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# Towards Circular Fabric Manufacturing: Fuzzy Linear Regression Modeling of Fabric Performance Using Recycled Fibre Content

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## Article

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## ABSTRACT

*The transition to circular textile manufacturing necessitates the effective incorporation of recycled fibers while ensuring consistent fabric performance. This research demonstrates the feasibility of producing circular knitted fabrics from recycled cotton, eco-viscose, and modal tri-blend fibres under industrial knitting conditions using full-scale machinery, and subsequently introduces a comparative modeling framework to evaluate the effects of recycled cotton content, yarn count, and stitch length on fabric areal density and bursting strength. A Box–Behnken design was employed to generate knitted fabric samples under controlled processing conditions. Quadratic regression and fuzzy linear regression were used to model the relationships between process variables and fabric responses. Both models demonstrated strong predictive capability, indicating that recycled fibre content interacts significantly with yarn count and stitch length in determining fabric compactness and mechanical resistance. Increasing yarn count and optimizing stitch length were found to enhance fabric structural stability. This study integrates predictive modeling with circular material utilization to establish a framework that enhances processes and forecasts performance in the production of fabric derived from recycled cotton fibers. The resulting fabrics showed GSM values of 118–160 g/m<sup>2</sup> and bursting strength of 549–853 kPa, indicating stable fabric structure and adequate mechanical performance even with recycled cotton incorporation.*

## KEYWORDS

*circular economy, recycled fibre, fuzzy linear regression, quadratic regression, Box-Behnken design*

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## INTRODUCTION

The textile industry is one of the most resource-intensive manufacturing industries in the world. It uses significant amounts of water, energy, and chemicals, and it generates a lot of solid waste and air pollution [1, 2]. The traditional linear manufacturing approach has a “take, make, and dispose” structure, which quickly uses up resources and creates a lot of waste. As a result, the circular economy has emerged as a strategic framework that promotes the reuse, recycling, and regeneration of materials to mitigate their environmental impact and extend product life cycles [3, 4]. In the textile sector, circular strategies focus on recovering fibres, employing recycled materials, and substituting fresh resources with ones that have been used before [5, 6]. The transition toward circular textile systems also aligns with the objectives of the United Nations Sustainable Development Goal 12 (SDG 12): Responsible Consumption and Production, which emphasizes efficient resource utilization and waste reduction in industrial processes. The incorporation of recycled fibres into textile manufacturing contributes directly to this goal by promoting material reuse and reducing dependence on virgin raw materials. A viable route for circular textile systems is provided by recycled cotton made from pre-consumer fabric waste. Growing virgin cotton requires substantial amounts of water, land, and chemicals, which hurt the ecology and the climate [7]. Recycled cotton, on the other hand, lessens the need for virgin fiber manufacturing and has a smaller impact on the environment as a whole [8]. However, recycled cotton fibers frequently display reduced staple length and toughness as a result of mechanical processing during recycling [9]. These traits could have an effect on the structure of the yarn, the cohesiveness of the fibers, and the mechanical performance of the fabric.

Regenerated cellulosic fibres can be introduced to improve performance while enhancing circularity. Circulose is a type of regenerated cellulose pulp made from recycled textile waste and wood pulp that comes from sustainably sourced wood pulp. It allows for closed-loop regeneration of cellulose and lessens the need for traditional viscose procedures [10, 11]. Textile production can become more circular by using Circulose instead of viscose, while yet maintaining desirable fiber properties [12]. This study also used modal fiber to make the yarn stronger, more stable in size, and smoother on the surface. Compared to regular viscose fibers, modal fibers are noted for being stronger and shinier [13, 14]. So, Circulose, recycled cotton, and modal work together to form a fiber system that is both environmentally sustainable and functionally effective.

Even while sustainable fiber replacement is important, there isn't much validation on an industrial scale yet. A lot of earlier research has looked at fiber characterization on a lab scale or yarn level examination

[15-17]. There is limited research evidencing the complete substitution of virgin cotton with recycled cotton in industrial knitting contexts while preserving satisfactory fabric performance. Yarn count and stitch length have a big effect on important structural and mechanical properties of knitted textiles, like GSM (fabric mass per unit area) and bursting strength [18, 19]. Modifications in fiber composition and structural characteristics influence loop shape, fabric density, and load distribution. So, predictive modeling is needed to figure out how to make these relationships better.

Methods like multi linear regression and response surface methodology are frequently utilized to assess interactions between process properties in the field of textile engineering [20-25]. Quadratic regression models are very effective at finding nonlinear effects and interactions between process factors [26]. These deterministic models give accurate core predictions and make optimization easier by requiring less experimentation.

Deterministic regression, on the other hand, assumes that the system will always act the same way. Recycled fiber systems exhibit greater variability due to variations in waste feedstock and regeneration processes [27, 28]. Ignoring this variability could make projections less accurate in real-world industrial settings. Recent sustainability research underscores the necessity of integrating uncertainty representation into predictive models to enhance decision-making support and risk awareness [29, 30].

Fuzzy linear regression is a novel technique to model that takes into consideration both uncertainty and imprecision. In fuzzy regression, coefficients are represented as fuzzy numbers with ranges instead of distinct values. This technique yields interval-based forecasts that capture the intrinsic variability present in engineering systems [31, 32]. Fuzzy modeling has been utilized in several technical fields; nevertheless, its implementation in recycled fiber-based circular textile manufacturing is still restricted. Moreover, there is a lack of comparative analyses between deterministic quadratic regression and fuzzy linear regression in the same industrial circular textile setting. Integrated investigations encompassing experimental design, complete virgin fiber substitution, industrial processing conditions, and comparative predictive modeling are essential. This study creates a complete framework for making circular fabric using recycled cotton derived from pre-consumer fabric waste. Circulose as a more environmentally friendly alternative to viscose, and modal fiber used here to make the fabric stronger and look better. Recycled cotton was utilized instead of virgin cotton to make the fabric more circular. The fabrics were made using a structured Box Behnken experimental design in a factory setting for knitting. recycled cotton derived from pre-consumer fabric waste.

Fuzzy linear regression and quadratic regression models were subsequently created, and both models were evaluated using statistical accuracy metrics and fuzzy uncertainty metrics. This study presents a feasible framework for sustainable textile production through the integration of circular fiber with deterministic and uncertainty-informed predictive modeling. The findings facilitate the advancement of circular textile production systems while maintaining structural integrity and mechanical efficiency.

## MATERIALS AND METHODS

### Raw Materials

The recycled cotton fibers from pre-consumer knitted clothing were collected from a local recycling facility in Dhaka, Bangladesh. The waste fabrics were shredded by machine to recover recycled cotton fibres. The recycled cotton had shorter fibers and more short fibers than virgin cotton since it had been processed mechanically many times. This study totally replaced virgin cotton with recycled cotton to maximize the utilization of circular material. Circulose-based regenerated cellulose fibre was used as an alternative to conventional viscose. Recycled textile waste and wood pulp from sustainable sources are mixed together to make circulose pulp. This regenerated cellulose technology helps fibers regenerate in a circular way while still working well mechanically. Modal fiber was used to make the yarn stronger, longer, and smoother on the surface. Modal fibers are made from beech wood pulp and are stronger and more stable than normal viscose fibers. Three different tri-blend fibre compositions were prepared to produce the yarns used in the study. The blend ratios of recycled cotton, eco-viscose, and modal fibre are presented in Table 1.

Table 1. Fibre blend compositions used for yarn production

Blend No.	Recycled Cotton (%)	Eco-viscose (%)	Modal (%)
1	25	45	30
2	30	40	30
3	20	50	30

To evaluate the quality of the produced tri-blend yarns, several standard yarn parameters were measured. Yarn unevenness (CVm%), imperfection index (IPI), and hairiness were determined using an USTER Evenness Tester under standard testing conditions. The count strength product (CSP) of the yarns was measured using a Lea Yarn Strength Tester following standard yarn strength testing procedures. For each yarn blend composition, ten tests were conducted and the average values were recorded. The measured yarn properties for yarns

containing different proportions of recycled cotton are presented in Table 2. The sharp increase in IPI with higher recycled cotton content associated with fibre characteristics rather than an experimental outlier. IPI, representing the combined occurrence of thick places, thin places, and neps, is highly sensitive to short fibre content. Recycled cotton introduces a higher proportion of short fibres, while modal and eco-viscose fibres have relatively longer and more uniform lengths (~38 mm). The increasing short fibre disrupts fibre control in the drafting zone, leading to a disproportionate rise in imperfections. This trend is consistent with the increase in CVm% and hairiness, and the reduction in CSP, indicating a systematic deterioration in yarn quality with increasing recycled fibre content.

Table 2. Yarn quality parameters of tri-blend yarns containing different recycled cotton proportions

Recycled Cotton (%)	CVm (%)	IPI	Hairiness	CSP
20	14.74	268	5.40	2295
25	15.79	568	5.55	2120
30	16.93	933	5.75	2067

### Fibre Blending and Yarn Manufacturing

The proper amounts of recycled cotton, Circulose-based regenerated fiber, and modal were uniformly blended together using the experimental design proportions. To ensure sufficient material for the production of industrial yarn and fabric, 25 kg of fiber mixture was prepared for each blending condition. Three blend compositions were made using recycled cotton as the base. Recycled cotton made up 20%, 25%, and 30% of the total. To ensure the strength and smoothness of the surface, the modal fiber content was kept at 30% in all mixtures. Circulose fiber made up the rest of the mix. To keep the total fiber composition at 100%, the amount of Circulose was modified based on how much recycled cotton was used.

The combined fibers went through an industrial blow room and then carding. A breaker draw frame with six doublings and a finisher draw frame with eight doublings were utilized to make the card slivers more even. These processes facilitated homogeneous fibre blending and fibre parallelization, resulting in uniform sliver formation. A simplex machine was used to turn the finisher draw frame slivers into rovings. Then, ring spinning was done in a factory to make yarns with counts of 26 Ne, 30 Ne, and 34 Ne. To make sure that the structure was stable and consistent, the processing parameters were changed based on the yarn count needs. Winding was performed using an industrial autoconer machine to produce uniform yarn packages suitable for knitting.

## Fabric Production

Knitted fabrics were produced using a commercial circular knitting machine under industrial operating conditions. A 25-inch diameter, 24 gauge knitting machine operating at 12 rpm was used. Stitch length was adjusted according to the experimental design. Thirty-six yarn packages were used to feed 36 feeders during knitting to ensure stable industrial scale production. After knitting, the fabrics were allowed to relax under standard atmospheric conditions for 24 hours prior to testing. This procedure confirmed the technical feasibility of producing fabric at industrial scale using fully recycled cotton combined with Circulose and modal fibres. An Autoburst Bursting Strength Tester was used to find out how strong the fabric was when it burst, and a James Heal GSM Sample Cutter was used to cut a 100 cm<sup>2</sup> piece of cloth to measure the fabric GSM.

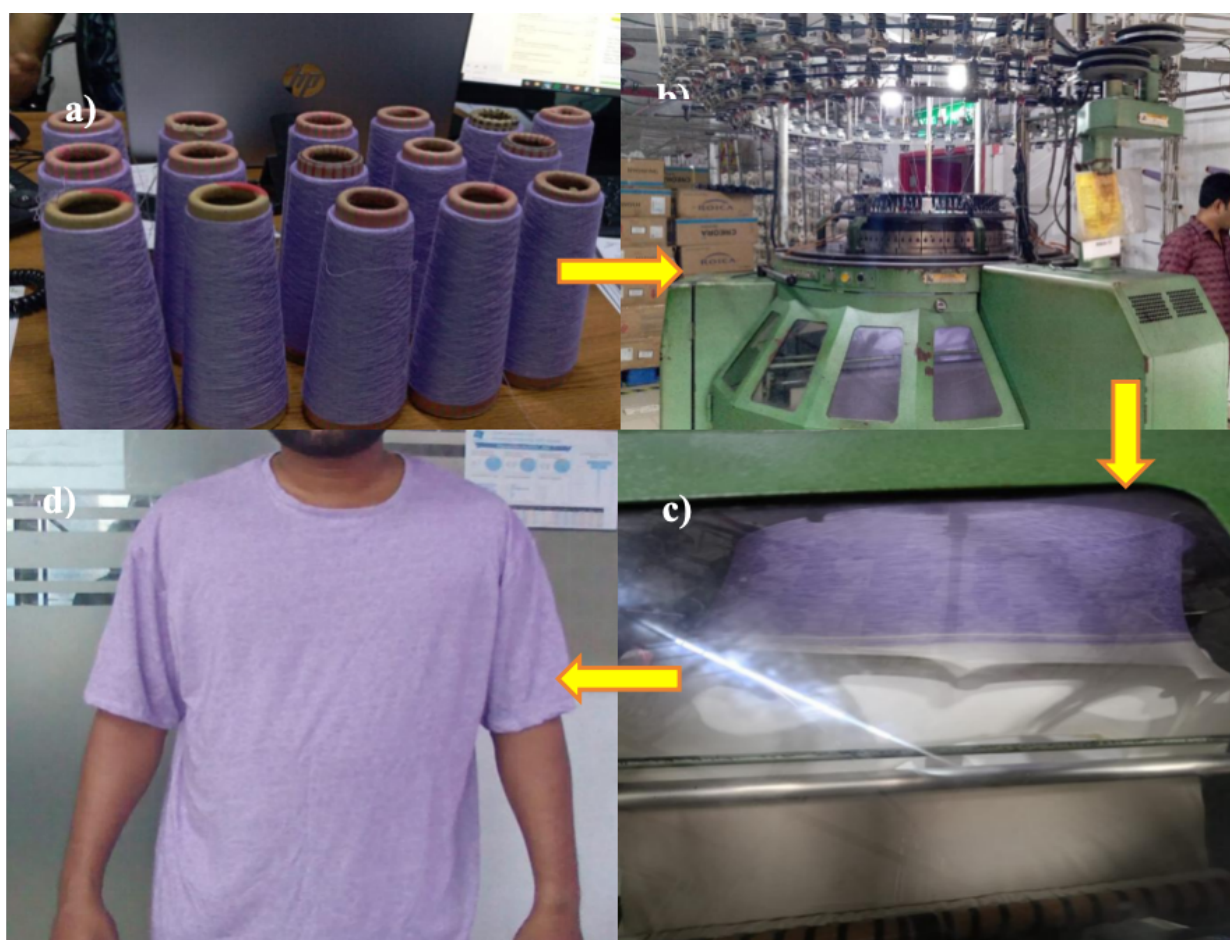


Figure 1. yarn packages of tri-blend yarn produced for knitting; (b) production of knit fabric in commercial circular knitting machine; (c) knit fabric; (d) T-shirt produced from fabric.

## Experimental Design

To investigate the combined effects of process parameters on fabric performance, a Box Behnken experimental design was employed. This design was selected because it efficiently evaluates quadratic response relationships using a limited number of experimental runs while maintaining statistical reliability [33, 34]. Three independent variables were considered in this study, namely yarn count (Ne), stitch length (mm), and recycled cotton fibre percentage in yarn. Each factor was studied at three levels representing low, center, and high conditions. The chosen parameter ranges were established considering industrial production viability and the stability of knitting performance. Table 3 shows the coded levels of the independent variables that were employed in the experimental design.

Table 3. Independent process variables and their coded levels used in the Box–Behnken experimental design

Parameter	Symbol	-1 (Low)	0 (Center)	+1 (High)
Yarn Count (Ne)	$X_{YC}$	26	30	34
Stitch Length (mm)	$X_{SL}$	2.70	2.75	2.80
Recycled Fibre (%)	$X_{RF}$	20	25	30

A three-factor, three-level Box Behnken design matrix was created using the chosen process variables and their coded levels. The design has fifteen experimental runs, three of which are repeated center points to check for experimental error and model adequacy. The coded numbers show standard factor levels, whereas the real values show the genuine industrial settings used to make fabric and yarn. Table 4 shows the entire design matrix, which includes both actual and coded values.

Table 4. A Box-Behnken design matrix with three factors and three levels, with coded values of -1, 0, and +1. The real values are the proportion of recycled cotton, the yarn count (Ne), and the stitch length (mm)

Run	A (coded)	B (coded)	C (coded)	Recycle Cotton (%)	Yarn Count (Ne)	Stitch Length (mm)
1	-1	-1	0	25	26	2.70
2	-1	+1	0	25	26	2.80
3	+1	-1	0	25	34	2.70
4	+1	+1	0	25	34	2.80
5	-1	0	-1	20	26	2.75
6	-1	0	+1	30	26	2.75
7	+1	0	-1	20	34	2.75
8	+1	0	+1	30	34	2.75
9	0	-1	-1	20	30	2.70
10	0	-1	+1	30	30	2.70
11	0	+1	-1	20	30	2.80
12	0	+1	+1	30	30	2.80
13	0	0	0	25	30	2.75
14	0	0	0	25	30	2.75
15	0	0	0	25	30	2.75

### Rationale for Employing Quadratic Regression and Fuzzy Linear Regression for Fabric Performance Modeling

The prediction of knitted fabric performance necessitates the consideration of both material properties and structural elements. The study shows that variables other than the percentage of recycled fibers affect the strength and amount of fabric per square meter. They are also affected by the yarn count and the length of the stitches. These three variables interact at the same time within the knitted structure.

Recycled cotton sourced from pre-consumer waste demonstrate diversity in fiber length and strength as a result of mechanical recycling methods [35]. But the makeup of the fibers alone does not affect how well the cloth works. The count of yarns influences the yarn's linear density and loop thickness [36]. The length of the stitches affects the shape of the loops and how tightly the fabric is packed [37]. The size of the loops and the density of the packing change when the yarn count changes [38]. When the stitch length changes, the fabric gets tighter and the load is spread out differently [19, 39]. So, the GSM and bursting strength of fabric depend on how the recycled fiber content, yarn count, and stitch length work together. These interactions are frequently nonlinear. For instance, adding more yarn may make the fabric denser at one stitch length but less stable at another stitch length. In the same way, the strength of recycled fiber may change depending on how fine the yarn is. Given the presence of nonlinear interactions, quadratic regression provides a suitable framework for predicting fabric performance.

Fabric properties such as GSM and bursting strength are governed by the combined effects of recycled fibre content, yarn count, and stitch length, which interact in a nonlinear manner. To capture these effects, a second-order polynomial (quadratic regression) model was employed [40]. The general second order polynomial model is expressed as:

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i + \sum_{i=1}^n \beta_{ii} X_i^2 + \sum_{i=1}^n \sum_{j=i+1}^n \beta_{ij} X_i X_j$$

Where,  $Y$  represents the response variable,  $X_i$  represents the independent variables, and  $\beta$  represents regression coefficients.

Quadratic regression makes reliable central predictions and is useful for process optimization and response surface analysis [41]. On the other hand, deterministic regression implies that experimental observations are unambiguous and certain [42]. However, recycled fibre systems exhibit inherent variability due to fibre damage, length irregularity, and process fluctuations. To incorporate such uncertainty, fuzzy linear regression (FLR) was applied. Fuzzy linear regression provides an alternative modeling methodology that integrates uncertainty into regression analysis [43, 44]. The general form of fuzzy linear regression is expressed as:

$$\tilde{Y} = \tilde{a}_0 + \sum_{i=1}^n \tilde{a}_i X_i$$

where each fuzzy coefficient is represented as:

$$\tilde{a}_i = (a_i^c, a_i^s)$$

Here,  $a_i^c$  is the central value and  $a_i^s$  is the spread associated with uncertainty.

This study creates a supplementary modeling framework by using both quadratic regression and fuzzy linear regression. Quadratic regression finds nonlinear relationships between the content of the fibers, the number of yarns, and the length of the stitches [45]. Fuzzy linear regression accounts for the uncertainty arising from variations in the recycled fiber and the process [46]. These methodologies work together to develop forecasts that are accurate, make sense in the real world, and take into account the fact that producing circular fabric on a big scale is not always easy.

## RESULTS AND DISCUSSION

The Box Behnken design stated above was employed in experiments to see how the number of yarns, the length of the stitches, and the amount of recycled fiber in the fabric all worked together to affect its performance. The fabric mass per unit area (in GSM) and bursting strength (in kilopascal) were measured for each run. These two reactions were selected because bursting strength indicates how well a building can withstand mechanical stress when loads are applied from various directions, while GSM indicates how compact a structure is [47].

Table 5 shows the full experimental design matrix and the values that were measured. The results show that the GSM and bursting strength vary significantly depending on the combination of process factors used. This kind of alteration shows that the way cloth operates relies on the fibers it has and how it is knit.

Table 5. Experimental design matrix and measured responses illustrating the impacts of recycled fiber content, yarn count, and stitch length on fabric GSM and bursting strength

Run	Recycle fibre % in yarn	Yarn Count (Ne)	Stitch Length (mm)	GSM	BS (kPa)
1	25	26	2.70	160	853
2	25	26	2.80	152	724
3	25	34	2.70	129	654
4	25	34	2.80	126	549
5	20	26	2.75	159	755
6	30	26	2.75	156	759
7	20	34	2.75	128	614
8	30	34	2.75	118	598
9	20	30	2.70	140	773
10	30	30	2.70	142	746
11	20	30	2.80	132	673
12	30	30	2.80	130	634
13	25	30	2.75	137	705
14	25	30	2.75	139	710
15	25	30	2.75	135	701

### Performance of the Fuzzy Linear Regression Model

Table 6 shows the statistical performance indicators for the fuzzy linear regression (FLR) models that were made to estimate fabric GSM and bursting strength based on the proportion of recycled fiber, yarn count, and stitch length. Using the core crisp predictions of the fuzzy model, the coefficient of determination ( $R^2$ ), the

mean absolute error (MAE), and the root mean square error (RMSE) were found. Also, total vagueness, which is the sum of the coefficient spreads, to measure uncertainty, was figured out.

Table 6. The fuzzy linear regression (FLR) models' performance metrics for predicting fabric GSM and bursting strength

Response Variable	R <sup>2</sup>	MAE	RMSE	Total Vagueness ( $\Sigma$ spreads)
GSM	0.9234	3.0106	3.4196	0.3085
BS (kPa)	0.9480	15.0677	17.2418	17.1818

The FLR model demonstrates strong predictive capability for both responses. GSM has an excellent linear explainability because its R<sup>2</sup> value is 0.9234. The low MAE and RMSE results show that the central predictions are correct within the range of the experiment [48]. Bursting strength has a R<sup>2</sup> value of 0.9480, which shows that it is even more accurate at predicting things. This shows that it is very dependent on the composition of the fibers and the structural factors.

The overall ambiguity numbers reveal that GSM behaves in a fairly steady way, but the bursting strength is uncertain. This behavior is physically justified because the structure of the loop, the strength of the yarn, and how the load is spread out under stress from all directions all determine how strong the yarn can burst. Overall, the FLR model generates accurate predictions and also takes into consideration the fact that interactions between recycled fiber and knitting settings can be uncertain.

### Analysis of Model Uncertainty and Total Vagueness

The spreads of the regression coefficients show how uncertain the model is in fuzzy linear regression. The total vagueness is the sum of these spreads [49]. It shows how unclear the model is overall. FLR gives interval-based predictions by adding variability to the regression coefficients, which is different from deterministic regression. In addition, a minor portion of the observed vagueness may arise from measurement-related uncertainties during sample testing, including instrument precision and testing conditions.

The total ambiguity value for GSM is 0.3085. The fact that the spread is so small shows that the amount of fabric mass per unit area is controlled by stable structural relationships between the proportion of recycled fiber, the yarn count, and the stitch length. The strong R<sup>2</sup> value of 0.9234, together with the low MAE of 3.0106 and RMSE of 3.4196, shows that GSM predictions are both correct and consistent in the experimental region. The total vagueness value for bursting strength, however, is much greater at 17.1818. The expected accuracy is still excellent, with R<sup>2</sup> equal to 0.9480, MAE equal to 15.0677, and RMSE equal to 17.2418. But the bigger

spread means that modifications in materials and structures have a bigger effect on bursting strength. This behavior makes sense physiologically since the strength of the yarn, how the loops fit together, how well the fibers hold together, and how the tension is distributed out in various directions all determine how strong the yarn is. In systems that employ recycled fiber, little changes to the length of the stitches or the quantity of yarns may have an effect on how the machine performs. Microscopic observations of the knitted fabric surfaces further support the variability associated with recycled fibre systems.

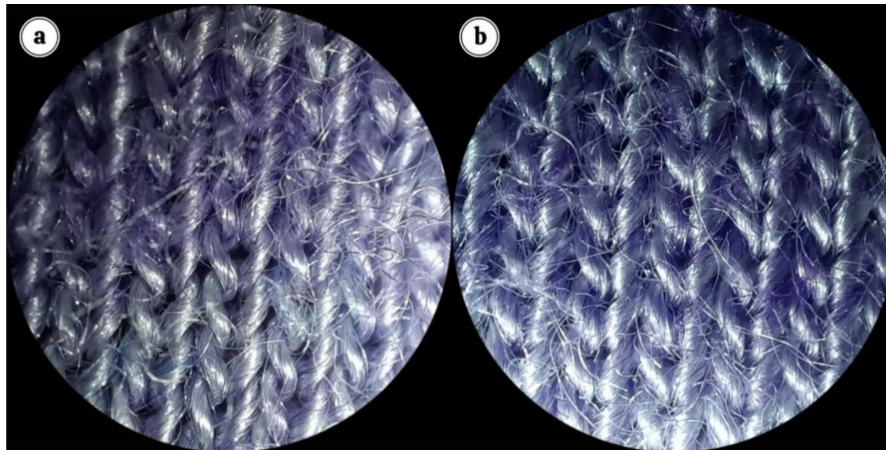


Figure 2. Microscopic images of knitted fabrics containing (a) 30% recycled cotton and (b) 20% recycled cotton, showing increased fibre protrusion and surface hairiness with higher recycled cotton content.

Figure 2 presents fabric images produced with 20% and 30% recycled cotton content in the tri-blend yarn. The sample containing 30% recycled cotton exhibits a higher number of protruding surface fibres compared with the 20% recycled cotton sample. These fibres originate mainly from the shorter fibre fragments generated during the mechanical recycling process. The increased surface hairiness and fibre protrusion introduce structural irregularities within the knitted loops, which may influence stress distribution under multidirectional loading conditions. Such structural variability provides physical evidence for the uncertainty captured by the fuzzy linear regression model, particularly in the prediction of bursting strength.

### Fuzzy Regression Equations for Fabric Property Prediction

Table 7 displays the fuzzy linear regression equations that were used to figure out the fabric's GSM and bursting strength based on the amount of recycled fiber, the yarn count, and the stitch length. Each regression coefficient in these equations is a fuzzy integer with a middle value and a range of values. The center value tells how much each parameter adds to the model, while the spread tells the model's uncertainty [50].

Table 7. Fuzzy linear regression (FLR) equations developed for predicting fabric GSM and bursting strength

Equation
$\tilde{Y}_{\text{GSM}} = (447.5745, 0) - (0.2000, 0)X_{\text{RF}} - (3.7181, 0.3085)X_{\text{Ne}} - (69.7872, 0)X_{\text{SL}}$
$\tilde{Y}_{\text{BS}} = (4064.3750, 0) + (0.1500, 0)X_{\text{RF}} - (19.8125, 0)X_{\text{Ne}} - (1008.5909, 17.1818)X_{\text{SL}}$

For GSM, yarn count exhibits a non-zero spread of 0.3085, indicating that structural fineness contributes to model uncertainty. The negative central coefficient of thread length shows that making the stitch longer makes the fabric less dense. The proportion of recycled fiber has a small negative central effect and no spread, which means that its effect is quite constant within the experimental range. The stitch length has a range of 17.1818 for bursting strength, which is why the overall ambiguity was higher earlier. This shows that the strength of a burst is very sensitive to the shape of the loop and how loose the structure is. The negative central effect of yarn count illustrates that finer yarns do affect mechanical resistance. The percentage of recycled fiber exhibits a minor positive central effect in the range that was chosen.

Overall, the fuzzy regression equations give both a way to evaluate process parameters and a way to show how unpredictable things are in circular fabric manufacturing processes.

### Interpretation of Fuzzy Regression Interval Plots

The fuzzy regression interval graphs (Figure 3) show that the experimental data and model predictions for both GSM and bursting strength are extremely near to one other. The GSM plot includes a number of data points in the little fuzzy interval, which makes sense considering the overall vagueness value is just 0.3085. The main prediction line fits the pattern of the test quite closely. This means that the structure keeps the same even when the yarn count, stitch length, and quantity of recycled fiber vary. The bursting strength plot, on the other hand, has a broader fuzzy interval since the total vagueness value is 17.1818, which is greater. Even if the variability is more, most of the experimental data is still within the range that was predicted. This means that the model works well. It makes logical that the bursting strength range is greater since the way the loops are set up and how the fibers interact have a higher influence on mechanical resistance than the weight of the fabric. In general, the figures show that the fuzzy linear regression model makes accurate central predictions while also capturing uncertainty in the conditions of making circular fabric.

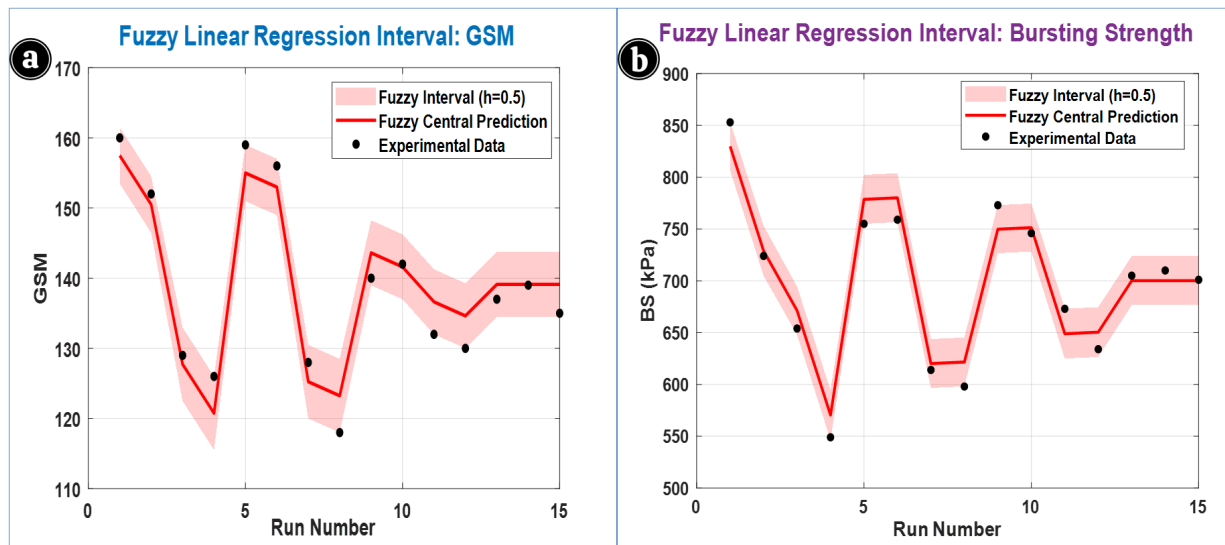


Figure 3. Fuzzy Regression Interval Plots: (a) GSM and (b) BS

### Response Surface Prediction Analysis

Figure 4 shows the three-dimensional fuzzy linear regression response surfaces for GSM and bursting strength when the recycled fiber levels are 20%, 25%, and 30%. The surfaces show how the number of yarns and the length of the stitches work together to affect the performance of the fabric in the experimental area. The response surfaces for GSM show that, in general, increasing the yarn count makes the fabric less heavy per unit area. This behavior makes sense since thinner yarns make fabric structures that are lighter and less dense [51]. Increasing the length of the stitches also lowers the GSM since longer loops make the fabric structure looser and less dense. The surfaces have the same slope patterns at all levels of recycled fiber, which shows that yarn count and stitch length have a constant effect on structure. However, little changes in the height of the surface can be seen when the amount of recycled fiber changes, which shows that it has a secondary effect on fabric density.

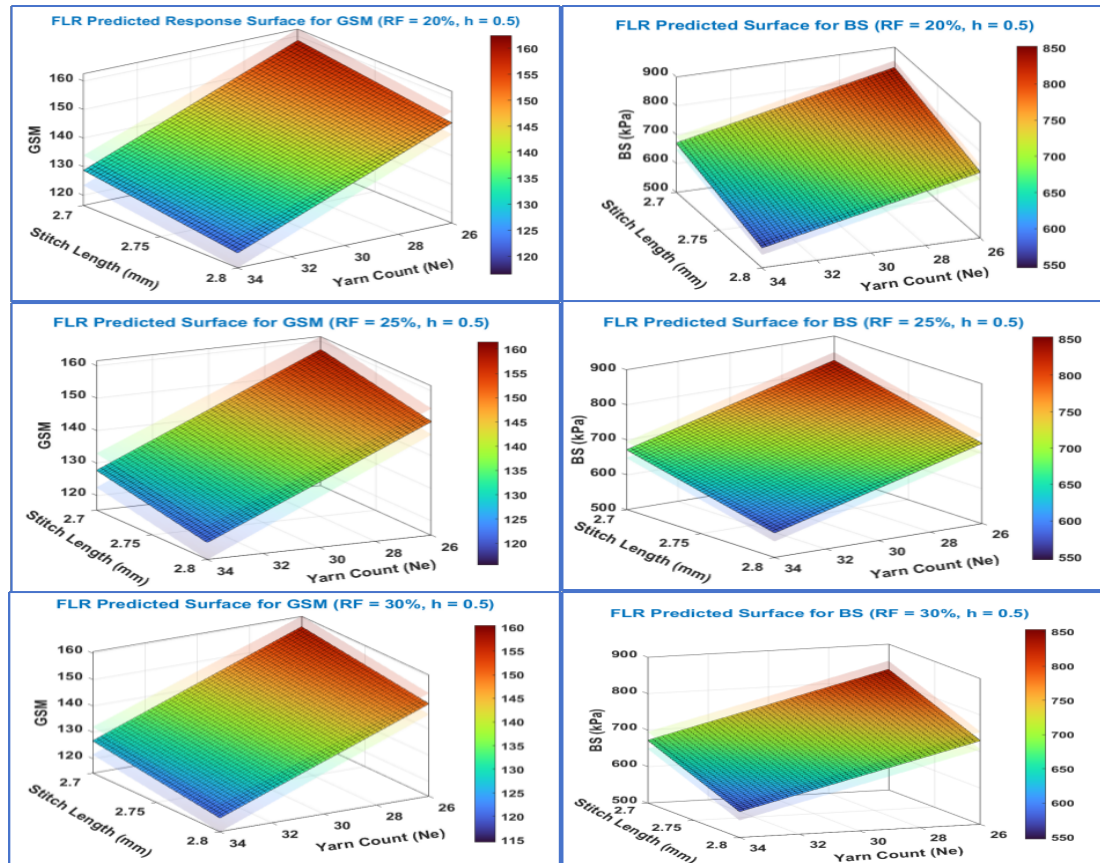


Figure 4. FLR projected response surfaces that show how the number of yarns and the length of the stitches affect the GSM and bursting strength of fabric at varying percentages of recycled fiber.

The surfaces show that both yarn count and stitch length have a big effect on mechanical performance when it comes to bursting strength. Longer stitches don't fit together as well; therefore, the structure isn't as tight, which makes the bursting strength lower. The quantity of yarns can also change how strong something is. For instance, yarns that are somewhat fine react more strongly to strength. The bursting strength surfaces had more fluctuation than GSM, which makes sense since the fuzzy interval analysis showed higher uncertainty. The response surface plots show that the length of the stitches, the number of yarns, and the quantity of recycled fiber all impact each other. The three-dimensional graphic indicates that fuzzy regression is a suitable technique to understand how circular knitted fabric systems work and how they are built.

### Performance of the Quadratic Regression Model

Table 8 displays the statistical performance metrics for the quadratic regression models that were used to guess the fabric's GSM and bursting strength based on the amount of recycled fiber, the yarn count, and the

length of the stitches. The root means square error (RMSE), mean absolute error (MAE), and coefficient of determination ( $R^2$ ) were used to check how accurate the model was.

Table 8. Statistical performance of the quadratic regression models for predicting GSM and bursting strength

Response Variable	$R^2$	MAE	RMSE
GSM	0.9350	1.5333	1.9536
BS (kPa)	0.9570	7.2222	8.6165

The quadratic regression model demonstrates its capability to reliably forecast both answers. The  $R^2$  score of 0.9350 for GSM suggests that the model can explain 93.5% of the variations in fabric mass per unit area. The MAE and RMSE values are low, which shows that the predictions were quite close to what really happened in the experiment. The model works even better for bursting strength, with a  $R^2$  value of 0.9570. The low MAE and RMSE statistics show that the mechanical behavior was anticipated rather effectively. The quadratic regression model demonstrates strong predictive capability of showing how the amount of recycled fiber, the number of yarns, and the length of the stitch interact in a nonlinear way. While the quadratic regression models demonstrated strong predictive accuracy, their statistical adequacy was further evaluated using analysis of variance (ANOVA).

Table 9. ANOVA results for the selected quadratic regression models of fabric GSM and bursting strength

Response variable	Source	Sum of squares	DF	Mean square	F-value	p-value	Remark
GSM	Model	2232.48	9	248.05	21.66	0.0017	Significant
	Lack of fit	49.25	3	16.42	4.10	0.2021	Not significant
	Pure error	8.00	2	4.00	-	-	-
Bursting strength	Model	84570.07	9	9396.67	42.19	0.0003	Significant
	Lack of fit	1073.00	3	357.67	17.59	0.0543	Not significant
	Pure error	40.67	2	20.33	-	-	-

The ANOVA results indicate that both models are statistically significant, with p-values of 0.0017 for GSM and 0.0003 for bursting strength. The corresponding F-values further confirm the strong explanatory power of the models. Moreover, the lack-of-fit tests were not significant ( $p = 0.2021$  for GSM and  $p = 0.0543$  for bursting strength), indicating that the models adequately represent the experimental data. Although the quadratic models were found to be statistically significant and exhibited no significant lack of fit, it should be noted

that the models were developed using the three-factor Box–Behnken design. While this design is sufficient for estimating second-order effects within the selected factor space, a larger experimental dataset would further enhance the robustness and generalizability of both the quadratic and fuzzy regression models. In industrial cycle manufacturing contexts, the quadratic model correctly and consistently predicts the mechanical and structural properties of fabric.

### Quadratic Regression Equations for Fabric Property Prediction

The quadratic regression equations in Table 10 were created to guess the GSM and bursting strength of fabric. These equations explain the percentage of recycled fiber, the yarn count, and the stitch length work together to change a fabric functions.

Table 10. Quadratic Regression Equation

Equation
$GSM = 1629.50 + 15.80X_{RF} - 35.8125X_{YC} - 715.00X_{SL} - 0.050X_{RF}^2 + 0.28125X_{YC}^2 + 100.00X_{SL}^2 - 0.0875X_{RF}X_{YC} - 4.00X_{RF}X_{SL} + 6.25X_{YC}X_{SL}$
$BS = 26952.00 + 50.8833X_{RF} - 31.1250X_{YC} - 17848.3333X_{SL} - 0.2467X_{RF}^2 - 1.1042X_{YC}^2 + 2933.3333X_{SL}^2 - 0.2500X_{RF}X_{YC} - 12.00X_{RF}X_{SL} + 30.00X_{YC}X_{SL}$
$X_{RF} = \text{Recycle Cotton\%}, X_{YC} = \text{Yarn Count (Ne)}, X_{SL} = \text{Stitch Length}$

For GSM, yarn count and stitch length have strong negative linear effects, which means that finer yarn and longer stitch length make the fabric less dense per unit area. The positive squared terms show that there is curvature in the experimental domain. The interaction terms show that the content of the fibers and the structural factors both affect how tightly the fabric is packed. For bursting strength, stitch length has a large negative linear influence. This shows that a looser fabric structure makes it less resistant to mechanical stress. The interaction factors between yarn count and stitch length show that there are important structural interaction effects. The existence of quadratic factors validates nonlinear mechanical behavior under fluctuating process circumstances [52].

### Interpretation of Quadratic Regression Model

The graphs that show the actual versus anticipated values for GSM and bursting strength show how well the quadratic regression model can make predictions. The projected values in both figures are closely aligned with the 45° reference line, which shows that the experimental and modeled responses are very similar.

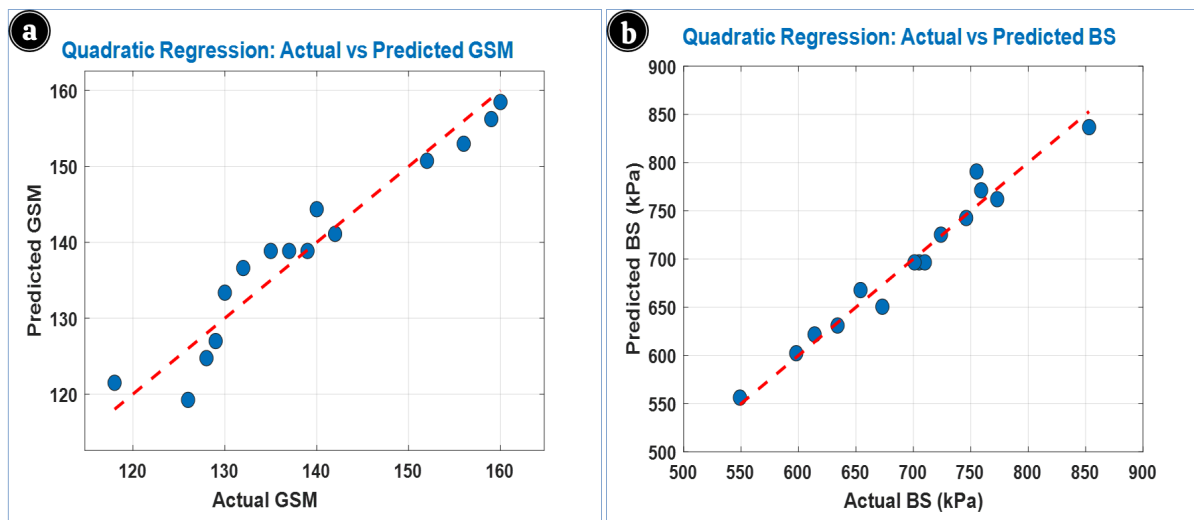


Figure 5. Actual versus Predicted Quadratic Regression Model (a) GSM and (b) BS

The data points for GSM are quite close to the reference line, which shows that the model is stable and makes accurate predictions. This observation aligns with the  $R^2$  value of 0.9350 and the minimal MAE (1.5333) and RMSE (1.9536). The little gap between the actual and predicted results suggests that the quadratic model correctly captures both linear and curvature effects in the region where the experiment took place.

There is also a significant connection to the power of the burst. The points remain close to the reference line, which is why the  $R^2$  value is so high (0.9570) and the prediction errors are so low (MAE = 7.2222, RMSE = 8.6165). Because recycled fiber systems aren't always the same, some differences in strength values may happen.

The figures show that the quadratic regression model can accurately and consistently forecast the cloth's mechanical and structural characteristics for the circumstances of the process.

### Quadratic Response Surface Analysis

Figure 6 shows the three-dimensional quadratic regression response surfaces for GSM and bursting strength when the fraction of recycled fiber is 20%, 25%, or 30%. The surfaces demonstrate how the quantity of yarns and the length of the stitches work together to change how the fabric works in the experiment.

The surfaces have a strong nonlinear trend for GSM. Adding more yarn decreases GSM because finer yarns make fabric structures that are lighter. As the length of the loops increases and the fabric gets less compact, the GSM likewise goes down. The curvature seen in the surfaces shows that there are quadratic impacts, which means that the relationship is not only linear. The overall form of the surface stays the same across all levels of recycled fiber, however there are some little changes in size that may be seen. For bursting strength, the reaction surfaces are quite sensitive to the length of the stitches. A longer stitch length makes the loop structure looser and the interlocking less strong, which makes the bursting strength lower. The number of yarns also affects how the material behaves mechanically. Generally, finer yarns make the material weaker. The pattern of the curved surface shows how the process variables interact with each other and how they affect each other in a second-order way.

The quadratic response surfaces show that there are interaction and curvature effects in the experimental domain. The quadratic model gives a smooth deterministic surface that shows how nonlinear structural and mechanical behavior changes with different amounts of recycled fiber.

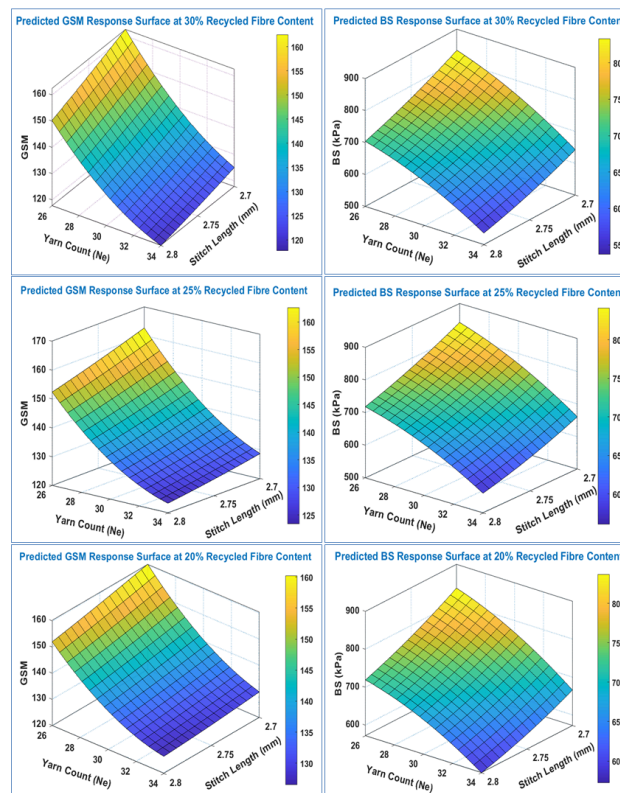


Figure 6. Quadratic regression predicted response surfaces illustrating the combined effects of yarn count and stitch length on fabric GSM and bursting strength at different recycled fibre percentages.

## CONCLUSION

This study examined the structural and mechanical performance of circular knitted fabrics made from pre-consumer recycled cotton, Circulose-based regenerated fiber, and modal under industrial manufacturing conditions using full-scale machinery. Recycled cotton totally replaced virgin cotton, and Circulose was employed as a more environmentally friendly alternative to regular viscose. Modal was added to enhance mechanical performance and surface characteristics. A Box Behnken experimental design was used to rigorously study how the proportion of recycled fiber, the number of yarns, and the length of the stitches affected the fabric's GSM and bursting strength.

Both quadratic regression and fuzzy linear regression models were successfully developed to predict fabric performance. The quadratic model demonstrated strong predictive capability, with  $R^2$  values of 0.9350 for GSM and 0.9570 for bursting strength, confirming its ability to capture nonlinear interaction and curvature effects. The fuzzy linear regression model also showed high prediction accuracy ( $R^2 = 0.9234$  for GSM and 0.9480 for bursting strength) while additionally quantifying model uncertainty through total vagueness analysis.

Response surface analysis indicated that fabric weight and mechanical resistance are significantly influenced by stitch length and yarn count. The structure of the fabric doesn't vary significantly within the designated range, even with a lot of recycled fiber in it. GSM exhibited relatively stable behavior, whereas structural variations had a more pronounced effect on bursting strength.

The findings indicate that extensive use of sustainable tri-blend yarns made from recycled cotton, Circulose, and modal might exhibit commendable structural and mechanical performance. The comparative modeling method provides some predictions and evaluations that take uncertainty into consideration. This ensures reliable fabric design and performance under variable industrial manufacturing conditions.

## RESEARCH HIGHLIGHTS

- A framework for a circular economy was used to make fabrics that have recycled fiber content.
- The Box–Behnken experimental design was used to systematically study how recycled fiber (%), yarn count, and stitch length affect each other.
- Fuzzy Linear Regression (FLR) modeling was developed to predict the GSM and bursting strength of cloth when the process is not certain.

- Quadratic regression modeling was created to forecast fabric GSM and bursting strength, and FLR gave prediction intervals that took uncertainty into account.
- The suggested modeling method helps with optimization in the making of circular textiles.

#### *Author Contributions*

**TRS:** Conceptualization, methodology, validation, resources, writing original draft; **NN:** Conceptualization, methodology, validation, software, formal analysis, data curation, writing original draft; **BCM:** Methodology, validation, formal analysis, writing original draft, **SS:** Methodology, validation, formal analysis, curation, writing original draft, **GMF:** Methodology, formal analysis; **MRH:** Conceptualization, methodology, overall supervision, Writing, reviewing and editing. All authors read and approved the final manuscript.

#### *Conflicts of Interest*

The authors declare no conflict of interest.

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#### *Data Availability*

Data will be made available on request.

#### *Declarations*

Ethics and consent to participate: Not applicable.

Consent for publication: Not applicable.

#### *Additional Information*

No additional information is available for this paper.

## REFERENCES

- [1] Roy Choudhury A. K. Environmental Impacts of the Textile Industry and Its Assessment Through Life Cycle Assessment. In: Roadmap to Sustainable Textiles and Clothing: Environmental and Social Aspects of Textiles and Clothing Supply Chain. Singapore: Springer Singapore; 2014. pp. 1–39. doi: 10.1007/978-981-287-110-7\_1
- [2] Thombre N., Patil P., Yadav A., Patwardhan A. A short review on water management and reuse in textile industry – a sustainable approach. Discover Water. 2025; 5(1):26. doi: 10.1007/s43832-025-00215-z

- [3] Rahaman M. T., Pranta A. D. Transitioning from Linear to Circular Economy in Textiles and Apparel: Significance, Case Studies, Innovations, and Research Directions. *Materials Circular Economy*. 2025; 7(1):48. doi: 10.1007/s42824-025-00204-6
- [4] Das A. K., Hossain M. F., Khan B. U., Rahman M. M., Asad M. A. Z., Akter M. Circular economy: A sustainable model for waste reduction and wealth creation in the textile supply chain. *SPE Polymers*. 2025; 6(1):e10171. doi: 10.1002/pls2.10171
- [5] Keßler L., Matlin S. A., Kümmerer K. The contribution of material circularity to sustainability—Recycling and reuse of textiles. *Current Opinion in Green and Sustainable Chemistry*. 2021; 32:100535. doi: 10.1016/j.cogsc.2021.100535
- [6] Reike D., Hekkert M. P., Negro S. O. Understanding circular economy transitions: The case of circular textiles. *Business Strategy and the Environment*. 2023; 32(3):1032–1058. doi: 10.1002/bse.3114
- [7] Mollae M., Mobli A., Mutti N. K., Manalil S., Chauhan B. S. Challenges and Opportunities in Cotton Production. In: *Cotton Production*; 2019. pp. 371–390.
- [8] Liu Y., Huang H., Zhu L., Zhang C., Ren F., Liu Z. Could the recycled yarns substitute for the virgin cotton yarns: a comparative LCA. *The International Journal of Life Cycle Assessment*. 2020; 25(10):2050–2062. doi: 10.1007/s11367-020-01815-8
- [9] Ütebay B., Çelik P., Çay A. Effects of cotton textile waste properties on recycled fibre quality. *Journal of Cleaner Production*. 2019; 222:29–35. doi: 10.1016/j.jclepro.2019.03.033
- [10] Durán-Rubí E., Vence X. Man-made Cellulosic Textile Fibres: Circular Bioeconomy To Reduce Impacts or Increase Supply? *Circular Economy and Sustainability*. 2025; 5(6):5675–5697. doi: 10.1007/s43615-025-00695-0
- [11] Photopoulos J. Spinning sustainability: meet the physicists turning wood into clothes. *Physics World*. 2023; 36(11):37. doi: 10.1088/2058-7058/36/11/23
- [12] Gaafer R. R. Utilizing Circulose fibers in the production of denim fabrics in the context of textile waste management: A case study in DNM textile factory. *International Design Journal*. 2025; 15(5):151–162. doi: 10.21608/idj.2025.389941.1344
- [13] Latif W. et al. Study of mechanical and comfort properties of modal with cotton and regenerated fibers blended woven fabrics. *Journal of Natural Fibers*. 2019; 16(6):836–845. doi: 10.1080/15440478.2018.1441084
- [14] Hawlader M. R., Nishi S. I., Uddin M. N., Mohammad A. A potential approach to analyze the optimum characteristics of cotton/modal & cotton/viscose blended yarn. *Global Journal of Research in Engineering*. 2018; 12(2):9–12.

- [15] Arafat Y., Uddin A. J. Recycled fibers from pre- and post-consumer textile waste as blend constituents in manufacturing 100% cotton yarns in ring spinning: A sustainable and eco-friendly approach. *Heliyon*. 2022; 8(11). doi: 10.1016/j.heliyon.2022.e11275
- [16] Doba Kadem F., Sevgi R. Süprem Örme Kumaşlarda Geri Dönüşüm Pamuk Elyaf Oranının Performans Özelliklerine Etkisinin Belirlenmesi. *Çukurova Üniversitesi Mühendislik Fakültesi Dergisi*. 2022; 37(3):609–616. doi: 10.21605/cukurovaumfd.1189930
- [17] Raiskio S., Periyasamy A., Hummel M., Heikkilä P. Transforming mechanically recycled cotton and linen from post-consumer textiles into quality ring yarns and knitted fabrics. *Waste Management Bulletin*. 2025; 3(1):76–86. doi: 10.1016/j.wmb.2024.12.006
- [18] Emdadul H., Md Shamim A. Effect of Stitch Lengths and Yarn Counts on Areal Density and Drape Behaviour of Different Weft Knitted Single Jersey Structures. *American Journal of Applied Scientific Research*. 2016; 2(6):33–37. doi: 10.11648/j.ajasr.20160206.11
- [19] Ariful I., Mohammad Billal H., Emdadul H., Ahmed Saber S., Arafat R. Factors Influencing Bursting Strength of Single Jersey Knitted Fabrics. *European Scientific Journal, ESJ*. 2022; 18(36). doi: 10.19044/esj.2022.v18n36p68
- [20] Hasanuzzaman, Dan P. K., Basu S. Optimization of ring-spinning process parameters using response surface methodology. *The Journal of The Textile Institute*. 2015; 106(5):510–522. doi: 10.1080/00405000.2014.929250
- [21] Shukla L., Nishkam A. Performance Optimization, Prediction, and Adequacy by Response Surfaces Methodology with Allusion to DRF Technique. *International Scholarly Research Notices*. 2014; 2014(1):634041. doi: 10.1155/2014/634041
- [22] Islam R., Uddin M. B., Hawlader M. R., Uddin A. J. Employing response surface methodology in the production of sustainable PC yarn from recycled polyester and recycled cotton. *Cleaner Waste Systems*. 2025; 12:100421. doi: 10.1016/j.clwas.2025.100421
- [23] Hawlader M. R., Siddiky M. R. H., Uddin A. J. From waste to wear: ANN-driven optimization of 100% sustainable tri-blend yarns from recycled cotton, recycled PET, and ecovero. *Sustainable Futures*. 2026; 11:101652. doi: 10.1016/j.sftr.2026.101652
- [24] Uddin M. N., Tumpa T. R., Hawlader M. R., Faysal G. M., Uddin A. J. Advancing circular Textiles: MLR-Based optimization of tri-blend Melange yarns from sustainable fibers. *Waste Management Bulletin*. 2026; 4(1):100277. doi: 10.1016/j.wmb.2025.100277

- [25] Alam I. K., Hawlader M. R., Rahaman M., Uddin A. J. Modeling and optimizing yarn characteristics in sustainable cotton blends through multiple linear regression and artificial neural networks. *Cleaner and Circular Bioeconomy*. 2026; 14:100210. doi: 10.1016/j.clcb.2026.100210
- [26] Belzak W. C. M., Bauer D. J. Interaction effects may actually be nonlinear effects in disguise: A review of the problem and potential solutions. *Addictive Behaviors*. 2019; 94:99–108. doi: 10.1016/j.addbeh.2018.09.018
- [27] Olivetti E. A., Gaustad G. G., Field F. R., Kirchain R. E. Increasing Secondary and Renewable Material Use: A Chance Constrained Modeling Approach To Manage Feedstock Quality Variation. *Environmental Science & Technology*. 2011; 45(9):4118–4126. doi: 10.1021/es103486s
- [28] Abteu M. A., Gebeyehu E. K., Dejene B. K., Atalie D. Recycled Cellulosic Natural Fibers and Their Reinforced Polymer Composites: Processing Methods, Applications, Challenges and Future Directions. *Sustainability*. 2021; 13(5):2500. doi: 10.3390/su13052500
- [29] Wu J., Shang S. Managing Uncertainty in AI-Enabled Decision Making and Achieving Sustainability. *Sustainability*. 2020; 12(21):8758. doi: 10.3390/su12218758
- [30] Tripathi S., Trigunait R., Pandey D. C. A Behavioral and Environmental Framework for Sustainable Retail Forecasting and Decision-Making. *Circular Economy and Sustainability*. 2025; 5(7):5935–5963. doi: 10.1007/s43615-025-00705-1
- [31] Kar N. B., Das S., Ghosh A., Banerjee D. Fuzzy linear regression model on mulberry silk cocoon characteristics. *Research Journal of Textile and Apparel*. 2019; 23(3):201–211. doi: 10.1108/RJTA-03-2019-0012
- [32] Fattahi S., Taheri S. M., Hosseini Ravandi S. A. Cotton yarn engineering via fuzzy least squares regression. *Fibers and Polymers*. 2012; 13(3):390–396. doi: 10.1007/s12221-012-0390-7
- [33] Iwundu M. P., Cosmos J. The Efficiency of Seven-Variable Box-Behnken Experimental Design with Varying Center Runs on Full and Reduced Model Types. *Journal of Mathematics and Statistics*. 2022; 18(1):196–207. doi: 10.3844/jmssp.2022.196.207
- [34] Maduna L., Patnaik A., Mvubu M., Hunter L. Optimization of air permeability of spunlaced filter fabrics using the Box–Behnken experimental design. *Journal of Industrial Textiles*. 2020; 50(5):675–691. doi: 10.1177/1528083719836946
- [35] Sari B., Uzumcu M. B., Ozsahin K. Analysing the effect of mechanically recycled cotton fibres from pre-consumer wastes on mechanical and fastness properties of knitted fabrics. *International Journal of Clothing Science and Technology*. 2024; 37(4):663–678. doi: 10.1108/IJCST-03-2024-0059

- [36] Chidambaram P., Govind R., Chandramouli Venkataraman K. THE EFFECT OF LOOP LENGTH AND YARN LINEAR DENSITY ON THE THERMAL PROPERTIES OF BAMBOO KNITTED FABRIC. 2011; 11(4):102–105. doi: 10.1515/aut-2011-110402
- [37] Ichetaonye S., Ichetaonye D., Adeakin O., Tenebe O., Yibowei M. Effect of stitch length on the physical properties of both plain and 1×1 Rib knitted fabrics. *J Textile Sci Eng.* 2014; 4(177):2.
- [38] Demir M. EXPLORING THE RELATIONSHIP BETWEEN YARN TYPE AND PACKING DENSITY: A STUDY OF SINGLE-PLY, TWO-PLY, AND SIRO-SPUN YARNS. *Tekstil ve Mühendis.* 2023; 30(130):124–130. doi: 10.7216/teksmuh.1320576
- [39] Md. Abdul H., Md. Mazedul I., Kabir S. M. F., Abdullahil K., Shamsuzzaman S. EFFECT OF YARN COUNT & STITCH LENGTH ON SHRINKAGE, GSM AND SPIRALITY OF SINGLE JERSY COTTON KNIT FABRIC. *European Scientific Journal, ESJ.* 2014; 10(36). [Online]. Available: <https://eujournal.org/index.php/esj/article/view/4897>.
- [40] Wang C., Jiang B., Zhu L. PENALIZED INTERACTION ESTIMATION FOR ULTRAHIGH DIMENSIONAL QUADRATIC REGRESSION. *Statistica Sinica.* 2021; 31(3):1549–1570.[Online]. Available: <https://www.jstor.org/stable/27034830>.
- [41] Nwabueze T. U. Review article: Basic steps in adapting response surface methodology as mathematical modelling for bioprocess optimisation in the food systems. *International Journal of Food Science and Technology.* 2010; 45(9):1768–1776. doi: 10.1111/j.1365-2621.2010.02256.x
- [42] Coppe A., Haftka R. T., Kim N. H. Uncertainty Identification of Damage Growth Parameters Using Nonlinear Regression. *AIAA Journal.* 2011; 49(12):2818–2821. doi: 10.2514/1.J051268
- [43] Tadesse M. G. et al. Prediction of the tactile comfort of fabrics from functional finishing parameters using fuzzy logic and artificial neural network models. *Textile Research Journal.* 2019; 89(19-20):4083–4094. doi: 10.1177/0040517519829008
- [44] Heshmaty B., Kandel A. Fuzzy linear regression and its applications to forecasting in uncertain environment. *Fuzzy Sets and Systems.* 1985; 15(2):159–191. doi: 10.1016/0165-0114(85)90044-2
- [45] Beyene K. A. Comparative study of linear and quadratic model equations for prediction and evaluation of surface roughness of a plain-woven fabric. *Research Journal of Textile and Apparel.* 2022; 27(2):281–298. doi: 10.1108/RJTA-08-2021-0107
- [46] Kwong C. K., Chen Y., Chan K. Y., Wong H. The Hybrid Fuzzy Least-Squares Regression Approach to Modeling Manufacturing Processes. *IEEE Transactions on Fuzzy Systems.* 2008; 16(3):644–651. doi: 10.1109/TFUZZ.2007.903324
- [47] Kang H. et al. Stress–strain and burst failure analysis of fiber wound composite material high-pressure vessel. *Polymers and Polymer Composites.* 2021; 29(8):1291–1303. doi: 10.1177/0967391120965387

- [48] Lodetti P. Z., Neto E. A. C. A., Martins M. A. I., Costa G. H. D. S., Ludwig M. A. MAE and RMSE Analysis of K-means Predictive Algorithm for Photovoltaic Generation. In: 2022 International Conference on Electrical, Computer and Energy Technologies (ICECET); 2022. pp. 1–6. doi: 10.1109/ICECET55527.2022.9872976
- [49] Coppi R., D’Urso P., Giordani P., Santoro A. Least squares estimation of a linear regression model with LR fuzzy response. *Computational Statistics & Data Analysis*. 2006; 51(1):267–286. doi: 10.1016/j.csda.2006.04.036
- [50] Ferraro M. B., Coppi R., González Rodríguez G., Colubi A. A linear regression model for imprecise response. *International Journal of Approximate Reasoning*. 2010; 51(7):759–770. doi: 10.1016/j.ijar.2010.04.003
- [51] Jeon B. S., Chun S. Y., Hong C. J. Structural and Mechanical Properties of Woven Fabrics Employing Peirce’s Model. *Textile Research Journal*. 2003; 73(10):929–933. doi: 10.1177/004051750307301014
- [52] Gupta S. K., Bukhari M. A., Barry O. R., Okwudire C. Data-driven modeling and analysis of nonlinear isolated mechanical system. *Mechanical Systems and Signal Processing*. 2023; 204:110760. doi: 10.1016/j.ymsp.2023.110760