Article

Investigation of the Physical Properties of Yarn Produced from Textile Waste by Optimizing Their Proportions

Hafeezullah Memon 1,*, Henock Solomon Ayele 2, Hanur Meku Yesuf 2,3 and Li Sun 4

1 College of Textile Science and Engineering, International Institute of Silk, Zhejiang Sci-Tech University, Hangzhou 310018, China
2 Ethiopian Institute of Textile and Fashion Technology, Bahir-Dar University, Bahir-Dar 1037, Ethiopia; henockso11@gmail.com (H.S.A.); 419005@mail.dhu.edu.cn (H.M.Y.)
3 College of Textiles, Donghua University, Shanghai 201620, China
4 Hangzhou Pulay Information Technology Co., Ltd., Hangzhou 310016, China; sunli@mypulay.com
* Correspondence: hm@zstu.edu.cn

Abstract: Since textile waste recycling is a global challenge, there is an emerging need to explore this research direction due to the little knowledge about textile recycling. This study aimed to study the property of yarns produced from recycled textile/cotton fiber blends for proportion optimization and to check whether they can be used for denim fabric production. The properties of recycled fiber and virgin cotton spun on open-end having 4.5 Ne were investigated with fiber proportions of 20/80, 25/75, 30/70, 35/65, 40/60, 45/55, and 50/50. The results were analyzed with Design-Expert software, using central composite design to optimize the proportion. The 40/60 proportion had the optimum result, and by using this optimized proportion, 10 Ne yarn was produced and used for denim fabric production. The sample denim fabric produced used recycled yarn as a weft, showing that the recycled fiber turned yarn can be used in manufacturing products such as denim. The physical properties of the denim fabric confirmed that the recycled goods have wearable quality. Since this research can be applied on an industrial scale, it would benefit textile academia, industry, the environment, and society.

Keywords: textile waste; virgin cotton; denim fabric; Design-Expert software

1. Introduction

Textile waste is categorized into pre-consumer waste and post-consumer waste [1]; the former is generated in the manufacturing process, and the latter contains worn-out or trashed textile products that are no longer serviceable [2]. Among the most severe environmental problems, solid textile waste management is the most significant one society faces. It has been well addressed that waste incineration and improper waste management in landfills have harmful environmental consequences. Some sustainable clothing consumption behaviors [3] and textile upgrading [4] have been proposed to solve this problem. Even though some textile wastes can be used as a fuel in waste to energy processes, this has a higher tendency to increase CO₂ emissions; in that regard, incineration of waste is a much better option comparatively given that there are no options [5,6]. Additionally, chemical recycling has been considered even worse than producing new virgin materials [7,8]. Since synthetic textile fabrics do not decompose, thus creating substantial environmental consequences, they produce methane gas, contributing to global warming after decomposition. Furthermore, textiles in landfills also release hazardous substances into soil and groundwater, contributing to environmental pollution. In the denim industry, mostly cotton is used, and several works have been conducted in the past to process denim [9–11]. Thus, a small percentage of pre- and post-consumer waste is reprocessed into fibers that can be used as yarn for woven or knitted fabrics [12]. This process of recycling textile fabrics comes with both environmental and economic benefits. Additionally, it immensely reduces the...
space required for landfills; has the benefit of not requiring energy- and time-intensive pre-processes for virgin materials; and reduces the costs of dyeing, scoring, fixing agents, and water consumption for their manufacturing [13,14].

Pre-consumer wastes are the industrial wastes generated in fibrous products’ manufacturing processes. Since wastes are generated at different manufacturing stages, the type of waste could be a single polymer or a very complex multi-material compound. Single polymers are usually useful, more manageable, and suitable for recycling as a corporate recycling process can separate them to their corresponding component [15]. Such approaches help identify the source of waste generation and design measures to reduce waste generation [16,17].

Post-consumer waste, also known as home waste, refers to fibrous materials and by-products scrapped after their service life is over [18,19]. Since most fibers are transformed into different products, the volume of post-consumer waste is higher when compared with the fiber consumption rate [20]. Some collection and sorting network chains are required to support commercially available activities to recycle this home waste significantly. In addition to directly reusing clothing, the collected textile fiber waste could be converted into usable nonwoven applications such as wipes or shredded into being used as fillers [21]. In addition, recently, the microstructure and performance characteristics of acoustic insulation materials made from post-consumer recycled denim fabrics have been assessed [11,22–24].

Sharma and Goel [25] developed nonwoven fabrics using polyester/cotton recycled fibers with different proportions (70:30, 50:50, and 70:30) with the needle punching method, and the various properties of the developed nonwoven fabrics were analyzed. It was indicated that the most proper ratio of nonwoven blended fabric based on physical properties was the 30:70 cotton/polyester fiber blend. Ichim and Sava [26] also studied the spinnability of recycled cotton fibers blended with virgin cotton at 20/80, 40/60, and 60/40 proportions. The result revealed that as the percentage of waste increases, the yarn has decreased breaking elongation but increased yarn irregularity and mass irregularity. Additionally, they indicated that these types of yarns with the percentage of reclaimed cotton could be used as a gauze bandage fabric due to its short lifespan and because their application focuses on absorbency rather than uniformity and strength. Thilak and Dhandapani [27] studied the influence of blend ratio on the quality aspects of recycled cotton and polyester yarn and indicated that the ratio of recycled polyester significantly affects the quality of recycled cotton and polyester blended yarn. As a result of increasing the tenacity of the blended yarn, the elongation at break and hairiness increases, and correspondingly, it decreases unevenness, thick and thin places, and neps.

In contrast, decreasing the linear density increases the tenacity, thick and thin places, elongation at break, neps, unevenness, and hairiness [27,28]. The intrinsic nature of the recycling process produces fibers with a short length of unopened or partially opened fibers, non-uniform, and a higher number of imperfections [29]. These restrictions enable only the production of coarser count yarns. However, the production of medium and fine count yarns is yet to be explored. Wei and Liang found that properly using waste textiles and clothing recycling has gained much attention in the post-COVID era [30]. New spinning systems, including friction, rotor, and ring spinning, have successfully produced recycled polyester and cotton yarns. Rotor spinning is one of the most widely used spinning techniques for producing reclaimed yarns [31].

Recently, Wang et al. [32] studied virgin polyester and cotton blending using principal component analysis and grey relational analysis. This work investigated the properties of recycled yarn produced from recycled fiber and virgin cotton with different proportions. The recycled fiber and virgin cotton were mixed in different proportions to coarser count yarns. Producing finer yarn is a future task that needs further research based on the results we acquire from this research. The number of runs and proportions were identified using Design-Expert software’s central composite design method [33].
2. Experimental

2.1. Materials

Pre-consumer (industrial) knitted waste fabric was collected from a cutting and stitching department of the garment industry. When cutting knitted fabric for garment production, much of the knitted fabric becomes waste material due to improper pattern laying and cutting problems. In addition, pre-consumer knitted waste fabric occurs in the knitting process due to defects. All defective knitted fabric was removed during fabric inspection. The type of waste and other waste fiber and fabric parameters were measured and are presented in Tables 1 and 2. The waste comprised different colors and parameters; therefore, it is taken in a range.

Table 1. Pre-consumer waste fabric parameters.

| Fabric Type | Knitting |
|-------------|----------|
| Structure   | Plain    |
| Weight (gm/m²) | 140–180 |
| Thickness (mm) | 0.4–0.6 |
| Course density (cpi) | 40–50 |
| Wale density (wpi) | 30–40 |
| Yarn count (tex) | 18–30 |
| Yarn twist (tpm) | 150–230 |

Table 2. Parameters of waste acrylic weft yarn.

| Fiber Type         | Regenerated Acrylic |
|--------------------|---------------------|
| Yarn count (tex)   | 738                 |
| Yarn twist (tpm)   | 185                 |
| Breaking strength (N) | 24.6               |
| Elongation (%)     | 11.97               |

Waste of weft yarn (recycled acrylic) was used as an additional material in the recycled fiber. This was mixed with waste fabric, and both were converted to fiber as shown in Figure 1; the parameters of waste yarn are shown in Table 2.

![Figure 1](image)

The collected fabric and yarn wastes were mixed and converted into recycled fiber using a Garnet shredding machine, and the recycled fiber was then tested for the different properties as shown below in Table 3. The fiber length, fineness, and strength were measured. The trash content was analyzed by the Shirley trash analyzer. Chemical (solvent) identification showed that cotton, acrylic, and polyester fibers were found in the recycled fiber at percentages of 32.5%, 49.8%, and 15.9%, respectively. The remaining percentage could be protein fibers such as wool and silk. The chemical analysis was carried out as per the ASTM-D5103-07 standard by using sulfuric acid (99.8%), sodium hydroxide (pellets), and zinc chloride.
Table 3. Recycled fiber properties.

| Parameters                  | Value |
|-----------------------------|-------|
| Fiber length (mm)           | 30    |
| Fiber fineness (dtex)       | 1.75  |
| Fiber strength (cN/tex)     | 27.6  |
| Elongation (%)              | 13.5  |
| Trash content and noil (%)  | 12.42 |

Virgin cotton fiber was collected from the factory, and the properties were tested using a High Volume Instrument; the results are presented in Table 4.

Table 4. Virgin cotton fiber properties.

| Parameters                  | Unit       | Average Value | Standard  | Performance Level |
|-----------------------------|------------|---------------|-----------|-------------------|
| Moisture                    | %          | 6.3           | 4.5–6.5   | Low moisture      |
| Micronaire value            |            | 3.58          | 3.0–3.6   | Fine              |
| Maturity                    |            | 0.82          | 0.75–0.85 | Immature          |
| UHML                        | mm         | 26.4          | 26.2–27.8 | Medium-long       |
| Uniformity index            | %          | 80.8          | 81–84     | Medium            |
| Short fiber content         | %          | 9.4           | 10–13     | Medium            |
| Strength                    | g/tex      | 25.1          | 25–27     | Medium            |
| Elongation                  | %          | 8.4           | ≥ 7       | Very high         |
| Trash content               | %          | 6.26          | 4–7       | Dirty             |
| Sticky point                | No.        | 0.6           | 0–2       | Very small        |

2.2. Yarn Production

The recycled fiber and virgin cotton were mixed in different proportions. The number of runs and proportions were identified using the central composite design method from Design-Expert software [34,35], as shown in Table 5.

Table 5. Optimized central composite design for recycled fiber/cotton fiber proportion.

| Std  | Run | Factor 1 A: Recycled Fiber% | Factor 1 B: Recycled Fiber% |
|------|-----|----------------------------|-----------------------------|
| 2    | 1   | 50                         | 50                          |
| 6    | 2   | 35                         | 65                          |
| 5    | 3   | 25                         | 75                          |
| 4    | 4   | 40                         | 60                          |
| 3    | 5   | 20                         | 80                          |
| 1    | 6   | 30                         | 70                          |

Yarn of 131 tex (4.5 Ne) was manufactured on a rotor spinning machine with seven different combinations of recycled fiber and cotton fiber. The yarn was investigated for its physical properties. The result was inserted into the software and analyzed using different tools, as presented in Table 6.

Table 6. Two-level factorial design for recycled fiber/cotton fiber proportion.

| Std  | Run | Factor 1 A: Recycled Fiber% | Factor 1 B: Recycled Fiber% |
|------|-----|----------------------------|-----------------------------|
| 5    | 1   | 35                         | 65                          |
| 4    | 2   | 40                         | 60                          |
| 6    | 3   | 45                         | 55                          |
| 7    | 4   | 30                         | 70                          |
| 2    | 5   | 20                         | 80                          |
| 3    | 6   | 25                         | 75                          |
| 1    | 7   | 50                         | 50                          |
This software performed another hundred runs between those seven proportions depending on the given results. From the 100 runs, the proportions which had the optimum result were selected. The selected optimum proportion was used to produce a 10 Ne count of yarn, and sample denim fabric was produced using this yarn. Thus, the fabric used recycled fiber/cotton blended yarn as a weft yarn because it was challenging to produce in a warp.

2.3. Denim Fabric Production

During sample denim fabric production, the recycled yarn is used as weft yarn because denim fabric is made of dyed warp and undyed weft yarn, so the recycled yarn cannot be used as warp; it cannot be dyed. The second reason is that there is the insufficient yarn for the warping process. In addition, it is better to use recycled yarn as a weft thread as it is hiding in the back side of the fabric. However, there is high weft breakage because the twist was not in the required amount. It has a twist multiplier of less than 3, but the required twist multiplier is 5.2–5.6. If it produces with the required twist level, it can be used for denim fabric production rather than a blanket. The fabric was produced using a TOYOTA air jet weaving machine with a loom speed of 848 rpm.

3. Results and Discussion

In order to study the effect of recycled fiber and cotton fiber content on the yarn property, seven different proportions were produced and are presented in Figure 2 from the software.

![Yarns produced with different proportions of recycled fiber and cotton fiber.](image)

The analyzed results by Design-Expert software with two factors (Factor 1: Recycled fiber; Factor 2: Cotton fiber) are presented in Table 7. The six responses (Response 1: Yarn strength; Response 2: Yarn elongation; Response 3: Yarn unevenness; Response 4: Thin place; Response 5: Thick place; Response 6: Neps) are presented in Tables 8 and 9.

| Parameters                      | Results                      |
|---------------------------------|------------------------------|
| Warp yarn                       | Cotton                       |
| Weft yarn                       | Recycled/cotton blend        |
| Warp and weft yarn count        | 10 s open-end yarn           |
| Warp density                    | 60 end per inch              |
| Weft density                    | 42 pick per inch             |
| Weave type                      | 3/1 right-hand twill         |

| Factors | Fiber   | Unit | Minimum | Maximum | Mean  | Std dev |
|---------|---------|------|---------|---------|-------|---------|
| A       | Recycled| %    | 20.00   | 50.00   | 35.00 | 10.80   |
| B       | Cotton  | %    | 50.00   | 80.00   | 65.00 | 10.80   |
Table 9. Description of responses (yarn properties).

| Response | Property            | Unit       | Obs | Max   | Min  | Mean   | Std dev |
|----------|---------------------|------------|-----|-------|------|--------|---------|
| R1       | Yarn strength       | cN/tex     | 7   | 7.13  | 4.38 | 5.95   | 0.8597  |
| R2       | Yarn elongation     | %          | 7   | 10.85 | 6.35 | 9.29   | 1.67    |
| R3       | Yarn unevenness     | U%         | 7   | 15.64 | 12.11| 13.57  | 1.16    |
| R4       | Thin place (~50%)   | -          | 7   | 68    | 12   | 33.14  | 17.81   |
| R5       | Thick place (+50%)  | -          | 7   | 812   | 104  | 345.5  | 251.58  |
| R6       | Neps (+200%)        | -          | 7   | 852   | 198  | 390.4  | 226.88  |

The six basic properties (Responses) of yarn were studied, and the result is presented in Table 9.

**Predicted value vs. actual value**: The predicted value was compared with the actual value for each response. In Figure 3, the solid line indicates the predicted value, and the dots indicate the actual value. The actual values of yarn strength, elongation, and unevenness coincided with the predicted values, as shown in Figure 3.

Figure 3. Predicted vs. actual values of yarn strength, elongation, and unevenness.

However, the actual values of yarn imperfection (neps as well as a thin and thick places) did not coincide with the predicted values as shown in Figure 4, which means that for this model, the yarn imperfections were less affected by the recycled fiber or cotton fiber.

Figure 4. Predicted vs. actual values of neps and thin and thick places.
3.1. Correlation and Regression

The relation between each factor and response is shown below in Figure 5: as the color goes to blue, the relation is a strong negative correlation (inverse relation), and as the color goes to red, the relation is a strong positive correlation (direct relation).

Recycled fiber has a strong negative correlation with yarn strength and yarn elongation (−0.922 and −0.948, respectively), which means that as recycled fiber increases, the yarn strength and elongation decrease. But it has a strong positive correlation with yarn unevenness, 0.959. It correlates 0.572, 0.386, and 0.598 with the thin place, thick place, and neps, respectively. The correlation between cotton fiber and each response is inverse of the correlation between recycled fiber and responses. Cotton fiber has a strong positive correlation with yarn strength and yarn elongation (0.922 and 0.948, respectively), which means that as cotton fiber increases, the yarn strength and elongation also increase. But it has a strong negative correlation with yarn unevenness, −0.959; as the cotton fiber increases, the yarn unevenness will decrease. The cotton fiber has a correlation of −0.572, −0.386, and −0.598 with thin and thick places and neps, respectively, shown in Figure 6. Therefore, yarn strength, elongation, and unevenness are highly affected by the proportions of cotton and recycled fiber, and the yarn-produced imperfections (thin and thick places and neps) are affected to some extent.

Figure 5. Correlation between recycled fiber and yarn properties.

Figure 6. Correlation between cotton fiber and yarn properties.
3.2. Interaction between Factor and Response

3.2.1. Interaction between Cotton Fiber/Recycled Fiber Proportion and Yarn Strength

The interaction between the factors (cotton fiber/recycled fiber proportion) and Response 1 (yarn strength) indicates that as the cotton fiber percentage increases, the yarn strength increases, but as the recycled fiber amount increases, the yarn strength decreases as shown in Figure 7. The optimum result was observed with the proportion of 72% cotton fiber and 28% recycled fiber.

![Figure 7. Two- and three-dimensional plots of the interaction of cotton fiber/recycled fiber proportion and yarn strength.](image)

3.2.2. Interaction between Cotton Fiber/Recycled Fiber Proportion and Yarn Elongation

The interaction between the factors (cotton fiber/recycled fiber proportion) and Response 2 (yarn elongation) indicated that as the cotton fiber percentage increases, the yarn elongation also increases, but as the recycled fiber amount increases, the yarn elongation decreases, as shown in Figure 8. The optimum result was observed with 66% cotton fiber and 24% recycled fiber, indicated by the red color.

3.2.3. Interaction between Cotton Fiber/Recycled Fiber Proportion and Yarn Unevenness

The interaction between the factors (cotton fiber/recycled fiber proportion) and Response 3 (yarn unevenness) indicated that as the cotton fiber percentage increases, the yarn unevenness decreases. However, as the recycled fiber amount increases, the yarn unevenness increases, as shown in Figure 9. To obtain the minimum result, cotton fiber should be above 70% and recycled fiber should be below 26%, which is indicated by the blue color.
3.2.4. Interaction between Cotton Fiber/Recycled Fiber Proportion and Thin Place (−50%)

The interaction between the factors (cotton fiber or recycled fiber proportion) and Response 4 (thin place) indicated that as the cotton fiber percentage increases, thin places on the yarn decrease, but as the recycled fiber amount increases, thin places increase, as shown in Figure 10. Thus, to obtain a favorable result, cotton fiber should be above 70% and recycled fiber should be below 26%, which is indicated by the blue color.
Figure 10. Two- and three-dimensional plots of the interaction of cotton fiber/recycled fiber proportion and yarn thin place (−50%).

3.2.5. Interaction between Cotton Fiber/Recycled Fiber Proportion and Thick Place (+50%)

The interaction between the factors (cotton fiber/recycled fiber proportion) and Response 5 (thick place) indicated that as the cotton fiber percentage increases, thick places on the yarn decrease, but as the recycled fiber amount increases, thick places increase, as shown in Figure 11. However, sometimes there is also a sudden change, possibly due to another factor. To obtain a favorable result, cotton fiber should be above 71% and recycled fiber should be below 25%, which is indicated by the blue color.

Figure 11. Two- and three-dimensional plots of the interaction of cotton fiber/recycled fiber proportion and yarn thick place (+50%).
3.2.6. Interaction between Cotton Fiber/Recycled Fiber Proportion and Neps (+200%)

The interaction between the factors (cotton fiber/recycled fiber proportion) and Response 6 (Neps) indicated that as the cotton fiber percentage increases, neps on the yarn decrease, but as the recycled fiber amount increases, neps also increase, as shown in Figure 12. To obtain a favorable result, cotton fiber should be above 60% and recycled fiber should be below 28%, which is indicated by the blue color.

![Figure 12. Two- and three-dimensional plots of the interaction of cotton fiber/recycled fiber proportion and Neps (+200%).](image)

After the responses were analyzed, one hundred runs were made by the software to find out the optimum proportion, as shown in Figure 13. The yarn properties were predicted for each of the hundred runs, and then, the optimum result was selected (the first run in Figure 13).

![Figure 13. Graphical selection of optimum proportion of recycled and cotton fiber.](image)
Finally, the software confirmed the optimum proportion, 39/61, with 95% confidence, as shown in Table 10. Thus, this proportion was used to produce the yarn of 10 Ne count for sample denim fabric production (as shown in Figure 14).

Table 10. Test results of each response for seven runs.

| Trial | Recycled fiber (%) | Cotton fiber (%) | Yarn strength (cN/tex) | Yarn elongation (%) | U% | Thin place (−50%) | Thick place (+50%) | Nep (+200%) |
|-------|--------------------|------------------|------------------------|--------------------|----|------------------|-------------------|------------|
| 1     | 20                 | 80               | 6.13                   | 9.89               | 13.23 | 32               | 307               | 480        |
| 2     | 25                 | 75               | 5.9                    | 8.67               | 13.74 | 42               | 562               | 404        |
| 3     | 30                 | 70               | 5.46                   | 8.07               | 14.37 | 68               | 812               | 852        |
| 4     | 35                 | 65               | 6.44                   | 10.54              | 13.07 | 26               | 212               | 254        |
| 5     | 40                 | 60               | 7.13                   | 10.85              | 12.11 | 12               | 184               | 198        |
| 6     | 45                 | 55               | 6.2                    | 10.63              | 12.81 | 28               | 238               | 227        |
| 7     | 50                 | 50               | 4.38                   | 6.35               | 15.64 | 24               | 104               | 318        |

Figure 14. Denim fabric produced from recycled yarn and cotton yarn.

Some physical properties of the produced sample fabric, such as tensile strength, elongation, tear strength, pilling, and abrasion, were tested, and the result is presented in Table 11.

Table 11. Confirmation of the selected optimum proportion.

| Response            | Prediction Mean | Prediction Median |
|---------------------|-----------------|-------------------|
| Yarn strength       | 5.65512         | 5.65512           |
| Yarn elongation     | 8.70025         | 8.70025           |
| Yarn unevenness     | 13.978          | 13.978            |
| Thin place (−50%)   | 36.9145         | 36.9145           |
| Thick place (+50%)  | 381.517         | 381.517           |
| Nep (+200%)         | 440.718         | 440.718           |
The result shows that the fabric has favorable tensile strength and elongation, even if it was produced without spandex (Table 12). The abrasion and pilling test indicated a moderate change in color with visual fraying and slight to moderate pilling. However, further study is needed to analyze denim fabric produced from recycled and pure cotton yarn.

| Parameters                  | Results          |
|-----------------------------|------------------|
| Thickness (mm)              | 1.07             |
| Tensile strength (N)        | 429, in weft direction |
| Elongation (%)              | 11.25, in weft direction |
| Tear strength (N)           | 48.62, in the weft direction |
| Pilling                     | 3/4              |
| Abrasion                    | 3                |
| Warp and weft yarn count    | 10 s OE          |

4. Conclusions

As per the designed method, the results show that as the composition of recycled fiber in the blend increases, the yarn properties such as strength, elongation, and evenness are reduced, and vice versa. The yarn imperfections increased to some extent as the recycled fiber amount increased. Thus, yarn strength, yarn elongation, and yarn evenness are significantly affected by the recycled fiber/cotton fiber proportion. Therefore, from the seven proportions (20/80, 25/75, 30/70, 35/65, 40/60, 45/55, and 50/50 recycled fiber/cotton fiber) and from the other 100 proportions between those seven proportions, which were made by Design-Expert software, the optimum result was found with the 39/61–40/60 proportion. Additionally, 10 Ne yarn was produced using this optimized proportion and used for denim fabric production, even if it was not on the required specification. The sample fabric had favorable physical properties. Therefore, the recycled fiber can be used to produce denim fabric by producing yarn with the required specification.

Author Contributions: Conceptualization, H.M. and H.S.A.; methodology, H.M. and H.S.A.; software, H.M. and H.S.A.; validation, H.M. and H.M.Y.; formal analysis, H.M. and H.S.A.; investigation, H.S.A. and H.M.Y.; resources, H.M. and H.M.Y.; data curation, H.M. and H.M.Y.; writing—original draft preparation, H.M. and H.S.A.; writing—review and editing, H.M. and L.S.; visualization, H.M., H.M.Y. and L.S.; supervision, H.M.; project administration, H.M.Y.; funding acquisition, H.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Research Fund for International Scientists (RFIS-52150410416), the National Natural Science Foundation of China, and the Research Startup grant of ZSTU (20202294-Y).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We acknowledge the technical staff of Eitex, Bahir-Dar University, for assisting us in obtaining trails and experiments.

Conflicts of Interest: The authors declare no conflict of interest. In addition, the funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References
1. Haslinger, S.; Hietala, S.; Hummel, M.; Maunu, S.L.; Sixta, H. Solid-state NMR method for the quantification of cellulose and polyester in textile blends. *Carbohydr. Polym.* 2019, 207, 11–16. [CrossRef]
2. Li, X.; Wang, L.; Ding, X. Textile supply chain waste management in China. *J. Clean. Prod.* 2021, 289, 125147. [CrossRef]
3. Jianfang, L.; Wanying, C. Research on status and dilemma of sustainable clothing consumption behavior. *J. Silk* 2020, 57, 18–25.
4. Liu, A.; Guo, J. Cycle fashion: Research on the development and design method of textile and garment upgrading. *J. Silk* 2020, 57, 132–139.

5. Beshah, D.A.; Tiruye, G.A.; Mekonnen, Y.S. Characterization and recycling of textile sludge for energy-efficient brick production in Ethiopia. *Environ. Sci. Pollut. Res.* 2021, 28, 16272–16281. [CrossRef]

6. Sandin, G.; Peters, G.M. Environmental impact of textile reuse and recycling—A review. *J. Clean. Prod.* 2018, 184, 353–365. [CrossRef]

7. Weiran, Q.; Pinghua, X.; Laili, W. Review on Polyester Fiber Recycling and Progress of Its Environmental Impact Assessment. *Adv. Textile Technol.* 2021, 29, 22–26. [CrossRef]

8. Qian, W.; Ji, X.; Xu, P.; Wang, L. Carbon footprint and water footprint assessment of virgin and recycled polyester textiles. *Text. Res. J.* 2021, 91, 2468–2475. [CrossRef]

9. Abd, S.; Hussain, T.; Nazir, A.; Raza, Z.A.; Siddique, A.; Azeem, A.; Riaz, S. Simultaneous Fixation of Wrinkle-Free Finish and Reactive Dye on Cotton Using Response Surface Methodology. *Cloth. Text. Res. J.* 2017, 36, 119–132. [CrossRef]

10. Ahmad, S.; Ashraf, M.; Abd, S.; Jabbar, M.; Shafiq, F.; Siddique, A. Recent Developments in Laser Fading of Denim: A Critical Review. *J. Nat. Fibers* 2022, 1, 1–11. [CrossRef]

11. Siddique, A.; Hassan, T.; Abd, S.; Ashraf, M.; Hussain, A.; Shafiq, F.; Khan, M.Q.; Kim, I.S. The Effect of Softeners Applications on Moisture Management Properties of Polyester/Cotton Blended Sandwich Weft-Knitted Fabric Structure. *Coatings* 2021, 11, 575. [CrossRef]

12. Aronsson, J.; Persson, A. Tearing of post-consumer cotton T-shirts and jeans of varying degree of wear. *J. Eng. Fiber Fabr.* 2020, 15, 1558925020901322. [CrossRef]

13. Grębosz-Krawczyk, M.; Siuda, D. Attitudes of young European consumers toward recycling campaigns of textile companies. *Autex Res. J.* 2019, 19, 394–399. [CrossRef]

14. Tshifularo, C.A.; Patmaik, A. Recycling of plastics into textile raw materials and products. In *Sustainable Technologies for Fashion and Textiles*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 311–326.

15. Wang, H.; Memon, H.; Abro, R.; Shah, A. Sustainable Approach for Melange Yarn Manufacturers by Recycling Dyed Fibre Waste. *Fibres Text. East. Eur.* 2020, 3, 18–22. [CrossRef]

16. Chaka, K.T. Beneficiation of Textile Spinning Waste: Production of Nonwoven Materials. *J. Nat. Fibers* 2021, 1–10. [CrossRef]

17. Bizuneh, B.; Tadesse, R. Investigation of Ethiopian apparel industry’s fabric waste and its management strategies. *J. Text. Inst.* 2022, 113, 141–150. [CrossRef]

18. Dash, A.K.; Nayak, R. Management of protective clothing waste. In *Waste Management in the Fashion and Textile Industries*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 233–251.

19. Jiaqi, L. Research on the Design of Used Clothes Recycling Space Oriented by Experiential Business. *Furnit. Inter. Des.* 2020, 9, 116–119. [CrossRef]

20. Stanescu, M.D. State of the art of post-consumer textile waste upcycling to reach the zero waste milestone. *Environ. Sci. Pollut. Res.* 2021, 28, 14253–14270. [CrossRef]

21. Leal Filho, W.; Ellams, D.; Han, S.; Tyler, D.; Boiten, V.J.; Paço, A.; Moora, H.; Balogun, A.-L. A review of the socio-economic advantages of textile recycling. *J. Clean. Prod.* 2019, 218, 10–20. [CrossRef]

22. Islam, S.; El Messiry, M.; Sikdar, P.P.; Seylar, J.; Bhat, G. Microstructure and performance characteristics of acoustic insulation materials from post-consumer recycled denim fabrics. *J. Ind. Text. 2020*, 1528083720940746. [CrossRef]

23. Siddique, A.; Hussain, T.; Ibrahim, W.; Raza, Z.A.; Abid, S. Optimization of discharge printing of indigo denim using potassium permanganate via response surface regression. *Pigm. Resin Technol.* 2018, 47, 228–235. [CrossRef]

24. Siddique, A.; Hussain, T.; Ibrahim, W.; Raza, Z.A.; Abid, S.; Nazir, A. Response surface optimization in discharge printing of denim using potassium permanganate as oxidative agent. *Cloth. Text. Res. J.* 2017, 35, 204–214. [CrossRef]

25. Sharma, R.; Goel, A. Development of nonwoven fabric from recycled fibers. *J. Text. Sci. Eng.* 2017, 7, 289–292.

26. Ichim, M.; Sava, C. Study on recycling cotton fabric scraps into yarns. *Bul. Agir.* 2016, 3, 65–68.

27. Vadicherla, T.; Saravanan, D. Effect of blend ratio on the quality characteristics of recycled polyester/cotton blended ring spun yarn. *Fibres Text. East. Eur.* 2017, 25, 48–52. [CrossRef]

28. Memon, H.; Khoso, A.N.; Memon, S. Effect of dyeing parameters on physical properties of fibers and yarns. *Int. J. Appl. Sci. Eng. Res.* 2015, 4, 401–407.

29. Wagaye, B.T.; Adamu, B.F.; Jhialil, A.K. Recycled Cotton Fibers for Melange Yarn Manufacturing. In *Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling*; Wang, H., Memon, H., Eds.; Springer: Singapore, 2020; pp. 529–546.

30. Shansen, W.; Jianfang, L. The impact of COVID-19 on the attention to sustainable clothing consumption: Analysis of Baidu indexes on old clothes recycling, old clothes renovation and old clothes donation. *J. Silk* 2021, 58, 40–46. [CrossRef]

31. Shi, J.; Liang, W.; Wang, H.; Memon, H. Recent Advancements in Cotton Spinning Machineries. In *Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling*; Wang, H., Memon, H., Eds.; Springer: Singapore, 2020; pp. 165–190.

32. Hanqi, W.; Weiil, W.; Xuefeng, G.; Weilai, C. Grey Relational Analysis of Principal Components of Sustainable Cotton Blended Yarn. *Adv. Text. Technol* 2021, 29, 55–61. [CrossRef]

33. Memon, H.; Chaklie, E.B.; Yesuf, H.M.; Zhu, C. Study on Effect of Leather Rigidity and Thickness on Drapability of Sheep Garment Leather. *Materials* 2021, 14, 4553. [CrossRef]
34. Xingying, Z.; Xiaojun, Y.; Dongpo, G. Influence of Vibration Characteristic Parameters on Vibration Response of Single Degree of Freedom System. *Pack. Eng.* 2020, 41, 75–81. [CrossRef]

35. Pengcheng, Z.; Junyuan, W.; Linyu, M.; Yiming, C. Optimization of process parameters for preparation of CS/PEO by electrospinning based on response surface methodology. *J. Silk* 2020, 57, 31–34. [CrossRef]