Qualitative and statistical analysis of cotton-flax blend yarn

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ABSTRACT

Purely cotton fabric lacks different functional and physical properties than cotton-flax blends fabric. The experimental part of the present study is to investigate the influence of flax fibres content in cotton-flax blended yarn quality. Five ring yarn samples of the same count, 16/1Ne but from different blend ratios (100C, 80C:20F, 70C:30F, 45C:55F, and 100F) were produced from the same spinning preparatory conditions. The primary outcome was measured by analyzing test results obtained from different testing instruments (Uster Evenness tester, Mesdan Tensile Tester, and Instron Lea strength tester). The secondary outcome was measured by statistical analysis. Evenness properties were better for 80:20 blends in CVm% (17.13), IPI (1346), and H (6.89). 100% cotton yarn possessed the richest evenness quality CVm% (13.23), IPI (168.4), and H (7.97) in contrast to the poorest result of 100% flax yarn. On the other hand, the highest strength (CSP 4631, RKM 30.22) and the lowest elongation, 2.29%, were both achieved for 100% flax yarn. Evenness properties and elongation deteriorated with the gradual increase in flax content. In terms of strength, tenacity and CSP both decreased with an increase in flax content, but 100% flax yarn exhibited the highest performance.

1. Introduction

Blending different fiber types is a common means of improving the performance and aesthetic and functional properties of a clothing. The quality and cost of blend yarn is controlled by material type, blend ratio, yarn specification, and machine type and settings [1, 2, 3]. Problems of acquiring the homogeneity of mixing are well known in textile practice. The radial fibre distribution in compact ring-cotton-flax blended yarn is more random than in classic ring yarn [4]. Fine yarns are poorly blended than coarse yarns and show up as noticeably disproportionate blends like 90/10, with more streaks than 50/50 blends [5].

Flax fibres (Linen usitatissimum L.), a herbaceous plant, have been used to produce high-quality linen fabric for thousands of years. The archaeo logical record of flax agronomy dates back to more than 6000 BC, and flax is naturally rich in polyunsaturated fatty acids (PUFA), e.g., ω-3 fatty acids [6]. Flax fibres generally have a density of 1.5 g/cm³, length of 4–80 mm, diameter of 5–76 μm, elongation of 2.4%, tensile strength of 1100 MPa, and Young’s modulus of 100 Gpa [7, 8]. Cotton (Gossypium hirsutum and Gossypium barbadense) display a similar density of 1.5–1.6 g/cm³, length of 15–56 mm, but a more extended elongation to break of 7.0–8.0%, a lower tensile strength of 287–597 MPa, and a lower Young’s modulus of 5.5–12.6 Gpa [8, 9]. Though flax is less elastic, and more likely to wrinkle than cotton, which may justify blending the two fibres [10].

Despite growing interest in cottonized flax and cotton blends, the weak cohesion of flax fibres makes it difficult to spin into yarn using conventional cotton processing methods [11]. The fibre crimps,waviness, or kinkiness influence fibre cohesion but flax fibres are robust and straight without crimps [12]. Some studies revealed that with higher flax content in cotton-flax blend yarn, irregularity, dust generation, and endotoxic level of the yarn go up, but strength falls [13, 14], and no bacteriostatic effects is gained [15]. Traditional sports apparel made with 100% cotton was comparable to the 75% cotton/25% flax yarn, and cotton/flax fabric had the highest absorptive capacity [16]. Chen et al. [17] prepared 100% Pima cotton yarn, 30/70 jute/cotton yarn, and 30/70 flax/cotton blended yarn. The results showed that 30/70 flax/cotton blends obtained higher tenacity and lowest CVm% than other blends.

2. Materials and methods

2.1. Materials

In this study, Pima cotton and flax fibre are selected for blending to produce 16/1 Ne yarn. The essential characteristics of fibres are given in Table 1.

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2.2. Methods

Fibre processing and spinning were operated under mill operating conditions in the cotton system in the NZ Textile mills ltd, Bangladesh. Both the Pima and flax fibres were opened manually, and after sandwich hand blending, the feed lattice was used to open and blend the fibres to be spun, followed by the Trutzschler blow room line CL-P, CLC-1, and CLC C3. The opened fibres were carded on a Trutzschler BC-05 at 50 kg/h to form slivers of linear density 109 grain/yd, then drawn on the breaker SB D40 and finisher draw frame, RSB D45, to form slivers of linear density 90 grain/yd. Yarns were spun at Jingwei F-1520 ring spinning frame (TPI 20.02, speed 9500 rpm) directly from the roving of 0.73 Ne made from roving frame Toyota FL-16 (TPI 1.45, speed 950 rpm). The target blend ratio was 80% cotton:20% Flax (80C:20F), 70% cotton:30% Flax (70C:30F), 45% cotton:55% Flax (45C:55F), and other two samples yarn were spun from 100% Pima cotton (100C), the control yarn and 100% flax (100F). After the yarn production, all yarn samples were kept under standard laboratory conditions (20°C ± 2°C and 65 ± 2% RH) for 24 h before testing as per ISO 139. Fibre parameters were evaluated on Uster HVI 1000 tester according to ASTM D 1445, ASTM D 1447, and ASTM D-1448. Tensile strength (RKM, CSP) and elongation (Elg) were determined according to ASTM method D 2256-90 on the Mesdan Lab AUTODYN II single end and MAG Elestretch XT lea strength tester according to ASTM D 1578-93(2016) standards. Yarn evenness was tested according to the determination of yarn evenness ISO 16549 on the Uster Tester 5.

Statistical analysis was done through regression and ANOVA for YQI of samples. The interpretations (MS, F statistic, and p-value) were made up of calculating statistic parameters to look for the degree of significance of the determinants affiliated to the feedback data and the determinant’s relative importance. The three yarn quality parameters (tenacity, elongation, irregularity) were combined in an index defined as yarn quality index YQI [18, 19]. The four HVI fibre parameters were combined as fibre quality index FQI [20]. The both indexes are shown in Table 3 for statistical analysis and expressed as Eqs.(1) and (2):

\[
YQI = \frac{\text{Strength} \times \text{Elongation}}{\text{CV}_m} \\
FQI = \frac{\text{Strength} \times \text{Mean length} \times \text{Elongation}}{\text{Fineness}}
\]

FQI of the blend was calculated based on the weighted average and presented in Tables 1 and 3. To graphically analyze, we used Boxster and Whisker diagram to focus on the interquartile range (IQR), mean value, variation in the highest range, and median value.

3. Results and discussion

The present study has aimed primarily to analyze the effect of blend ratio on cotton-flax blended yarns properties and focus on optimal blend ratio. The yarn test report is summarized in Table 2. We tested blend ratio analysis method: ISO 1833–1:2006 by cuprammonium hydroxide sample weight 150 mg each and found 79/21% (80C:20F blend), 68.5/31.5% (70C:30F), 43.7/56.3% (45C:55F).

3.1. Yarn evenness properties

Table 2 and Figure 1, Boxter and Whisker diagram of CVm% reveals that yarn irregularity increased with increasing flax ratio in cotton-flax blended yarns and reached the highest 30.51 in the 100% flax yarn. In contrast, 100% cotton yarn has the lowest value of CVm%, 13.23. Among the blends, we noted that the optimum value of yarn evenness was CVm%, 17.13 obtained with the 80C:20F blend yarn. This higher irregularity with higher flax content was produced from the drafting wave due to lower FQI, UI, and higher SFI. Importantly, the higher MIC
substantiated the higher irregularity. It is evident also that CVm% for 100% cotton yarn is of concentrated and symmetric distribution, while with the increase of flax content, the interquartile range (IQR) goes more expansive, and IQR is the highest for 100% flax yarn. Yarn shows the positively skewed distribution for 45C:55F blend because the whisker is longer on the right side of the median than on the upper side.

Figures 2, 3 and 4 demonstrate that IPI, and its component Thin (/C0 50%), Thick (+50%), and Neps (+200%), all were lowest for the control sample, 100% cotton yarn 168.4, 0.3, 73.4 and 94.7 but with the gradual increase of flax content, these were the highest for 100% flax yarn as 10392, 2945, 1711 and 5736 respectively. On the other hand, in the case of the 45C:55F blend, these were the highest 9845,1831, 2950, and 5064, respectively. Thin (−50%) places distribution is very concentrated and symmetric for lower content flax, but the distribution continues to widen, and IQR is the highest for 100% flax yarn, and in the case of the blend, it is 45C:55F blend. The most extended variations in maximum and minimum whisker length have been attributed to these products. Though thick (+50%) places distribution is very concentrated and symmetric for 100% cotton yarn, the gradual increase in flax content distribution spreads. IQR is the highest for 100% flax yarn and blend, and IQR is the widest for 45C:55F blend yarn, but the upper and lower whisker spread equally.

IPI distribution is concentrated and symmetric for higher cotton content yarn (up to 30%). However, with the increase in flax content, distribution widens, and IQR is the highest for the 45C:55F blend though distribution became narrower for 100% flax yarn. On the other hand, Figure 5 shows that the Hairiness Index H, gradually decreased with the increase of flax fibre and reached its lowest value in the case of 100% flax yarn (3.08). In contrast, 80C:20F blend yarn has the lowest among blended yarns (6.2) than 45C:55F blend despite the higher content of flax.
fibre. The longer length of flax compared to cotton fibre is reasoned to produce lower hairiness. H index distribution is very concentrated and symmetric for all the yarn samples. The most prolonged upper whisker was observed for 45C:55F blend, but IQR is almost constant for all flax yarn.

3.2. Yarn tensile properties

Table 2 illustrates that the tenacity and bundle strength of 100% flax yarn was the highest (30.22 cN/Tex and 4631 CSP), almost nearly double 100% cotton yarn (18.70 cN/Tex and 2958 CSP). However, in the case of blends, with the gradual increase of flax content, both tenacity and bundle strength declined and reached the lowest magnitude of 14.39 cN/Tex and 1873 CSP respectively for the 45C:55F blend. The higher strength and length of the flax fibre compared to cotton fibre was translated to 100% flax yarn in spite of greater linear density. In the case of blend yarn, lower FQI, the increasing CVm%, and markedly thin places with higher flax content in the blends boosted the lower RKM and CSP. In contrast, yarn elongation gradually declined with increasing flax content; the lowest elongation, 2.29% was produced in the case of 100% flax yarn, almost triple down against the highest elongation 6.78% of the 100% cotton yarn. In the case of blends, the 45C:55F blend resulted in the lowest elongation of 4.86%. The inferior extension at break of flax fibre and higher thin places substantiated this low elongation with higher flax content.

In Figure 6, although no outlier was observed in the case of 100% flax yarn, it is clearly understood that there are outliers and irregular whiskers in the cotton content yarn. Despite these outliers, strength distribution is negatively skewed and asymmetric for higher cotton content yarn. However, with the increase in flax content, distribution becomes more expansive, and IQR reaches the highest for 100% flax yarn, and no outlier is observed.

The Boxster and Whisker diagram of elongation, Figure 7 illustrates that no outlier was observed in the case of elongation except 45C:55F blend yarn, but it is clearly understood that the distribution is randomly correlated with flax content. However, distribution spreads widely, and IQR is the highest for 70C:30F blend with negatively skewed though after that with the increase of flax, it turns into narrower and symmetric distribution.

Table 4. ANOVA: single factor.

| Source of variation | SS  | df | MS  | F     | P-value | F crit |
|---------------------|-----|----|-----|-------|---------|--------|
| Between Groups      | 282.80 | 4  | 70.70 | 185.63 | 1.70 × 10⁻²³ | 2.63   |
| Within Groups       | 13.71  | 36 | 0.38 |       |         |        |

Table 5. POST-HOC and ALPHA test.

| Groups                | P-value (T-test) | Significant | POST-HOC | ALPHA test |
|-----------------------|-----------------|-------------|----------|------------|
| 80C:20F Vs 70C:30F    | 4.933 × 10⁻⁰⁶  | Yes         | ANOVA    | 0.05       |
| 80C:20F Vs 45C:55F    | 3.107 × 10⁻¹⁴  | Yes         | POST-HOC | 0.01667    |
| 70C:30F Vs 45C:55F    | 9.497 × 10⁻⁰⁷  | Yes         |          |            |
Figure 8 exhibits that the control sample, 100% cotton yarn possessed the highest YQI, 9.58. In the case of blends, 80C:20F blend yarn gained the highest YQI, 8.43, while the 45C:55F blend holds the lowest one (2.34). With the increase in flax fibre percentage, the yarn does not show better YQI. It is clearly understood that the distribution is strongly correlated with flax content. Distribution is negatively skewed, asymmetric, and spreads widely, and IQR trends longer for higher cotton content yarn. Long whiskers were observed for control yarn and 70C:30F blend yarn.

3.3. Statistical analysis

We carried out ANOVA on the YQI of the yarn samples from Table 3, and related data are summarized in Table 4. We have noted that ANOVA results in p-value $2 \times 10^{-12}$ with $F_{	ext{crit}}$ 0.000555, and it points out that there is a significant difference among the YQI. The Post-HOC test (Table 5) of YQI was carried out to trace out blends in terms of YQI that vary significantly among the blends. The Post-HOC analysis reveals that YQI (1.91 ± 0.31) of the 45C:55F blend constituting the highest proportion of flax fibre was significantly poorer compared with YQI of 80C:20F blend (7.22 ± 0.56) and 70C:30F blend (3.85 ± 0.70). Regressions analysis was done to investigate the correlation between YQI and flax content, $F$, presented in Table 6 and Eq. (3).

$$
YQI = 7.51 - 0.073 \times L
$$

(3)

Firstly, The regression statistics reveal that dependent variable YQI and independent variable $F$, flax content is highly correlated with $R^2$ (0.68) and multiple R 0.83. Secondly, the correlation between YQI and FQI is robust with $R^2$ (0.71) and multiple R 0.84. Moreover, ANOVA statistics predict the correlation with significance level $P$-value of $2.78 \times 10^{-11}$, but the correlation between YQI and FQI is insignificant with $P$-value (>0.05) of 0.073. Eq. (3) qualifies the degree of dependency of YQI on the F (flax proportion) from the coefficient statistics intercept 7.51 and coefficient of relation -0.073, negatively.

4. Conclusion

This work, carried out at NZ textile mills ltd, investigated the effects of blend ratio on yarn properties such as hairiness, unevenness, imperfections, tenacity, elongation, and YQI. These properties were analyzed through statistical and graphical methods in order to optimize the yarn blends in pursuance of an optimal blend. To sum up, the evenness and tensile properties of the yarn are primarily influenced by the characteristic of raw materials, FQI, and the blend ratio in the ring spinning system. The control yarn, 100% cotton yarn exhibited the best performance in evenness, tensile and YQI results. On the other hand, 100% flax yarn performed the poorest one. Yarn quality gradually increased in terms of unevenness, thin, thick and imperfections with the increase of flax content in the yarn structure. In contrast, it decreased the tenacity, elongation, and hairiness values. This deterioration was more prominent when flax proportion increased to 20% from 30% compared to its increase from 30% to 55% and is negatively related to the share of flax fibres in cotton-flax blend yarn. Yarn properties were optimum even at 80C:20F blend ratio, whereas the 45C:55F produces the most uneven yarn.

Moreover, for the yarn quality index, it is seen that the effect of the blend ratio and FQI is statistically significant on YQI. It can conclude that the flax fibre ratio in the mix and its yarn properties are influenced by fibre proportion and specifications. The research results will serve for the development of a cotton-flax blend in order to improve the quality and cost of cotton-flax yarn at the optimal blend ratio.

Declarations

Mohammed Farhad Mahmud Chowdhury: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mohammad Nayemul Islam: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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