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The Influence of Humidity Control on Jute Yarn Quality: A Path Toward Sustainability

Md Mehedi Hasan Niloy[a*], Shoaib Islam Zico[b], Rafid Ahmed Chowdhury[a], Mahmudul Hasan Perves[c], Elias Khalil[d]

[a]Department of Industrial and Production Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh
[b]Department of Jute and Fibre Technology, University of Calcutta, Kolkata, West Bengal 700073, India
[c]Department of Industrial and Production Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh
[d]Tangail Textile Engineering College, Tangail, Bangladesh.
Corresponding Author: mehediniloy334010@gmail.com

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ABSTRACT

Jute, a natural hygroscopic fiber, is highly sensitive to environmental humidity, which significantly affects its physical properties. This study examines the impact of a humidity control system on jute yarn quality during spinning, focusing on yarn count, breaking strength, moisture content, quality ratio and twists per inch (TPI). Experiments were conducted under two humidity conditions: 67% relative humidity (RH) (system active) and 52% RH (system inactive). Results indicate that maintaining optimal humidity (67% RH) enhances yarn quality by improving tensile strength (+9.7%), reducing end breakages (-78.6%), and ensuring consistent yarn count and TPI. Higher humidity reduces fiber brittleness, leading to better fiber integrity and reduced production inefficiencies. In contrast, lower humidity resulted in inconsistent yarn properties and increased breakages. These findings emphasize the importance of humidity control systems in enhancing jute yarn quality, reducing waste, and improving efficiency in textile manufacturing.

Keywords: Jute yarn, Humidity control, Spinning process, Fiber properties, Sustainable textiles.

1. INTRODUCTION

In the highly technical domain of textile manufacturing, the pursuit of excellence in yarn production is a continuous endeavor. Within this context, environmental conditions, particularly humidity, have emerged as critical determinants of yarn quality (Cottrell et al., 2023). This study investigates the significant impact of humidity management systems on the quality of jute yarn during the spinning process. Jute, a highly absorbent and sustainable natural fiber, remains central to this inquiry due to its distinct characteristics, which necessitate precise environmental control (Cole, 2024).

The moisture content in fibers like jute significantly impacts their essential physical properties (Singh et al., 2018). The amount of water absorbed influences many of a fiber's physical properties, including tensile strength and breakage (Aranha et al., 2024). So, variations in the relative humidity of the surrounding environment during yarn production are expected to alter yarn breakage rates and overall product quality (Cottrell et al., 2023; Yu et al., 2016).

In examining the relationship between humidity and the quality of jute yarn, various crucial parameters come under scrutiny. Yarn strength changes with the level of relative humidity (Smail et al., 2021). Key quality metrics include yarn count, which defines the fineness or thickness of the yarn and plays a crucial role in determining its application and performance characteristics. Yarn strength, a fundamental parameter, is analyzed to assess the tensile capacity and durability of jute yarn under different humidity conditions (Shi et al., 2022). The coefficient of variation (CV), a statistical measure, provides insights into yarn consistency and uniformity, essential for producing reliable and standardized products (Dai et al., 2023). Additionally, moisture content is significant, as it directly influences the hygroscopic nature of jute fibers, affecting their pliability and handling during the spinning process (Shahinur et al., 2022). Twist per inch (TPI) is another crucial factor, impacting the yarn's structure, strength, and overall performance (Singh et al., 2018). Through precise measurement and analysis of these quality parameters, this study enhances the understanding of the intricate interplay between humidity and jute yarn quality, paving the way for optimized production processes and improved product excellence in the jute industry.

At the core of this investigation is the recognition that raw jute fibers are highly sensitive to humidity fluctuations (Samir et al., 2022). Achieving excellence in jute yarn manufacturing requires a thorough analysis of how regulated humidity settings optimize critical yarn properties such as tensile strength, fineness, and overall quality.

Relative humidity (RH) control contributes to sustainability in jute yarn production by improving fiber behaviour and process efficiency. Maintaining optimal RH enhances yarn strength, quality ratio, TPI stability, and reduces hairiness compared to low RH conditions. This leads to fewer end breakages, reduced material wastage, and lower reprocessing rates (Shi et al., 2022). As a result, energy consumption per unit of acceptable yarn decreases despite the use of humidity control systems. Moreover, RH control enables better utilization of jute—a renewable and biodegradable fiber—without chemical treatments, supporting cleaner production and sustainable manufacturing practices in the jute industry.

This study involves experimental work, data analysis, and the presentation of findings to the jute industry. The primary objective is to provide practical recommendations for enhancing the production of high-quality jute yarn through effective humidity control systems. A standardized testing atmosphere has been established, defined by a relative humidity of 65% and a temperature of 20°C. Practical tolerances allow for slight variations, with a testing RH of 67% ± 2% and a temperature of 28°C ± 2°C (*Practice for Conditioning and Testing Textiles*, 2016).

In synthesizing existing knowledge and presenting new insights, this scientific exploration aspires to contribute to the evolving landscape of textile science and technology. The primary objective of this research is to examine the impact of humidity control systems on jute yarn quality. By unraveling the influence of humidity control systems on the jute yarn production process, this study not only enhances understanding of textile manufacturing but also paves the way for advancements that redefine jute yarn quality standards. Proper humidity regulation can achieve multiple goals, such as increasing yarn count and quantity, reducing fiber damage, and maintaining fiber integrity. Implementing a humidity control system helps preserve the mechanical properties of jute fibers, ensuring smooth processing, enhancing the durability of the finished yarn, and improving overall production efficiency in the textile industry.

2. MATERIALS AND METHODS

2.1 Humidity control system

A humidity control system is an innovative solution designed to regulate moisture levels within industrial environments where hygroscopic materials, such as jute, are processed (Shahinur et al., 2022). Maintaining an optimal moisture level is crucial for ensuring yarn quality, as fluctuations can significantly impact fiber integrity and overall production efficiency. This system provides an effective method for achieving and sustaining the ideal moisture content in the final yarn.

The system operates in a continuous cycle, consisting of three main components: an air filtering system, a humidifier, and an air-blowing section.

Fig. 1: (a) Air filtering system (b) Water injection system (c) Air blowers

The process begins with the intake of air from within the plant, which first passes through the air filtering system to remove impurities. The filtered air then moves through a water injection system, where it is humidified. Finally, air blowers distribute the conditioned air throughout the facility, ensuring a consistent humidity level. This cycle repeats continuously to maintain optimal environmental conditions.

2.2 Average count measurement

Jute count is defined as the weight in pounds of 14,400 yards of yarn (Paul et al., 2022). This measurement is used to express the fineness of jute yarn, a critical parameter in assessing yarn quality. The humidity level can influence the apparent thickness of the yarn due to moisture absorption by the fibers, which, in turn, affects the yarn count. The impact of humidity control systems on yarn count is particularly significant, as maintaining an optimal moisture level ensures consistency in yarn properties. Yarn count can be determined using the following Equation (1).

$$\text{Yarn Count, N} = \frac{W/l}{L/w} \quad (1)$$

Here,

N = Yarn count, W= Weight of a sample of yarn,

l= Unit of length, L= Length of the sample,

w= Unit of weight.

To obtain an accurate measurement, the weight of 25-yard yarn samples is recorded using a precise weighing machine. The yarn count is then calculated using Equation (1), ensuring reliable and standardized assessments of yarn fineness. This systematic approach helps maintain quality control in jute yarn production by minimizing variations caused by environmental factors.

2.3 Breaking strength

The breaking strength of jute yarn is significantly influenced by humidity levels, as moisture absorption affects the fiber's tensile strength. Higher humidity levels generally enhance fiber flexibility and cohesion, reducing brittleness and increasing tensile strength, while lower humidity can lead to weaker, more fragile yarn. Breaking strength is measured using a yarn lea strength tester, a specialized machine that assesses the tensile properties of yarn. The testing process involves securing the yarn sample between two jaws and subjecting it to a controlled extension rate until failure occurs. The recorded breaking strength provides a quantitative measure of the yarn's durability and performance under stress.

2.4 Moisture content (%)

The moisture content (MC%) of jute yarn is directly influenced by surrounding humidity levels, which impact critical quality parameters such as tensile strength and quality ratio. Maintaining an optimal moisture level is essential for ensuring yarn durability and consistency. A moisture meter is used to measure the moisture ratio in jute yarn. The obtained moisture ratio is then converted into moisture content (%) using the Equation (2).

$$\text{Moisture Content (\%)} = \frac{\text{Moisture Ratio} * 100}{100 + \text{Moisture Ratio}} \quad (2)$$

2.5 Quality ratio (%)

The quality ratio is one of the properties of jute yarn that indicates the breaking load (Islam et al., 2024). It is calculated as the percentage ratio of single yarn strength (in pounds) to yarn count (in lbs/spyndle), where 1 spyndle = 14,400 yards. The quality ratio is determined using the Equation (3).

$$\text{Quality ratio (\%)} = \frac{\text{Single yarn strength in pound (lb)}}{\text{Yarn count in lbs/spyndle}} \quad (3)$$

2.6 Twists in per inch (TPI)

Twists per inch (TPI) refers to the number of twists or turns in one inch of yarn. This parameter plays a crucial role in defining yarn strength, structure, and flexibility. TPI is measured using a specialized testing machine, which displays the twist level for quality control and process optimization.

2.7 Ends down

Ends down refers to the number of yarn breakages before being twisted onto a bobbin. Frequent end breakages can negatively impact spindle speed, reduce yarn quality, and affect the mechanical condition of spinning machines. Proper humidity control and optimized spinning conditions help minimize ends down, improving production efficiency and yarn durability.

2.8 Measuring RH

Relative humidity (RH) in the production area was measured using a calibrated digital thermo-hygrometer installed at the spinning zone near the jute yarn processing machines. The instrument continuously monitored RH and temperature in real time to ensure accurate environmental control.

3. EXPERIMENTAL ANALYSIS

Yarn samples were collected daily under both system-on and system-off conditions to measure key quality parameters, including yarn count, breaking strength, moisture ratio, quality ratio, twists per inch (TPI), and number of ends down.

3.1 Samples specification

Table 1 provides details of the samples, including their length, weight, and the corresponding tests conducted. A total of fifteen samples were collected for each test, with no specific precautions required during sampling.

Sample	Sample Description	Type of Test
Jute Yarn	25 Yards	Average Count Measurement
Jute Yarn	22-inch Length	Breaking Strength Measurement
Jute Yarn	Yarn with Bobbin	Moisture Content measurement
Jute Yarn	Yarn with Bobbin	Quality Ratio measurement
Jute Yarn	15-inch Length	TPI Measurement

In the experimental setup, the humidity control system was programmed to maintain two specific humidity levels: 67% RH as the "on" state and 52% RH as the "off" state. These levels were selected based on preliminary investigations and industry standards, representing typical environmental conditions in jute yarn manufacturing.

RH readings were recorded at regular intervals during the experimental period, and calibration of the measuring device was verified prior to data collection to ensure measurement accuracy and reliability.

During the experimental trials, jute yarn samples were subjected to these controlled humidity conditions for a predetermined duration. The breaking strength, average count, quality ratio and TPI of the jute yarn were measured under each condition.

Breaking strength was assessed using a universal testing machine, which applied controlled tension to the yarn until failure, providing an accurate measure of its tensile properties. The average count, representing yarn fineness, was measured in terms of the number of hanks per unit weight. The quality ratio, a composite measure of multiple yarn properties, was determined using standardized assessment criteria (Alias et al., 2018).

3.2 System on

While the humidity control system was active, a total of fifteen samples of 10/1 count yarn were collected to measure yarn weight. The key parameters measured included yarn count, breaking strength, moisture ratio, quality ratio, and TPI. Additionally, the number of ends down was recorded over an 8-hour shift.

The relative humidity (RH) level was maintained at 67.4% on Day 1, 67.3% on Day 2, and remained at 67.3% on Day 3. The quality parameters measured under these conditions are presented in Tables 2, 3, and 4, respectively. Table 5 provides a summary of the analyzed quality parameters across all three days under controlled humidity conditions.

Table 2: Quality parameters on Day 1 while system on

Yarn Weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
8.95	11.37	4.4	15.6		4.3	
8.8	11.17	3.8	16.7		4.1	
8.32	10.57	4.2	14.6		3.9	
8.51	10.81	4.8	16.3		4.5	
8.91	11.31	4.2	14.4		3.8	
8.38	10.64	4	16		4.3	
8.42	10.69	5.6	15.8	91.65	4.5	51
8.79	11.16	3.6	15.8		4.4	
8.35	10.6	3.8	16.6		4.6	
8.46	10.74	4.8	16.7		4.2	
8.85	11.24	3.8	15.1		4.3	
8.22	10.44	4	16.7		4.2	
8.6	10.92	5	16.3		4.6	
8.57	10.88	5.6	16.1		4.4	
8.36	10.62	5	15		4.1	
Average	10.88	4.44	15.85	91.65	4.28	51
SD*	0.3	0.66	0.77		0.2	
CV** (%)	2.80%	14.80%	4.80%		5.50%	

Table 3: Quality parameters on Day 2 while system on

Yarn Weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
8.78	11.15	3.4	15.7		4.3	
8.24	10.46	4.8	16		4.6	
8.38	10.64	3.2	15.4		4.3	
7.51	9.54	4	15.2		3.9	
8.35	10.6	3.6	13.4		4.5	
8.56	10.87	5.4	15.4		4.5	
8.64	10.97	4.2	16.5		4.3	
7.3	9.27	3.6	16.4	90.67	4.3	42
8.55	10.86	4.4	16.4		4.5	
8.39	10.65	4.4	15.8		4.4	
8.39	10.65	4.4	15.9		4.2	
8.48	10.77	4.4	15.8		4.4	
7.65	9.71	3.4	15.7		4	
7.97	10.12	4.4	15.3		4.3	
8.28	10.51	5.8	16.5		4	
Average	10.45	4.23	15.69	90.67	4.3	42
SD	0.55	0.74	0.77		0.2	
CV (%)	5.30%	17.40%	4.90%		4.70%	

Table 4: Quality parameters on Day 3 while system on

Yarn Weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
8.14	10.34	4.8	15.5		4.5	
8.27	10.5	4.8	15.2		4.1	
8.14	10.34	4	15.1		4.9	
7.49	9.51	4	15.5		4.2	
8.46	10.74	3.6	15.7		3.7	
7.9	10.03	4.6	16.2		4.6	
8.53	10.83	3.8	15.7		4.1	
8.54	10.84	4.2	16.2	89.86	4.4	67
7.97	10.12	3.8	15		3.9	
7.61	9.66	4.4	15.3		4.1	
8.68	11.02	4.8	16		4.3	
8.44	10.72	3.6	15.8		4.5	
7.32	9.3	4.1	15.9		3.9	
8.83	11.21	4.4	15.63		4.1	
8.52	10.82	3.65	15.7		4.3	
Average	10.4	4.17	15.63	89.86	4.24	67
SD	0.57	0.44	0.37		0.3	
CV (%)	5.50%	10.60%	2.40%		7.30%	

Table 5: Summary of Quality parameters while system on

	Average count	CV (%) of average count	Breaking strength (kgs)	Moisture ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
Day 1	10.88	2.80%	4.44	15.85	91.65	4.3	51
Day 2	10.45	5.30%	4.23	15.69	90.67	4.3	42
Day 3	10.4	5.50%	4.17	15.63	89.86	4.2	67
Average	10.58	4.50%	4.28	15.72	90.73	4.27	53

3.3 System off

With the humidity control system off, fifteen samples of 10/1 count yarn were collected to measure yarn weight. The count, breaking strength, moisture ratio, quality ratio, and TPI were recorded, along with the number of ends down over an 8-hour shift.

The relative humidity (RH) levels were 52.3% on Day 1, 51.8% on Day 2, and 52.5% on Day 3. The measured quality parameters for each day are presented in Tables 6, 7, and 8, respectively. Table 9 provides a summary of the analyzed quality parameters across all three days under system-off conditions.

Table 6: Quality parameters on Day 1 while system off

Yarn weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
7.95	10.1	4.4	13.8		4	
8.17	10.37	3.8	12.9		4.1	
8.05	10.22	3.6	13.2		3.7	
7.67	9.74	4.4	15.2		4	
7.64	9.7	3.4	14.2		4.5	
7.71	9.79	4	13.4		4.5	
7.61	9.66	3.8	14.4		4.4	
7.97	10.12	3.4	14.1	86.44	4.3	236
7.81	9.92	4	12.3		4.5	
8.14	10.34	3.6	13.3		4.4	
6.73	8.55	3.6	12.5		4.2	
8.35	10.6	3.8	13.3		4.4	
7.81	9.92	3.6	13		4.4	
7.51	9.54	3.8	12.3		4.3	
7.86	9.98	5.2	13.7		4	
Average	9.9	3.89	13.44	86.44	4.25	236
SD	0.48	0.47	0.81		0.2	
CV (%)	4.80%	12.10%	6.10%		5.60%	

4. RESULTS AND DISCUSSION

This section presents a comparative analysis of key quality parameters under controlled and uncontrolled humidity conditions. Table 10 provides a summary of the measured parameters, highlighting the influence of humidity control on jute yarn quality.

Table 7: Quality parameters on Day 2 while system off

Yarn weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
8.14	10.34	3.63	13.17		4.2	
7.57	9.61	4.22	13.01		4.1	
8.04	10.21	3.88	13.1		4.2	
7.83	9.94	3.37	13.07		4.22	
6.97	8.85	3.52	13.04		4.61	
8.02	10.18	4.3	13.42		3.98	
7.82	9.93	4.15	13.31		4.42	
7.05	8.95	3.36	13.87		3.95	
7.31	9.29	4.06	13.26	86.89	4.28	262
7.56	9.6	3.71	13.68		4.12	
7.5	9.53	4.07	13.14		4.37	
7.73	9.82	4.01	13.8		4.54	
8.1	10.29	4.22	13.32		4.18	
7.35	9.33	3.86	13.78		4	
7.57	9.62	3.67	13.44		4.13	
Average	9.7	3.87	13.36	86.89	4.22	262
SD	0.46	0.31	0.3		0.2	
CV (%)	4.80%	8.00%	2.20%		4.60%	

Table 8: Quality parameters on Day 3 while system off

Yarn weight (25 Yards)	Count	Breaking Strength (Kgs)	Moisture Ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
7.25	9.21	3.8	13.37		4.2	
8.09	10.27	4.33	13.21		4.1	
7.24	9.19	3.67	13.3		4.9	
7.88	10.01	3.86	13.37		4.2	
7.89	10.02	3.64	13.24		3.7	
7.74	9.83	3.94	13.42		4.1	
7.6	9.65	4	14.02		4.1	
8.21	10.43	4.01	13.37		4.4	
7.68	9.75	4.19	13.26	88.29	3.9	247
6.88	8.74	4.16	13.68		4.1	
8.34	10.59	3.96	13.14		4.3	
7.71	9.79	3.62	13.5		4.3	
7.35	9.33	4.11	13.32		3.9	
8.19	10.4	3.77	13.78		4.1	
7.53	9.57	3.89	13.44		4.2	
Average	9.79	3.93	13.43	88.29	4.17	247
SD	0.52	0.21	0.24		0.3	
CV (%)	5.40%	5.40%	1.80%		6.50%	

Table 9: Summary of Quality parameters while system off

	Average count	CV (%) of average count	Breaking strength (kgs)	Moisture ratio (%)	Cyc QR (%)	TPI	Number of ends down (8 hours)
Day 1	9.79	4.80%	3.93	13.43	86.44	4.17	236
Day 2	9.7	4.80%	3.87	13.36	86.89	4.22	262
Day 3	9.9	5.40%	3.89	13.44	88.29	4.25	247
Average	9.8	4.99%	3.9	13.41	87.21	4.21	248

Table 10: Summary Table of Quality Parameters

Quality Parameters	System On	System Off
Actual Count (lbs/1 Ply)	10	10
Average Count (lbs/1 Ply)	10.58	9.8
CV (%) Of Average Count (%)	4.5	4.99
Strength (Kgs)	4.28	3.9
Moisture Ratio - M/R (%)	15.72	13.41
Quality Ratio - QR (%)	90.73	86.44
Twist Per Inch – TPI	4.27	4.21
Ends Down	53	248
Work Environment	Better	Good

The following subsections analyze the impact of humidity control on individual quality parameters, providing insights into how the system enhances jute yarn performance.

4.1 Average Count

The average count remained consistent with the actual count when the humidity control system was active.

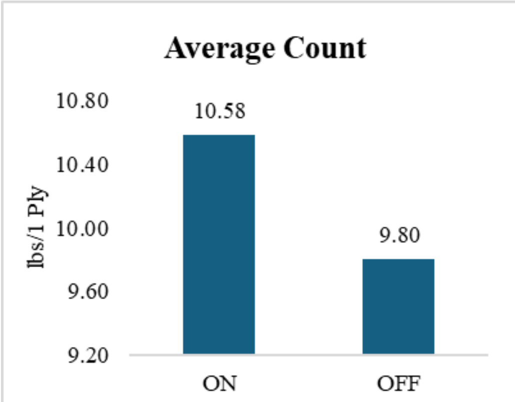

Fig.2: Average count

As shown in Figure 2, the actual count was 10 lbs/1 ply, and the measured average count was 10.58 under controlled humidity. In contrast, when the system was off, the average count fell to 9.8, below the actual count. This reduction is attributed to moisture absorption, as jute fibers expand in a humid environment, increasing mass and diameter. The findings suggest that proper humidity regulation ensures the desired yarn count, leading to improved consistency and quality.

4.2 Breaking Strength

Humidity control had a significant impact on the breaking strength of jute yarn.

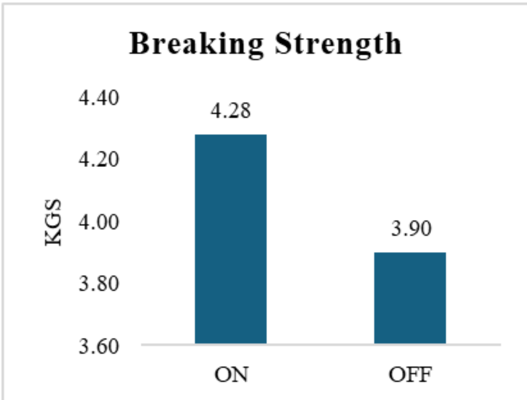

Fig.3: Breaking strength

Figure 3 shows that the breaking strength was 4.28 kg under controlled humidity but dropped to 3.90 kg when the system was off. Higher humidity levels promote moisture absorption, enhancing fiber flexibility and cohesion, thereby improving the yarn's ability to withstand stress. While in low humidity, the fibers become brittle, leading to reduced tensile strength.

4.3 The Quality ratio (%)

The quality ratio (QR) was also higher when the humidity control system was on.

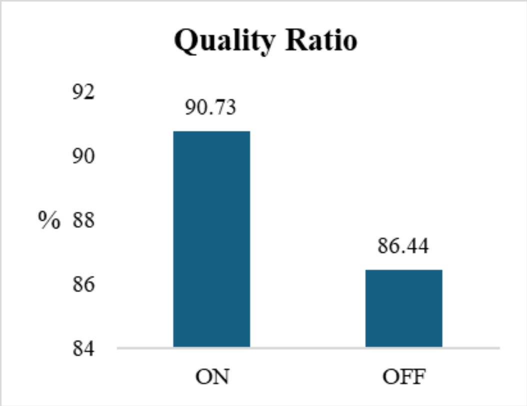

Fig.4: Quality ratio (%)

Figure 4 indicates that QR was 90.73% under controlled conditions, compared to 86.44% when the system was off. The improvement in QR can be attributed to better fiber cohesion, as moisture absorption enhances both strength and elasticity.

4.4 Twist Per Inch (TPI) level

The TPI level remained closer to the intended value under controlled humidity. A stable humidity environment helps fibers twist more uniformly, producing a tighter and more structured yarn.

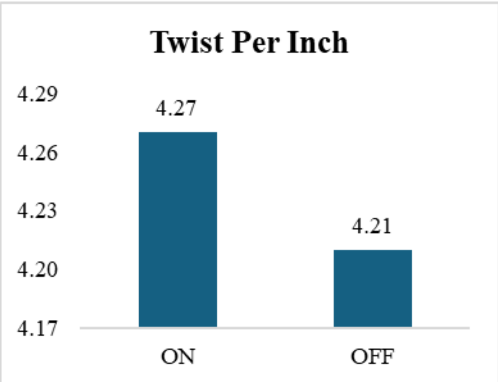

Fig.5: Twist per inch (TPI)

The set TPI level was 4.25, and the observed TPI values were 4.27 with the system on and 4.21 with the system off (Figure 5). Without humidity control, the lack of sufficient moisture can lead to inconsistent twisting, affecting overall yarn quality.

4.5 Ends down

A major advantage of the humidity control system was the significant reduction in ends down (yarn breakages).

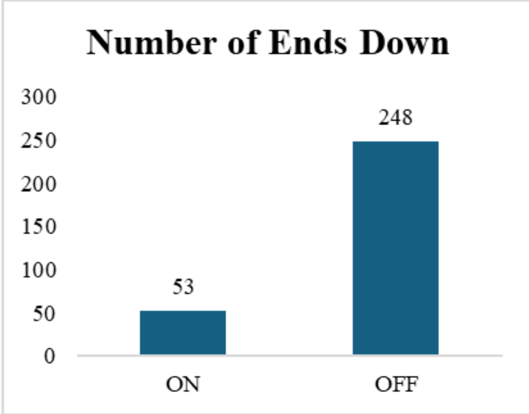

Fig.6: Number of ends down

Figure 6 illustrates that under controlled humidity, end breakages occurred 53 times per spinning frame per shift, whereas this number increased to 248 when the system was off. Higher humidity levels reduce the frequency of yarn breakages because moisture absorption makes the fiber more flexible and less prone to breaking.

5. CONCLUSION

This study highlights the significant impact of humidity control systems on jute yarn quality, reinforcing the necessity of maintaining optimal environmental conditions in textile manufacturing. The findings demonstrate that a stable humidity level of 67% enhances key quality parameters, including breaking strength, moisture content, and twist per inch (TPI), while significantly reducing end breakages. In contrast, uncontrolled humidity conditions resulted in decreased yarn strength, higher breakages, and inconsistencies in product quality. The system's ability to maintain consistent fiber integrity and prevent brittleness contributed to higher yarn strength and quality ratio. These results align with previous studies (Chen et al., 2024; Smail et al., 2021), which emphasize the role of humidity regulation in ensuring fiber integrity and improving textile performance. They found that in uncontrolled environments, fluctuations in humidity led to inconsistent yarn strength, whereas in controlled environments with stable humidity (between 60-70% RH), yarn showed consistent quality and improved resilience.

The implications for the jute industry are substantial. Implementing humidity control systems can:

- Reduce material wastage by minimizing defects caused by inconsistent fiber properties.
- Improve machine efficiency by reducing end breakages and ensuring smoother operations.
- Enhance overall product quality, making jute yarn more competitive in the market.

Beyond material benefits, the integration of humidity control systems fosters a more stable and productive work environment, reducing operational disruptions and enhancing overall efficiency. By adopting effective humidity management strategies, textile manufacturers can optimize production processes, improve sustainability, and ensure superior product consistency. This research provides valuable insights for industrial applications and serves as a foundation for future advancements in jute yarn processing and environmental control technologies.

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Declaration of competing interest

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

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