A statistical model for predicting bursting strength of plain knitted fabrics from various fancy yarns

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ABSTRACT – REZUMAT

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Fancy yarns contain certain planned irregularities in their structure in terms of colour and/or texture. The realisation by designers that these structural irregularities can create surface effects and achieve unique looks has led to an increase in research on fancy yarns. By incorporating these yarns, the surface characteristics of fabrics can be altered, resulting in improvements in softness and permeability. However, in addition to these aesthetic elements, the mechanical properties of products made from these yarns are also important. These irregularities in the yarn structure affect the physical properties of the yarn and, consequently, the fabrics made from it. The physical properties of the fabrics are also very important in terms of user satisfaction. This study investigated the prediction of bursting strength of knitted fabrics made from fancy yarns, which affect the properties of the fabrics produced. The research was carried out on plain knitted fabrics produced with four different fancy yarns: boucle, looped, knotted, and slub. The breaking strength and elongation at break of the fancy yarn type, as well as the fabric weight, thickness, elasticity, and stitch density properties, which affect bursting strength, were tested. Regression analysis of bursting strength was performed, and the adjusted R^2 *value of the resulting model was found to be 0.997.*

Keywords: *boucle yarns, looped yarns, knotted yarns, slub yarns, bursting strength, dummy variables*

Un model statistic pentru estimarea rezistenței la rupere a tricoturilor glat realizate din diverse fire fantezie

Firele fantezie prezintă anumite neregularități intenționate în structura lor, în ceea ce privește culoarea și/sau textura. Conștientizarea de către designeri a faptului că aceste neregularități structurale pot crea efecte de suprafață și pot conferi un aspect unic a condus la o intensificare a cercetărilor în domeniul firelor fantezie. Prin încorporarea acestor fire, caracteristicile de suprafață ale materialelor textile pot fi modificate, ceea ce duce la îmbunătățirea emolierii și a permeabilității. Cu toate acestea, pe lângă aceste elemente estetice, proprietățile mecanice ale produselor realizate din aceste fire sunt, de asemenea, importante. Aceste neregularități din structura firului afectează proprietățile fizice ale firului și, în consecință, materialele textile realizate din acesta. Proprietățile fizice ale materialelor textile sunt, de asemenea, foarte importante din punct de vedere al satisfacției utilizatorilor. Prezentul studiu a investigat predicția rezistenței la rupere a tricoturilor realizate din fire fantezie, care influențează proprietățile materialelor textile produse. Cercetarea a fost efectuată pe tricoturi glat, realizate cu patru tipuri diferite de fire fantezie: bouclé, buclate, cu noduri și cu nopeuri. Au fost testate rezistența la rupere și alungirea la rupere ale tipului de fir fantezie, precum și proprietățile tricotului, precum masa, grosimea, elasticitatea și desimea, care influențează rezistența la rupere. S-a efectuat o analiză de regresie a rezistenței la rupere, iar valoarea R^2 *ajustată a modelului rezultat a fost de 0,997.*

Cuvinte-cheie*: fire bouclé, fire buclate, fire cu noduri, fire cu nopeuri, rezistență la rupere, variabile fictive*

INTRODUCTION

Fancy yarns are formed by intentionally introducing irregularities into the structure of flat yarns. The use of fancy yarns also enables the economical production of original designs with high aesthetic and decorative appeal. However, while these irregularities enhance the visual appearance of fabrics, they also lead to variations in the physical properties of the yarns and the resulting fabrics. Adequate strength is one of the most critical parameters defining the performance of textile products.

A typical fancy yarn consists of three components: the *core* or *main* yarn, the *effect* material, and a *binder* that holds the structure together [1]. Among these, the main yarn has the greatest impact on the overall strength of the fancy yarn, while the effect material primarily contributes to aesthetic characteristics [2]. The structure of fancy yarns is shown in figure 1.

Due to their aesthetic advantages, fancy yarns are widely used in both woven and knitted fabrics, with increasing popularity in fields such as outerwear, upholstery, knitwear, and home decoration [4–6]. According to a market analysis by Data Insights Market, the global fancy yarn sector – valued at an estimated $4.21 billion in 2025 – is expected to grow at a CAGR of 4.3% from 2025 to 2033 [7].

The literature includes several studies examining how yarn production parameters influence the properties of fabrics made from different types of fancy yarns. Nergis and Candan found that the most critical parameter affecting the bursting strength of plain

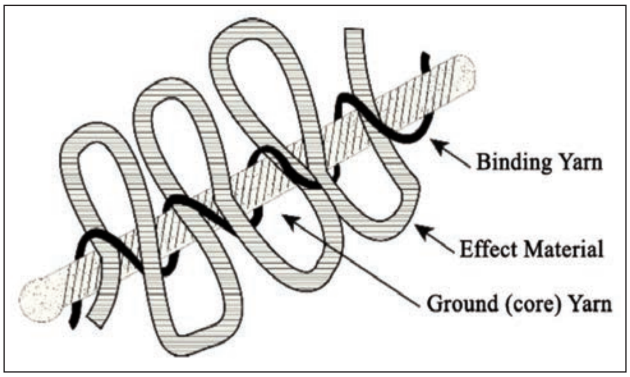

Fig. 1. The basic structure of fancy yarns [3]

knitted fabrics made from chenille yarns was the property of the component yarns [8]. In another study, Nergis reported that no clear relationship was found between bursting strength and the presence of elastane in chenille yarn in knitted fabrics produced from elastane chenille yarns [9]. Additionally, Turay et al. investigated knitted fabrics made from 100% wool and 100% acrylic bouclé yarns, reporting that acrylic fabrics exhibited higher bursting strength values [10]. The results of the study by Atef et al. showed that 1×1 rib fabrics have higher burst strength than plain knit and 3×1 rib fabrics. Furthermore, fabrics produced from yarns with a higher polyester content had higher burst strength compared to those with a higher cotton content [11]. Özdil and Kanat used four different types of fancy yarns produced from wool, PAC and wool/PAC blends as raw materials in their study examining the bursting strength of fabrics woven from fancy yarns. The study found that the effect of the raw material was statistically insignificant, while the effect of the yarn type was found to be significant [3].

Some studies have investigated the effect of fabric parameters knitted with conventional yarns on bursting strength. These studies indicate that yarn tenacity, elongation, fabric mass, stitch density, fabric thickness, and extension properties have an effect on bursting strength [12–13]. In addition, the bursting strength of knitted fabrics has been extensively studied using both regression-based and intelligent modelling approaches due to its strong dependence on structural and material parameters. Ghosh investigated plain knitted fabrics and showed that stitch length and density, fabric thickness, tightness factor, fabric weight (GSM), and porosity significantly affect bursting strength, with regression and ANOVA results revealing a particularly strong correlation between GSM and bursting strength ($R^2 \approx 0.94$) [14]. Islam et al. used multiple regression and ANOVA analyses to demonstrate that stitch length, yarn count, and tightness factor have significant effects, whereas GSM and fabric thickness exhibit relatively weaker influence [15]. Overall, regression-based studies confirm that structural parameters such as stitch density, loop length, and yarn fineness play dominant roles in bursting behaviour. In parallel, intelligent modelling approaches improve prediction accuracy for nonlinear relationships: Ertuğrul and Uçar showed that ANN and ANFIS outperform conventional regression models [16], and Jamshaid et al. reported superior accuracy of ANFIS over response surface regression [17].

As can be seen from the literature cited above, previous studies have focused on estimating the bursting strength of fabrics knitted from conventional yarns. Unlike other studies, this study used fabrics knitted from fancy yarns and the effect of fancy yarn type on the prediction of bursting strength of knitted fabrics was investigated in detail. Variance analyses and regression analyses were carried out using SPSS. This research, which was unstudied previously, aims to identify the fancy yarn and fabric parameters that are important in predicting fabric bursting strength.

MATERIALS AND METHODS

In this study, plain knitted fabrics were obtained from four different fancy yarn types: bouclé, loop, knotted, and slub yarns; 100% wool, 50% wool 50% PAC and 100% PAC yarns in Nm 12 count, and the effect of yarn type on the bursting strength of these fabrics was investigated in detail. Plain knitted fabrics were produced on an E7 knitting machine by using the NSSC122 model SHIMA SEIKI.

Yarn types featuring periodically thickened sections along their length are referred to as slub yarns. Bouclé yarn is classified as a compound yarn and is produced by combining a twisted core yarn with an effect yarn (or roving), resulting in characteristic wavy surface protrusions. In this structure, the effect yarn forms small loops by being twisted in the opposite direction and at a higher speed than both the core and the binder yarns [11, 18]. Knotted yarn is characterised by the presence of knots occurring at either regular or irregular intervals along its length. Loop yarn, on the other hand, consists of a base yarn around which an overfed effect yarn is wrapped, generating circular loop-like projections on the surface [2]. The properties of the yarns used in this study are summarised in table 1, and visual representations of the yarns and fabrics are given in figure 2.

Table 1

YARNS USED IN THE STUDY				
Material	**Yarn type**			
%100 Wool	Bouclé yarn	Loop yarn	Knotted yarn	Slub yarn
%50 Wool/%50 PAC				
%100 PAC				

Yarn and fabric properties affecting the bursting strength of fabrics, as mentioned in the literature, were investigated. Tests were carried out on conditioned fabrics at 20±2°C; 65±4% Rh. All the tests applied to yarns and fabrics and their standards were given in table 2.

Table 2

YARNS AND FABRIC TESTS STANDARDS	
Test	**Test Standard**
Yarn breaking strength	ISO 2062
Elongation at break	ISO 2062
Fabric weight	EN 12127
Fabric thickness	ISO 5084
Stitch density	EN 14971
Elasticity	ISO 20932-1
Bursting strength	ISO 13938-2

RESULTS AND DISCUSSION

The means of the results of all tests applied to the yarn and fabric are given in the table 3. Among all types of yarn, the lowest weight value is seen in fabrics from loop yarn, and the highest weight value is seen in fabrics from slub yarn. In fabrics knitted at the same density, the loops on the yarn cause a more open fabric structure. Fabrics from slub yarns, on the other hand, have a less open structure, resulting in higher weight values.

As can be seen from the table, excluding boucle yarns, the lowest yarn strength was observed in woollen yarns and the highest yarn strength in PAC yarns. This can be explained by the higher fibre strength of PAC.

As shown in figure 3, the bursting strength of the fabric increases with increasing yarn strength, and the bursting strength of slub yarn and the fabric produced from this yarn are much higher than those of others. The lowest bursting strength was observed in fabrics produced from boucle yarn. In slub yarns, the presence of thicker regions positively affects the strength

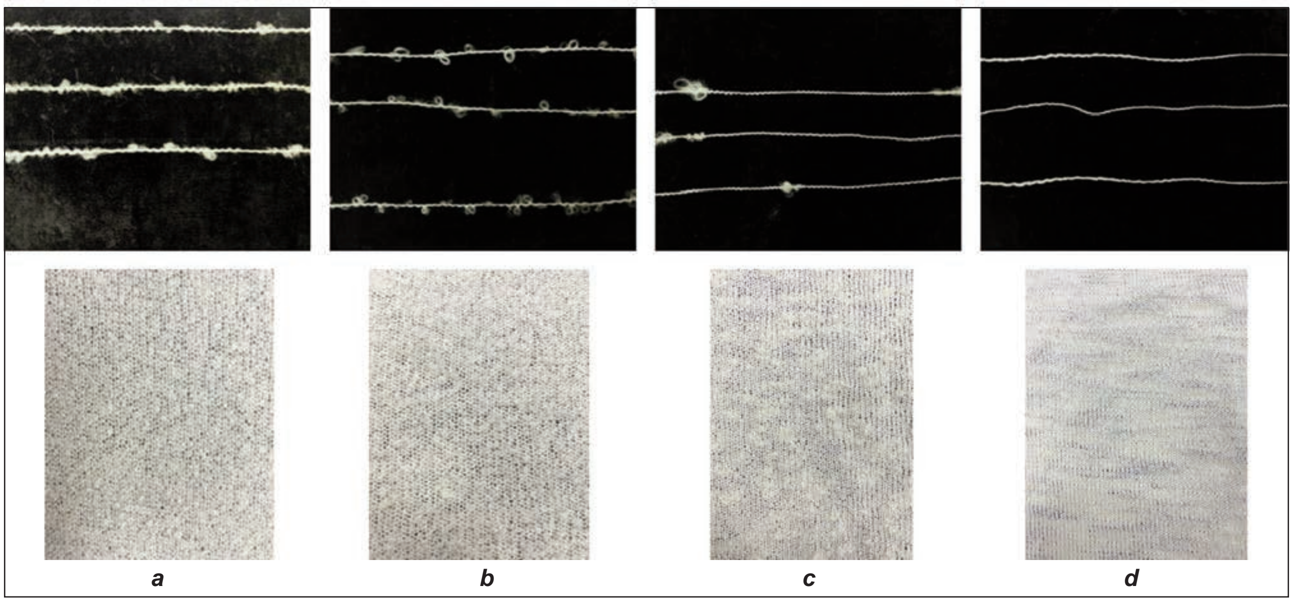

Fig. 2. Images of yarn types and fabrics knitted with these yarns [3]:
a – bouclé yarn; *b* – loop yarn; *c* – knotted yarn; *d* – slub yarn

Table 3

MEAN VALUES OF TEST RESULTS								
Yarn type	**Material**	**Yarn strength (N)**	**Yarn elongation (mm)**	**Mass per unit area (g/m^2)**	**Fabric thickness (mm)**	**Stitch density (stitch number/cm^2)**	**Fabric elasticity (%)**	**Bursting strength (kPa)**
Boucle	Wool	7.81	123.41	184.13	2.05	20.83	128	150.50
Boucle	Wool/ PAC	9.88	120.71	176.40	1.70	28.44	133	184.87
Boucle	PAC	8.40	79.22	166.30	1.40	26.00	103	152.73
Loop	Wool	9.44	154.56	156.16	1.87	25.83	118	170.36
Loop	Wool/ PAC	9.49	137.99	170.76	1.80	30.00	98	175.24
Loop	PAC	9.64	127.00	153.48	1.57	25.83	100	173.72
Knotted	Wool	10.94	108.16	247.04	1.91	36.94	112	218.43
Knotted	Wool/ PAC	11.61	91.26	243.52	1.87	33.33	93	219.58
Knotted	PAC	11.67	75.81	220.92	1.55	30.22	75	248.20
Slub	Wool	13.76	91.08	322.06	1.59	35.00	90	281.24
Slub	Wool/ PAC	18.00	97.98	330.56	1.50	42.00	80	345.06
Slub	PAC	20.64	86.08	263.84	1.31	35.00	75	354.82

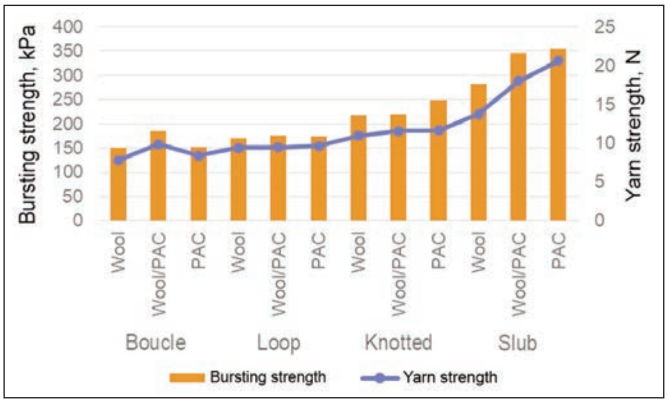

Fig. 3. Bursting strength and yarn strength of fabrics according to yarn type

Therefore, the effect of yarn types on the bursting strength of the fabric was investigated using one-way analysis of variance (ANOVA). According to the ANOVA test results given in table 4, the differences between the groups were found to be significant at $\alpha = 0.05$, and the differences between the groups were determined using post-hoc tests.

Since the Levene test result showed that the variance between the groups was different, multiple comparison tests were determined according to Tamhane. The multiple comparisons test results and the subsets of yarn type according to bursting strength values are shown in the tables 5 and 6, respectively.

Table 4

VARIANCE ANALYSES OF BURSTING STRENGTH					
Type	**Sum of squares**	**df**	**Mean square**	**F**	**Sig**
Between groups	230580.395	3	76860.132	147.057	0.000*
Within groups	24564.829	47	522.656		
Total	255145.224	50			

Note: * Statistically significant according to α = 0.05.

Table 5

MULTIPLE COMPARISONS ACCORDING TO TAMHANE						
Yarn type (I)	**Yarn type (J)**	**Mean difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence interval**	
					Lower Bound	**Upper Bound**
Boucle	Loop	–10.40533	6.33945	0.584	–31.7621	10.9514
	Knotted	–66.13333*	7.97804	0.000	–89.9015	–42.3652
	Slub	–164.34000*	11.14432	0.000	–196.5804	–132.0991
Loop	Boucle	10.40533	6.33945	0.584	–10.9514	31.7621
	Knotted	–55.72800*	5.22951	0.000	–71.9874	–39.4686
	Slub	–153.93467*	9.37521	0.000	–182.4081	–125.4612
Knotted	Boucle	66.13333*	7.97804	0.000	42.3652	89.9015
	Loop	55.72800*	5.22951	0.000	39.4686	71.9874
	Slub	–98.20667*	10.55249	0.000	–128.8156	–67.5978
Slub	Boucle	164.34000*	11.14432	0.000	132.0991	196.5809
	Loop	153.93467*	9.37521	0.000	125.4612	182.4081
	Knotted	98.20667*	10.55249	0.000	67.5978	128.8156

Note: * The mean difference is significant at the 0.05 level.

value of the yarn and, consequently, the fabric. Another reason why fabrics from slub yarns have the highest bursting strength values is their high density and mass per unit area. In boucle and loop yarns, the effect yarn does not contribute to the strength value because it is not in the same direction as the main yarn structure.

Variance analyses

When the bursting strength values are statistically analysed, the skewness and kurtosis values are found to be 0.735 and –0.845, respectively. Since these values are within the range of +/– 1.5, it is stated that the data set shows a normal distribution according to the literature.

Table 6

SUBSETS OF YARN TYPE ACCORDING TO BURSTING STRENGTH			
Yarn type	**Subset for α=0.05**		
	1	**2**	**3**
Boucle	162.7000		
Loop	173.1053		
Knotted		228.8333	
Slub			327.0400

Linear regression

Additionally, multiple linear regression analysis was performed to determine the relationship between yarn and fabric properties and bursting strength. The parameters affecting bursting strength (BS), such as yarn breaking strength (YS) and elongation (YE), fabric weight (FW), fabric thickness (FT) and elasticity (FE), and stitch density (SD), were evaluated. Since the effect of raw material on bursting strength was not found to be significant in the previous study, it was not included as a parameter [3]. Furthermore, considering the statistically significant effect of yarn type on bursting strength, yarn type was also included as an independent variable in the regression analysis. Since yarn type is a nominal variable, it was converted into a dummy variable for the analysis. Knotted yarn was defined as the reference variable. The dummy variables were defined in table 7.

Table 7

TRANSFORMATION OF DUMMY VARIABLES			
Yarn type	**D1**	**D2**	**D3**
Boucle	1	0	0
Loop	0	1	0
Knotted	0	0	0
Slub	0	0	1

The regression model with dummy variables is given below (equation 1):

$$Y = a_0 + a_1 D_1 + a_2 D_2 + a_3 D_3 + b_1 X_1 + \\ + b_2 X_2 + \cdots + b_k X_k + \varepsilon \quad (1)$$

Here, Y represents the dependent variable, and X's represent the independent variables. D_1, D_2, and D_3 represent dummy variables, and when the yarn type is boucle, $D_1 = 1$ and D_2, $D_3 = 0$; when it is loop, $D_2 = 1$ and D_1, $D_3 = 0$; when it is slub, $D_3 = 1$ and D_1, $D_2 = 0$; and when it is knotted, D_1, D_2, $D_3 = 0$.

Before the analysis, the skewness and kurtosis tests were used to verify that all variables showed a normal distribution, and the linear relationship between the dependent and independent variables was checked using graphs (figure 4). Means, standard deviations and Skewness and Kurtosis values of independent variables were given in table 8.

When table 8 is examined, it is seen that all Skewness and Kurtosis values are between ±1.5. Therefore, the normality test is satisfied. In addition, when figure 4 is examined, it is seen that the relationship between all independent variables and the dependent variable, bursting strength, is linear.

Yarn strength, elongation, fabric weight, fabric thickness, elasticity, and stitch density, along with dummy variables, were selected as independent variables in regression analysis. Pearson correlation coefficients of variables were given in table 9.

Examining the table, we see high ($R > 0.70$) and moderate ($0.3 < R < 0.7$) correlations between the independent and dependent variables. A positive correlation was observed between bursting strength and yarn strength, while a negative correlation was found between bursting strength and other variables

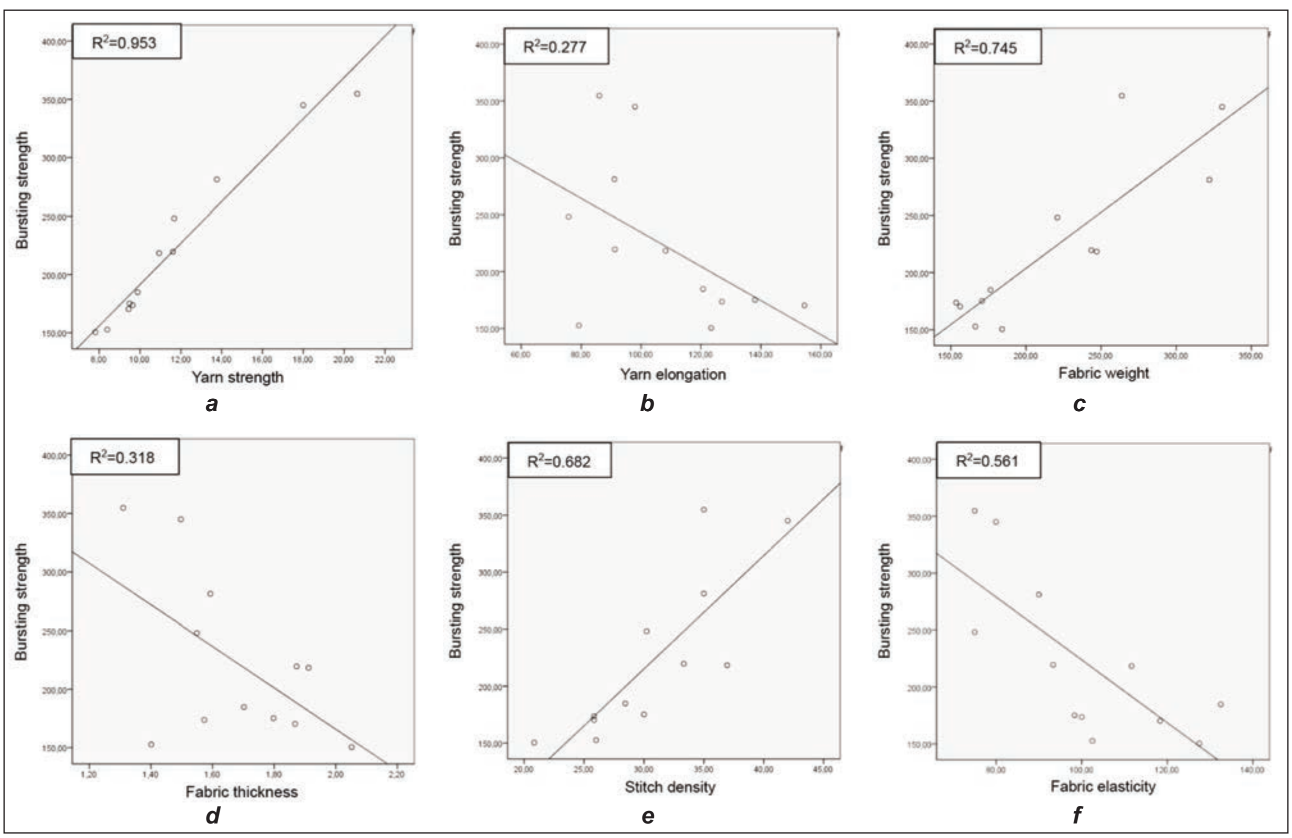

Fig. 4. Relationship between dependent and independent variables: *a* – Yarn strength; *b* – Fabric thickness; *c* – Fabric weight; *d* – Stitch density; *e* – Fabric elasticity; *f* – Yarn elongation

Table 8

DESCRIPTIVE STATISTICS AND SKEWNESS AND KURTOSIS VALUES OF INDEPENDENT VARIABLES				
Variable	**Mean**	**Standard Deviation**	**Skewness**	**Kurtosis**
YS	11.7743	3.90698	1.470	1.485
YE	107.7703	24.93194	0.471	–0.796
FW	219.5978	62.40707	0.730	–0.702
FT	1.6773	0.22634	0.013	–0.955
SD	30.7870	5.90164	0.242	–0.202
FE	100.3472	19.27492	0.275	–0.900

Table 9

PEARSON CORRELATIONS COEFFICIENTS OF VARIABLES										
Pearson correlation	**BS**	**YS**	**YE**	**FW**	**FT**	**SD**	**FE**	**D_1**	**D_2**	**D_3**
BS	1.000	0.976	–0.526	0.863	–0.564	0.826	–0.749	–0.511	–0.423	0.884
YS	0.976	1.000	–0.457	0.769	–0.602	0.765	–0.712	–0.475	–0.347	0.879
YE	–0.526	–0.457	1.000	–.0554	0.592	–0.428	0.644	0.000	0.776	–0.388
FW	0.863	0.769	–.0554	1.000	–0.287	0.859	–0.591	–0.425	–0.575	0.830
FT	–0.564	–0.602	0.592	–0.287	1.000	–0.333	0.666	0.109	0.184	–0.561
SD	0.826	0.765	–0.428	0.859	–0.333	1.000	–0.603	–0.582	–0.364	0.669
FE	–0.749	–0.712	0.644	–0.591	0.666	–0.603	1.000	0.641	0.163	–0.584
D_1	–0.511	–0.475	0.000	–0.425	0.109	–0.582	0.641	1.000	–0.333	–0.333
D_2	–0.423	–0.347	0.776	–0.575	0.184	–0.364	0.163	–0.333	1.000	–0.333
D_3	0.884	0.879	–0.388	0.830	–0.561	0.669	–0.584	–0.333	–0.333	1.000

(except dummies). Furthermore, the correlation between yarn strength and elasticity and bursting strength was quite strong ($R > 0.70$), while the correlation between elongation and fabric thickness and bursting strength was moderate ($0.3 \leq R \leq 0.70$). However, a correlation coefficient greater than $r > 0.80$ between the independent variables indicates multicollinearity. To avoid the multicollinearity problem observed between fabric weight and stitch density, stitch density was removed from the regression equation.

The regression analysis was repeated, and when the coefficients of the resulting model were examined, it was found that the effect of fabric weight was insignificant at the 95% confidence interval ($p = 0.754$); therefore, this variable was also excluded from the analysis.

In the new regression analysis, it is observed that the errors of the estimates show a normal distribution (figure 5, *a*). Furthermore, when examining figure 5, *b*, it is seen that the values are homogeneously distributed across the graph, thus ensuring homoscedasticity.

The Durbin-Watson test was used to check whether the errors were independent of each other. According to the literature, a Durbin-Watson test result in the range of 1 and 3 indicates that the errors are not autocorrelated. Since the value here is 2.275, it is seen that the model satisfies this condition (table 10).

Table 10 also shows that the adjusted R-squared value of the model is quite high. The relationship between the dependent and independent variables in this model is very strong. The independent variables in the model explain 99.7% of the variation in the dependent variable. Table 11 below shows the significance level of the model. The model is significant with $p = 0.000 < 0.05$. In other words, the independent variables in the model have a significant effect on the dependent variable.

Table 10

MODEL SUMMARY				
R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**
0.999	0.999	0.997	3.92973	2.275

Table 11

VARIANCE ANALYSES OF THE MODEL					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**
Regression	55401.448	7	7914.493	512.505	0.000
Residual	61.771	4	15.443		
Total	55463.220	11			

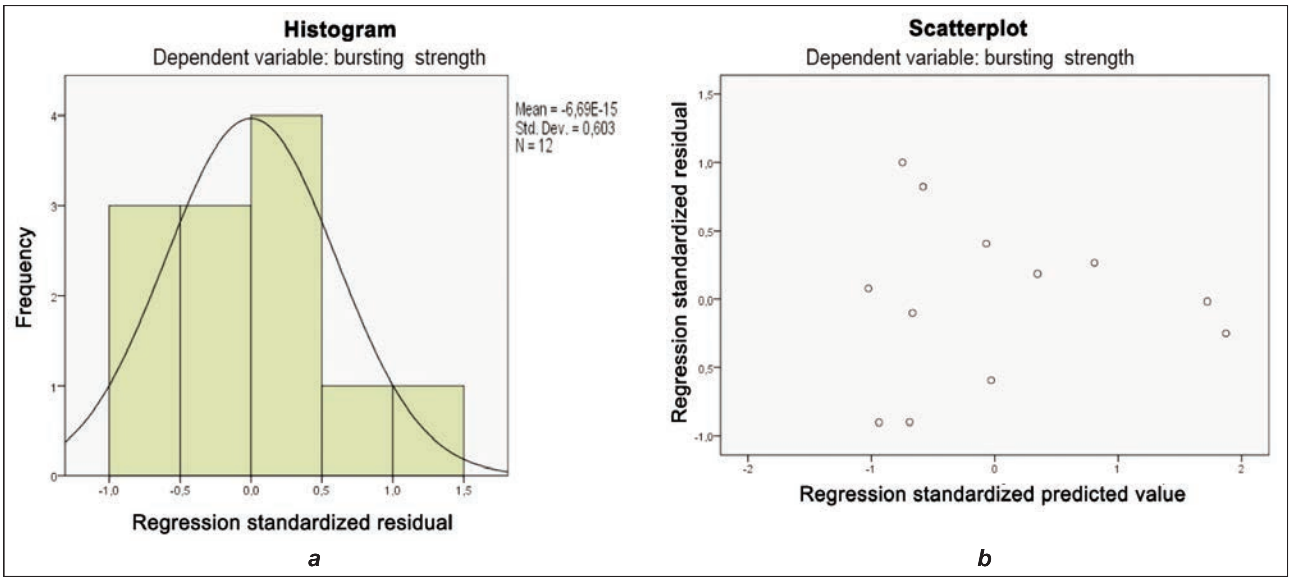

Fig. 5. Residual plots of model: *a* – Histogram; *b* – Residuals vs. Predicted Value

Since there are four categories for yarn type and the dataset is limited, the VIF values were checked in a model with only numerical data, after removing dummy variables, to evaluate the level of multicollinearity [19]. The fact that these values are 1 < VIF < 5 indicates that there is no multicollinearity problem (table 12).

Table 13 shows the regression coefficients. Examination of the table reveals that all independent variables in the model significantly affect the dependent variable (Sig. $p<0.05$). The regression equations for predicting bursting strength (BS) of the fabric for each yarn type are given below.

Table 12

VIF VALUES OF DEPENDENT VARIABLES		
Model	**Collinearity statistics**	
	Tolerance	**VIF**
YS	0.461	2.171
YE	0.534	1.871
FT	0.478	2.094
FE	0.341	2.935

Regression equation for knotted fabrics is (D_1, D_2, D_3 = 0) (equation 2):

$$BS = 307.803 + 4.393 * YS + 2.560 * YE - 109.489 * FT - 1.814 * FE \quad (2)$$

Regression equation for boucle fabrics is (D_1 = 1; D_2, D_3 = 0) (equation 3):

$$BS = (307.803 - 51.826) + 4.393 * YS + 2.560 * YE - 109.489 * FT - 1.814 * FE \quad (3)$$

Regression equation for loop fabrics is (D_2 = 1; D_1, D_3 = 0) (equation 4):

$$BS = (307.803 - 151.789) + 4.393 * YS + 2.560 * YE - 109.489 * FT - 1.814 * FE \quad (4)$$

Regression equation for slub fabrics is (D_3 = 1; D_1, D_2 = 0) (equation 5):

$$BS = (307.803 + 16.495) + 4.393 * YS + 2.560 * YE - 109.489 * FT - 1.814 * FE \quad (5)$$

In the obtained equations, yarn strength and elongation, fabric thickness and elasticity were found to be effective factors. Yarn strength and yarn elongation have a positive effect on bursting strength, while fabric thickness and fabric elasticity have a negative effect.

Table 13

COEFFICIENTS OF THE MODEL					
Model	**Unstandardized coefficients**		**Standardized coefficients**	**t**	**Sig.**
	B	**Std. Error**	**Beta**		
(Constant)	307.803	34.729		8.863	0.001
YS	4.393	1.352	0.242	3.248	0.031
YE	2.560	0.383	0.899	6.685	0.003
FT	–109.489	19.203	–0.349	–5.702	0.005
FE	–1.814	0.299	–0.492	–6.059	0.004
D1	–51.826	7.054	–0.330	–7.347	0.002
D2	–151.789	18.315	–0.967	–8.288	0.001
D3	16.495	5.823	0.105	2.833	0.047

CONCLUSION

This study investigated the bursting strength of plain knitted fabrics made from different types of fancy yarns and presented a statistical model on this subject. The effect of yarn type on bursting strength was found to be statistically significant.

Yarn strength and elongation, fabric thickness and elasticity parameters were tested, and regression analysis was performed using these parameters along with yarn type as a variable. Since yarn type is a nominal variable, the analysis was performed using dummy variables. Statistical prerequisites for the independent variables used in the regression equation were checked, and the model was revised accordingly. The regression equations for predicting the bursting strength of the fabric for each yarn type were presented.

In conclusion, it was shown that yarn type, yarn strength and elongation, fabric thickness and elasticity explain 99.7% of the bursting strength of plain knitted fabric produced from fancy yarn.

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