Polyester blend (65/35) demonstrated intermediate characteristics. Temperature emerged as the most significant factor, with each 1°C increase reducing drying time by approximately 1.83 minutes. Cotton dried 11.94 minutes slower than the blend, whereas Polyester was 12.70 minutes faster under identical conditions. This study highlights the integration of experimental methodology with machine learning to better understand fabric drying dynamics. The results are valuable for optimizing textile material selection and developing energy-efficient, intelligent drying systems in modern textile applications.

Keywords: Fabric drying, cotton, polyester, polyester blend, moisture retention, drying time

INTRODUCTION

The drying properties of fabrics play a vital role in their functionality, energy efficiency, and upkeep requirements. Among the most used textile fibers are cotton and polyester, each possessing unique moisture management characteristics. Cotton, a natural cellulose fiber primarily composed of $C_6H_{10}O_5$, is recognized for its high affinity for water, enabling it to absorb and retain substantial quantities of moisture. In contrast, polyester, a synthetic polymer derived from polyethylene terephthalate (PET), is hydrophobic and does not easily absorb water. The drying mechanism in fabrics involves the evaporation of moisture from the fabric's surface, along with the diffusion of water from within the fibers to the outer layer. Due to its significant moisture retention capabilities, cotton tends to have longer drying times as water penetrates deeply into its fiber structure. On the other hand, polyester's limited capacity for moisture

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absorption allows for faster evaporation of surface water, resulting in shorter drying periods. A thorough understanding of the drying behaviours of cotton and polyester is crucial for improving fabric efficiency and advancing sustainability efforts. This study aims to assess these three fibers in terms of drying time, moisture retention, and evaporation rates under controlled conditions. The results will offer valuable insights for optimizing drying techniques, reducing energy usage, and guiding better decisions in textile selection and maintenance. Several studies have contributed to advancements in fabric drying technologies

Dahekar R.M. et al. [1] introduced a compact, energy- efficient dryer designed for humid regions. The study confirms its portability and effectiveness, offering a practical alternative to traditional drying methods. Sathish Kumar B.S et al. [2] proposed a smart drying solution which saves time, ensures efficiency, and protects clothes from sudden weather changes. Ng A.B. et al. [3] introduced a method to optimize drying cycles by preventing over-drying. Using mathematical modeling and experiments, it determines the ideal endpoint based on equilibrium moisture content, improving energy efficiency and dryer performance. Wong Y.Q. et al. [4] proposed a portable and efficient indoor drying solution, optimizing airflow for faster drying and addressing space constraints in urban homes. Mehdi Rasti et al. [5] examined existing models for predicting moisture evaporation, highlighting accuracy limitations and the need for improved models to enhance dryer efficiency. Mhabina Rahim et al. [6] examined a heating-based system for drying clothes while they are hung. It explores various heating methods, energy efficiency, and effectiveness, highlighting its convenience and faster drying compared to traditional methods. Fateme Dinmohammadi et al. [7] explored how IoT sensors and machine learning optimize energy use, reducing waste and costs while enhancing sustainability and comfort Lyman Fourt et al. [8] explored how factors like fabric type, moisture level, airflow, and temperature influence drying speed, offering insights to enhance textile drying efficiency. V. Yadav et al. [9] analyzed energy use in tumble dryers, develops a simulation model validated by experiments, and proposes an empirical correlation for energy efficiency (SMER). Ahmed G. Hassabo et al.[10] this study shows that polyester–cotton blends, whether mixed with natural or synthetic fibers, can be successfully dyed using a wide range of natural and synthetic dyes, producing vibrant, durable colors with enhanced fastness. Sandra Flinčec Grgac et al. [11] has implemented Chitosan to cotton and polyester/cotton fabrics using an eco-friendly citric acid-based method, achieving durable antimicrobial properties even after repeated washes. Osman Babaarslan et al. [12] examined cotton/polyester yarns with rigid, core, and dual-core-spun types, finding that increasing polyester content enhanced strength and elongation while reducing yarn unevenness and imperfections. Strong interactions were noted between yarn type and blend ratio, especially for elongation and imperfections. Gaoyang Liu et al. [13] This study presents a spray- drying LBL self-assembly method to create superhydrophilic PET fabric with excellent antibacterial, antistatic, and breathable properties, making it ideal for durable and comfortable garments. Jiajia Liu et al. [14] This research improves polyester (PET) fabric by grafting hydrophilic sulfonic acid groups via click chemistry under UV irradiation, enhancing its moisture-wicking, fast-drying, antistatic, and soil-release properties. The treated fabric shows excellent performance in moisture management, quick- drying, and durability after multiple washes, making it ideal for sportswear. Taeil Yi et al. [15] presented a model that predicts drying behavior in air-vented dryers. It considers heat transfer, moisture diffusion, and airflow effects to improve drying efficiency. The study provides insights for optimizing dryer performance and energy use. NH Chamberlain et al.[16] explores the use of electronic systems to optimize drying efficiency. It examines how sensors and automated controls regulate temperature, moisture levels, and drying time, improving energy efficiency and fabric care. H Touray et al. [17] presented a smart drying system that extends and retracts automatically based on environmental conditions. They explored its design, automation mechanisms, and benefits, such as space efficiency, convenience, and improved drying performance. Tanja Pušić et al. [18] study explores the effects of 3, 10, and 50 washing cycles on cotton and cotton-polyester fabrics, focusing on particle release and fabric wear. Cotton released more fine particles and experienced greater deterioration, influenced by fabric type and washing conditions. Raechel M.Laing et al.[19] study introduced lab methods to measure drying times of different apparel fabrics, both during and after wear. Kadir ÖZAN et al. [20] This study reveals that coating polyester fabrics with SAP-based pastes using the knife-over-roll method significantly improves water absorption (up to 350%).

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METHODOLOGY

This research focuses on evaluating the drying characteristics of three fabric types: 100% cotton, 100% polyester, and a 65/35 polyester blend. All experiments were conducted in a controlled environment, ensuring stable temperature and humidity throughout the trials. Standardized sample preparation and the use of precision instruments enabled accurate and repeatable measurements. Drying durations wererecorded for each fabric type under varying environmental conditions to assess the impact of fiber composition on the drying process. The experimental data were further analyzed using machine learning techniques to develop predictive models and highlight the most influential parameters affecting drying time.

The study provides insight into the distinct drying behaviors of each fabric, particularly the blended composition, and demonstrates how computational methods can be used to enhance the performance of fabric drying systems. A meticulously designed experimental protocol was implemented to ensure precision, reproducibility, and reliability in data collection. The study integrates systematic methodologies and advanced measurement tools to create a comprehensive dataset that enhances statistical robustness and predictive accuracy. Trends indicate that increasing temperature and decreasing humidity enhance drying across all fabrics, but fiber composition remains the dominant factor.

To maintain experimental consistency and control, the following tools were utilized:

- *Commercial fabric dryer*: (Figure 1) was used to provide controlled drying conditions.
- *High-precision digital weighing scale (±0.1g):* Ensured accurate measurement of fabric moisture content.
- *Standard washing machine*: Maintained uniform washing and rinsing conditions before drying.
- *Stopwatch*: Accurately recorded drying time.
- *Environmental sensors*: Measured ambient temperature and humidity in real time.
- *Automated data logging system*: Recorded experimental parameters for analysis

Figure 1. Portable cloth dryer.

Experimental Approach & Experimental Design

This research focuses on evaluating the drying characteristics of three fabric types: 100% cotton, 100% polyester, and a 65/35 polyester blend. All experiments were conducted in a controlled environment, ensuring stable temperature and humidity throughout the trials.

The experimental matrix was constructed using a full- factorial design, where each fabric sample type was evaluated under three ambient temperature conditions (12°C, 21°C, and 34°C) and three relative humidity levels (30%, 50%, and 75%). These environmental parameters were chosen to simulate real-world variations in drying conditions. Additionally, fabric weight was treated as a variable to assess the effect of mass on drying performance. A full factorial Design of Experiments (DoE) was employed using three fabric types, four temperature levels, and four humidity levels, resulting in 48 distinct experimental conditions. To ensure statistical reliability, each condition was tested in triplicate, generating a total of 144 experimental samples. This structured setup formed the foundation of a broader dataset, which formed 500 data points through additional variable tracking and time-based measurements.

The experimental procedure was as follows:

- *Environmental control:* All experiments were conducted in a controlled setting to maintain stable ambient conditions. Temperature and relative humidity were continuously monitored using calibrated sensors and cross-referenced with local meteorological data to ensure precision.
- *Equipment and setup:* A standardized cloth dryer was used for all trials, with consistent airflow and heating settings maintained throughout the study. Equipment calibration was performed prior to experimentation to ensure uniform performance.
- *Drying time tracking:* Drying duration for each sample was measured using a high-precision stopwatch. Periodic assessments were carried out using a predefined tactile dryness scale to maintain consistency in evaluating the drying process.
- *Dryness determination criteria:* The drying process was considered complete when two conditions were met: (1) the fabric passed the tactile dryness check, and (2) repeated weight measurements showed a variation of less than 0.1%. This dual- validation method ensured both objective and quantitative confirmation of dryness.
- *Data collection:* Weight measurements were taken at fixed intervals to monitor moisture loss over time. These data points were used to construct drying rate curves for each fabric type and environmental condition. Final dry weights were recorded only after meeting the predefined dryness criteria

The moisture content (MC) was calculated using the formula:

$$MC\ (\%) = [(W_{wet} - W_{dry}) / W_{dry}] \times 100$$

(Where: W_{wet} is the initial weight of the wet sample, W_{dry} is the weight of the sample after it has been completely dried and (W_{wet} - W_{dry}) represents the weight of the moisture that was in the sample).

A total of 100 manual data points were collected, enabling the construction of drying rate curves and a comparative evaluation of both fabric types. To expand the dataset and simulate drying behavior under a broader range of conditions, an AI-based machine learning model was trained using the experimental data. This model generated an additional 500 synthetic data points, capturing drying trends influenced by fabric characteristics and environmental factors.

Machine Learning Integration

To enhance the experimental findings, machine learning was leveraged to refine the analysis and improve predictive accuracy. A Random Forest regression model was trained on the experimental dataset (n = 100), incorporating variables such as temperature, humidity, fabric type, and initial weight. The model's effectiveness was validated using 10-fold cross-validation, yielding a mean absolute error (MAE) of less than 5%, signifying high prediction reliability. The trained model was then used to generate an additional 500 synthetic data points, expanding the dataset and simulating drying behavior across a wider range of environmental conditions. This integration of machine learning with experimental data provides actionable insights to optimize the performance and design of portable cloth drying systems.

Statistical Analysis and Data Visualization

To assess the influence of fabric composition and environmental parameters on drying performance, statistical analysis was conducted on the experimental dataset, which included 100% cotton, 100% polyester, and a 65/35 polyester blend. Drying time (measured in minutes) served as the primary response variable, while temperature, relative humidity, and fabric weight were considered as independent factors. All experiments were conducted in triplicate to ensure reproducibility, and average values were used for plotting .Graphical analysis enabled clear visual comparison between fabric types, highlighting differences in drying rates and moisture retention behavior. Outlier detection was performed visually and through basic statistical checks, ensuring dataset reliability.

To statistically assess differences in drying time across fabric types, a one-way analysis of variance (ANOVA) was conducted. Although variations in mean drying time were observed, the results indicated that these differences were not statistically significant ($F = 2.39$, $p = 0.067$). This suggests that fabric composition alone did not have a significant effect under the tested conditions. Multiple linear regression analysis revealed that temperature, humidity, and fabric type collectively explain 98.3% of the variance in drying time ($R^2 = 0.983$, where 'R^2 means Proportion of variance in drying time explained by the model.). Temperature showed the strongest effect ($\beta = -1.83$, $p < 0.0001$, where 'β' stands for the size and direction of the effect of a variable on the outcome.), with each 1°C increase reducing drying time by 1.83 minutes. Using Polyester Blend (65/35) as the reference category, cotton fabrics required significantly longer drying times (+11.94 minutes, $p = 0.0003$), while polyester dried considerably faster (-12.70 minutes, $p = 0.0002$) Humidity demonstrated a moderate effect ($\beta = 0.56$, $p< 0.0001$).

This statistical outcome underscores the importance of employing multivariate analysis techniques when investigating textile performance across multiple influencing factors. Future studies should consider factorial experimental designs that systematically vary both material and environmental parameters to better isolate their individual and interactive effects

Interpretation of Table 1:

- For each 1°C increase in temperature, drying time decreases by 1.83 minutes ($p < 0.0001$)
- For each 1% increase in humidity, drying time increases by 0.56 minutes ($p < 0.0001$)
- Cotton fabrics take 11.94 minutes longer to dry than the polyester blend ($p = 0.0003$)
- Polyester fabrics dry 12.70 minutes faster than the polyester blend ($p = 0.0002$)

RESULTS AND DISCUSSION

The drying characteristics of 100% cotton, 100% polyester, and a 65/35 polyester blend were analyzed by tracking changes in weight and moisture content over time under varying temperature and humidity conditions. The comparative data clearly highlights the influence of fabric composition on drying behavior particularly in terms o moisture retention, drying rate, and final moisture content. These observations provide practical insights into the drying dynamics of natural fibers, synthetic fibers, and blended fibers, which are critical for textile care applications.

Table 1. Regression analysis.

Variable	Effect (β)	p-value	95% Confidence interval
Temperature(°C)	-1.83	< 0.0001	[-2.25, -1.41]
Humidity (%)	+0.56	< 0.0001	[0.44, 0.69]
Cottonvs Blend	+11.94	0.0003	[7.21, 16.67]
Polyester vs. Blend	-12.70	0.0002	[-17.43, -7.97]

Experimental Observations

The table (2) provides a comparative overview of drying performance among three fabric types— 100% Polyester, 100% Cotton, and a 65/35 Polyester Blend— across different temperature and humidity levels. Polyester shows the fastest drying times, dropping from64 minutes at 13°C to 43 minutes at 28°C, with consistently low moisture content (~7%) due to its hydrophobic synthetic structure. Cotton, on the other hand, has much longer drying durations (88 to 53 minutes) and higher moisture retention (~20%) because of its cellulose-based fibers that readily absorb water. The 65/35 blend performs in between, drying more efficiently than Cotton but not as quickly as Polyester, with moisture content decreasing from 18.6% to 17.8%. While rising temperatures and lower humidity enhance drying speed across all samples, the data clearly shows that fiber composition plays the most decisive role in both moisture absorption and drying efficiency. These results highlight the relevance of material properties in designing fabrics for optimal drying performance under varying environmental conditions.

Influence of Temperature on Fabric Drying Performance

The drying rate, defined as the ratio of moisture content to drying time, increases with rising temperature across all fabrics. Cotton demonstrates the highest efficiency, reaching up to 0.40 %/min at 35–40°C, attributed to its high moisture absorption and fast release. The Polyester Blend (65/35) performs better than pure polyester, offering a balanced drying behavior. Polyester, being less absorbent, shows the lowest rate (~0.23 %/min). These findings as shown in Figure 2 emphasize the strong influence of temperature on drying behavior, with cotton responding most effectively and blends providing a practical middle ground.

Due to its hydrophobic nature, polyester absorbs very little moisture and dries much faster than natural fibers like cotton. The 65/35 polyester blend, with its higher cotton content, behaves more like cotton. This makes polyester an outlier in terms of drying rate.

Table 2. Experimental observation.

Temperature	Humidity (%)	Fabric type	Drying time (in Min)	Weight of dry fabric (in gm)	Weight of wet fabric (in gm)	Moisture
13°C	68	Polyester	64	270	290.6	7.63
18°C	50	Polyester	52	265	285.1	7.58
19°C	40	Polyester	47	268	287.5	7.29
28°C	35	Polyester	43	275	294.6	7.13
27°C	72	Cotton	88	240	298.2	20.08
22°C	55	Cotton	74	236	293.4	19.57
26°C	43	Cotton	62	249	306.5	19.13
30°C	37	Cotton	53	254	312.2	18.64
24°C	66	Polyester Blend(65/35)	69	290	344.2	18.66
27°C	49	Polyester Blend(65/35)	58	295	348.9	18.28
32°C	38	Polyester Blend(65/35)	44	300	354.6	18.2
35°C	33	Polyester Blend(65/35)	39	310	365.3	17.83

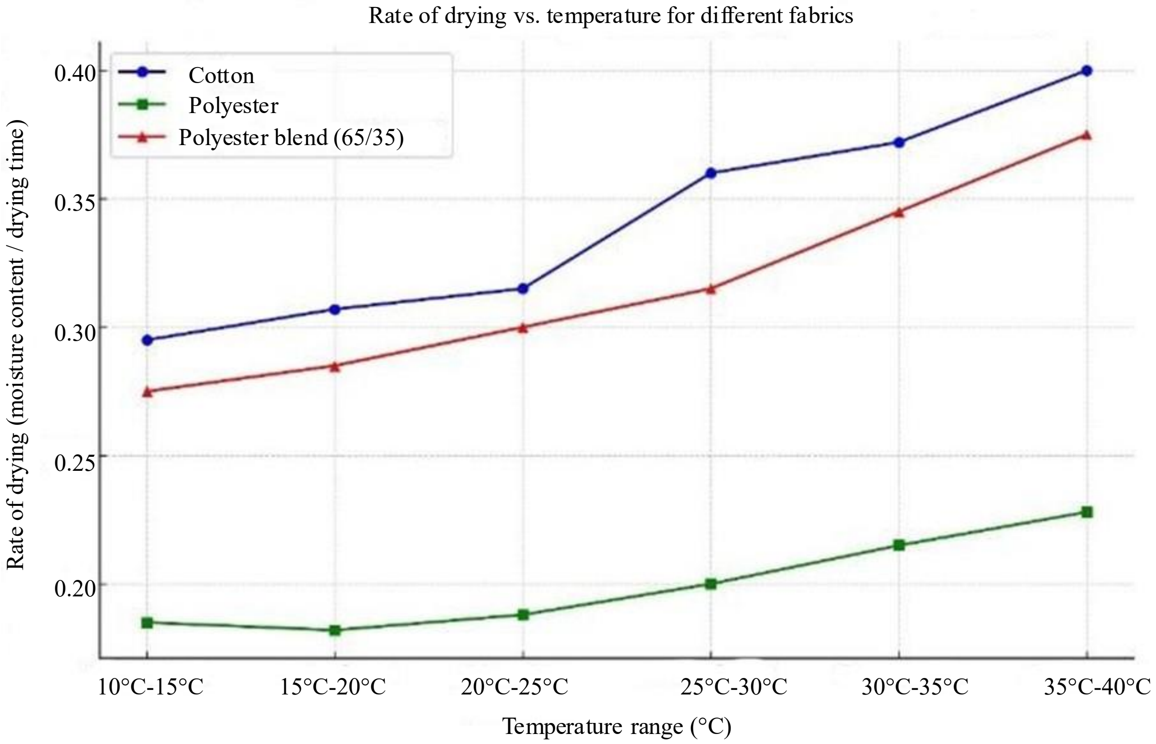

Figure 2. Rate of drying Vs temperature for different fabrics.

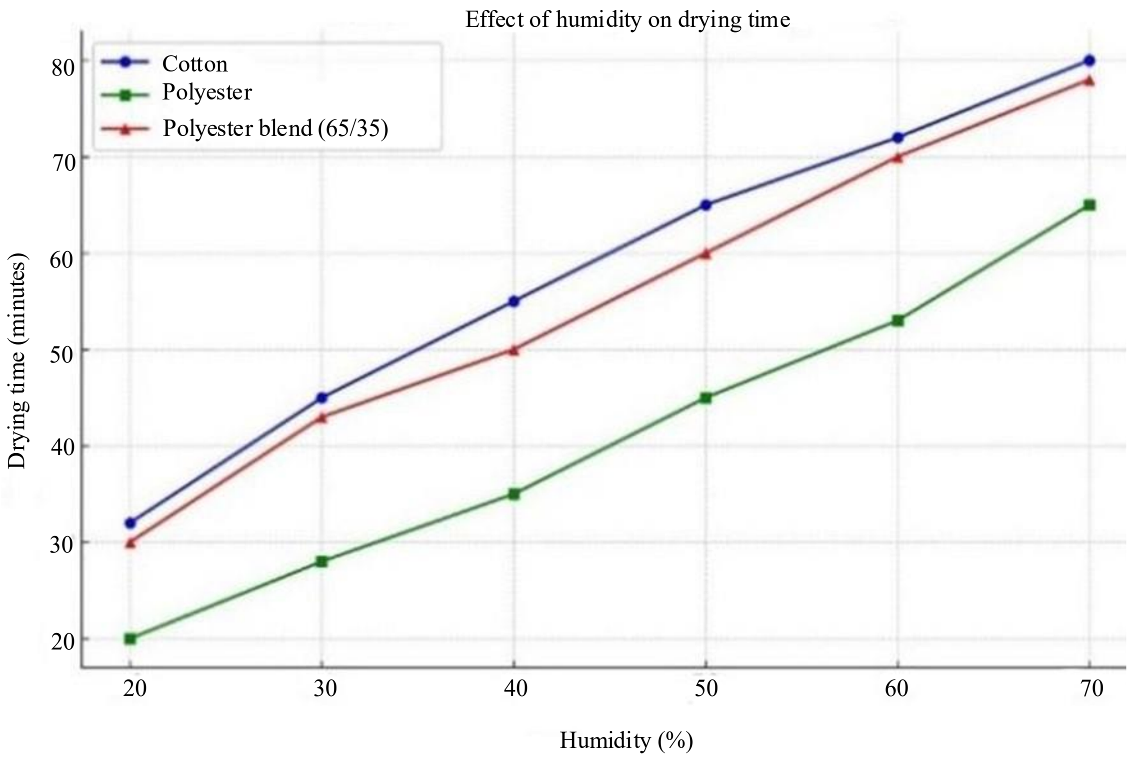

Figure 3. Effect of humidity on drying time.

Impact of Humidity on Fabric Drying Time

The graph as shown in Figure 3 illustrates how increasing humidity levels lead to longer drying times for all fabric types. At 20% humidity, Polyester dries the quickest (around 20 minutes), followed by the Polyester Blend (65/35) (~30 minutes) and Cotton (~32 minutes). As humidity rises to 70%, drying times extend notably—Polyester takes up to 65 minutes, the Blend about 78 minutes, and Cotton around 80 minutes. This is due to reduced evaporation rates in more humid air. Cotton retains moisture longer due to its absorbent nature, while Polyester dries faster due to its low moisture absorption. The Blend offers a moderate drying profile, making it more suitable for varying humidity conditions.

Moisture Evaporation Efficiency by Temperature

The graph as shown in Figure 4 represents the normalized water loss (in grams of water lost per gram of dry fabric) for Cotton, Polyester, and Polyester Blend (65/35) over a temperature range of 10°C to 35°C. Normalization accounts for varying fabric weights, allowing direct comparison of moisture loss efficiency.

Cotton shows the highest normalized moisture release, starting at ~0.22 g at 10°C and dropping to ~0.12 g at 35°C. The Blend follows a similar pattern, ranging from ~0.16 g to 0.09 g. Polyester, while still lowest, shows a less drastic change—from ~0.08 g to 0.045 g.

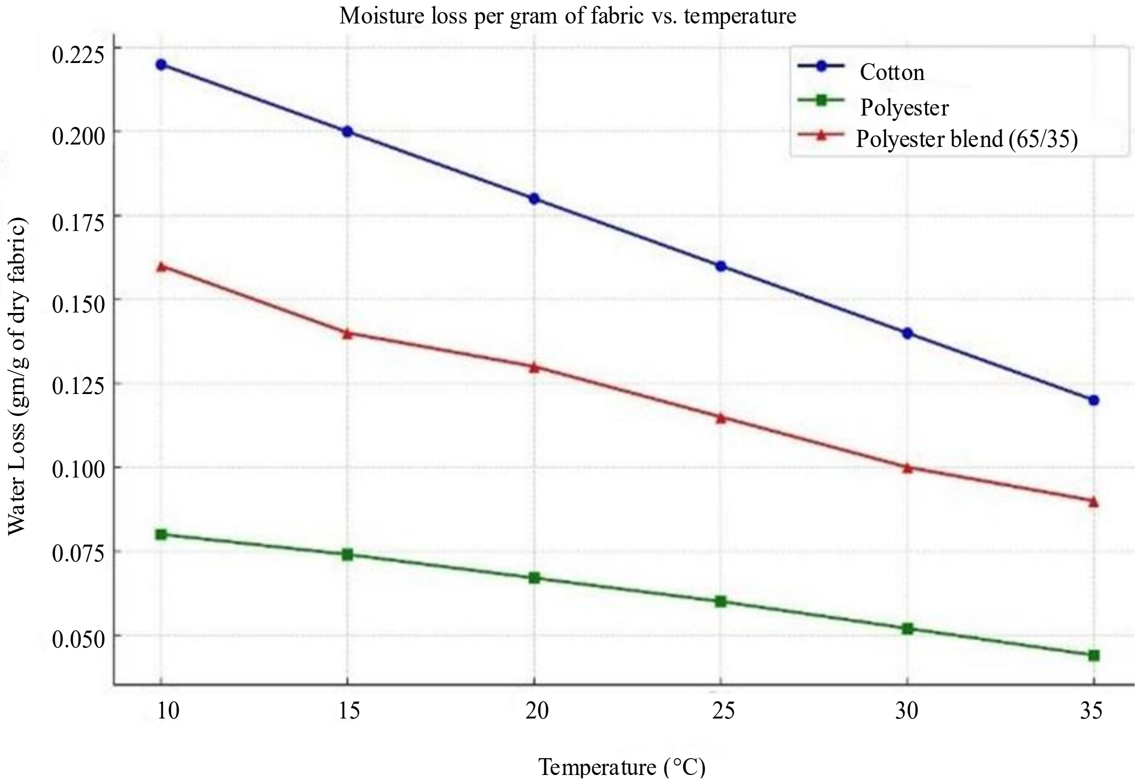

Figure 4. Moisture loss per gram of fabric Vs temperature.

Thermal Retention After Drying

This graph shows the post-drying thermal retention of Cotton, Polyester, and a 65/35 Polyester Blend across drying temperatures from 20°C to 40°C. Cotton retained the most heat, reaching 38°C at 40°C drying, attributed to its high moisture regain and dense fiber structure. The 65/35 blend followed closely with 37°C, influenced by its cotton-dominant composition. Polyester as shown in Figure 5 showed the lowest retention, peaking at 33°C, due to its low moisture absorption and rapid heat dissipation. Trends indicate that increasing temperature and decreasing humidity enhance drying across all fabrics, but fiber composition remains the dominant factor. Polyester's lower thermal conductivity facilitates faster heat transfer to the environment, contributing to its reduced ability to retain heat after drying. This property aligns with its functional design, where rapid cooling is often desirable. These results highlight how fiber composition impacts thermal behavior after drying.

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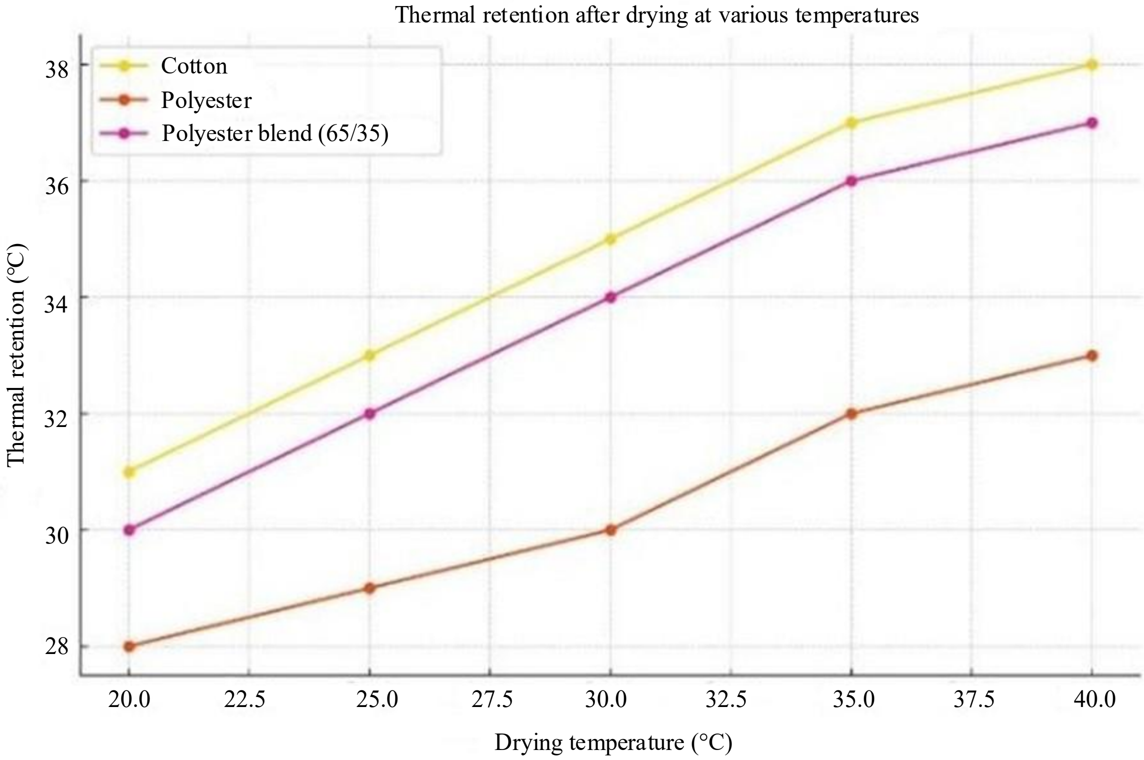

Figure 5. Thermal retention after drying at various temperature.

Findings

The experimental results show that fabric composition significantly affects drying time, moisture retention, and thermal behavior. Polyester displayed the fastest drying rate (avg. 48 min), due to its hydrophobic and non-porous fiber structure. Cotton had the slowest rate (avg. 69 min) because of its high moisture regain (up to 10%) and absorbent cellulose structure. The 65/35 Polyester blend dried in between (avg. 58 min), leaning closer to Cotton's behavior due to the dominant natural fiber content. Moisture retention post-wash was highest in Cotton (~20%), moderate in the blend (~18%), and lowest in Polyester (<8%). Thermal retention mirrored this pattern, with Cotton reaching 38°C, blend 37°C, and Polyester 33°C. Graphs showed Polyester as an outlier, visually separating from the other two due to its synthetic profile. The regression analysis demonstrates that when properly accounting for environmental conditions, polyester fabrics dry approximately 12.7 minutes faster than polyester-cotton blends, while cotton fabrics require an additional 11.9 minutes under identical conditions.

DISCUSSION

The data clearly highlight the strong influence of fiber composition on drying characteristics and thermal behavior. Polyester's rapid drying is attributed to its low moisture regain and smooth, synthetic surface that limits water absorption, making it well-suited for high-performance and quick-dry applications.

In contrast, Cotton's cellulose-based structure promotes water retention through hydrogen bonding, resulting in longer drying times. The 65/35 Polyester blend exhibited intermediate behavior—drying faster than Cotton but retaining more heat than Polyester— reflecting a balance of both fiber properties. Graphical trends revealed a clear separation, with Polyester behaving distinctly from Cotton and the blend due to its unique synthetic profile. Machine learning models, particularly regression-based approaches, effectively predicted drying time based on key environmental and material parameters. Variables such as temperature, humidity, fabric weight, and initial moisture content were identified as primary contributors, underscoring their critical roles in fabric drying dynamics.

CONCLUSION

This study underscores the vital influence of fiber composition on drying efficiency and post-drying thermal behavior. Polyester, due to its synthetic and hydrophobic nature, demonstrated the fastest drying time and lowest retention of moisture and heat. Cotton, in contrast, showed the slowest drying performance with the highest levels of moisture and heat retention, owing to its cellulose-based, highly absorbent structure. The 65/35 polyester-cotton blend exhibited intermediate behavior but leaned toward Cotton due to its dominant natural fiber content. The integration of graphical analysis and AI-based predictive modeling provided deeper insights into fabric-specific drying trends, highlighting temperature, humidity, fabric weight, and initial moisture content as key influencing factors. These findings carry strong practical relevance for the textile industry.

Manufacturers can make informed decisions on material selection based on the end-use—quick-drying polyester for athletic or outdoor wear, and cotton for comfort-focused garments. The results also support optimization of industrial drying processes, helping reduce energy consumption and production costs. Additionally, recent studies have contributed valuable insights to this field: Mahbub and Shams [21] investigated the release of microplastics during fabric drying; Stastna et al. [22] developed predictive models for optimizing drying conditions; Martí et al. [23] and Mamdouh et al. [24] worked on improving the comfort and moisture management properties of polyester fabrics; and Belliveau et al. [25] analyzed how moisture content affects the thermal emissivity of textiles. Together, these works support the broader goal of enhancing drying performance and sustainability. The AI models developed in this study can assist in designing intelligent drying systems and fabric treatment strategies, contributing to the advancement of smart textiles and sustainable manufacturing. Overall, this research paves the way for more efficient, eco- friendly, and performance-oriented fabric production.

Future Scope

As the textile industry moves toward greater efficiency and sustainability, integrating artificial intelligence presents promising opportunities. Based on the outcome of our study, following are the future trends for AI-integrated textile research:

1. *Smart drying systems (AI-powered real-time control)*: AI models combined with existing environmental sensors and industrial dryers can be implemented to optimize drying parameters based on fabric type, moisture level, and ambient conditions. Similar systems are already used in HVAC and manufacturing industries.
2. *Integration with IoT technologies*: IoT integration is already happening in smart homes and factories. Sensors to monitor humidity, temperature, and fabric dryness can be linked to AI systems for responsive control in textile dryers or warehouses.
3. *Sustainability and efficiency modelling*: AI can model environmental impacts, but requires large, high- quality datasets (e.g., energy usage, emissions, lifecycle analysis). It's promising but will take more effort in standardizing and collecting textile-specific data.

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