TEKSTİL VE KONFEKSİYON

VOL: 33, NO. 1
DOI: 10.32710/tekstilvekonfeksiyon.1026926

Linear Model Equation for Prediction and Evaluation of Surface Roughness of Plain-Woven Fabric

Kura Alemayehu Beyene 0000-0002-2293-5048
Nuredin Muhammed 0000-0001-9335-3064

Ethiopian Institute of Textile and Fashion Technology, Bahir Dar University, Bahir Dar, 1037, Ethiopia

Corresponding Author: Kura Alemayehu Beyene, kuraalemayehu@gmail.com

ABSTRACT

Nowadays, evaluating fabric touch can be a great interest of industries to match the quality needs of consumers and parameters for the manufacturing process. Modeling helps to determine how structural parameters of fabric affect the surface of a fabric and also identify the way they influence fabric properties. Moreover, it helps estimate and evaluates without the complexity and time-consuming experimental procedures. In this research paper, the linear regression model was developed that was utilized for the prediction and evaluation of surface roughness of plain-woven fabric. The model was developed based on nine different half-bleached plain-woven fabrics with three weft Yarn counts 42 tex, 29.5 tex & 14.76 tex, and three weft thread densities (18 picks per cm, 21 picks per cm & 24 picks per cm) and then the surface roughness of plain-woven fabric was tested by using Kawabata (KES-FB4) testing instrument. The findings reveal that the effects of count and density on the roughness of plain-woven fabric were found statistically significant at the confidence interval of 95%. The weft yarn count has a positive correlation with surface roughness values of plain-woven fabrics. On the other hand, pick density has a negative correlation with the surface roughness values of plain-woven fabrics. The correlation between measured surface roughness by KES-FB4 and calculated surface roughness by the model equation show how they are strongly correlated at 95% (R^2 of 0.97).

ARTICLE HISTORY

Received: 23.11.2021

Accepted: 13.12.2022

KEYWORDS

Surface Roughness, Linear Regression Modeling, Prediction, Plain-Woven Fabric, and Structural Parameters

1. INTRODUCTION

The properties of fabrics depend on their physical, chemical, and structural characteristics. Fiber type, yarn type, yarn smoothness, fabric structure, fabric thickness, and the presence of additional materials like membranes influence the comfort of clothing. In addition, the dyeing, finishing, and coating processes can also influence a material's properties [1,5].

Nowadays, consumers demand fabrics and clothing which not only look good but also feel comfortable and follow easy care. Consumers choose comfort as the most important attribute that they seek apparel products, which is followed by easy care and durability. As comfort is an individualistic sense it is very difficult to define, design, or determine it [2, 3]. Measuring and evaluating fabric surface properties can be of great interest in the industry nowadays to match the quality requirements for the consumer and the parameters for the manufacturing process purpose [3]. The most important properties of the fabrics which affect the sensorial comfort properties of fabric and cloth are the constructional parameters during manufacturing. The most effective parameters that can be counted on the surface properties of fabrics and cloths are such as thickness, weight per square meter, the pattern of weave, thread density, crimp%, yarn count, etc. [3, 5].

The surface of the textile fabrics is not absolutely flat and smooth. Its geometrical roughness to certain extents is considerable. The roughness was defined as irregularities in the surface that can be described geometrically as the size of roughness elements or mechanically by the friction coefficients. Roughness is a descriptive term for a fabric surface that has the feel of sandpaper as per ASTM-D123–09. Smoothness and roughness of fabric and cloth materials are important sensorial properties for the design of many textile fabrics including plain bed-sheet, medical textiles, hygiene and healthcare products, sportswear, underwear,

To cite this article: Beyene KA, Muhammed N. 2023. Linear Model Equation for Prediction and Evaluation of Surface Roughness of Plain-Woven Fabric. *Tekstil ve Konfeksiyon* 33(1), 88-94.

lingerie, and other consumer products that needs to have special sensitive surface tactile properties [6, 7]. The surface roughness influences the fabric hand and it plays a significant role in the end use of the fabric. A factor having an important role in the configuration of the surface characteristics of the fabric is the crimp of the yarns, under the consideration that the yarn densities of warp and weft are of the same class. If the crimp values of the weft and warp yarns are close to each other, the fabric produced is balanced in terms of appearance. The geometrical roughness characteristics of the fabrics provide information on their structural characteristics. The surface of the textile fabrics is not absolutely flat and smooth. Its geometrical roughness to certain extents is considerable. The surface roughness influences the fabric hand and it plays a significant role in the end-use of the fabric. A factor having an important role in the configuration of the surface characteristics of the fabric is the crimp of the yarns, under the consideration that the yarn densities of warp and weft are of the same class. If the crimp values of the weft and warp yarns are close to each other, the fabric produced is more or less balanced in terms of appearance [8-11]

Modeling is the process of perception of textiles by the skin fills the gap between two contemporary existing solutions: objective and subjective assessment of handling properties of fabrics [12-16]. The different number of mathematical models concerning the human body, clothing, and environment offer useful equations and tools. This is used in identifying important parameters in material design and for predicting fabrics and clothing performance under some environmental conditions [4, 16].

The measurement and evaluation of fabric surface roughness are assessed by using either contact or non-contact methods. In this regard, many devices and techniques have been developed and employed. The Kawabata Evaluation System for Fabrics (KESF), Fabrics Analysis by Simple Tests (FAST), and Fabric Touch Tester (FTT) systems are available for measuring the fabric handle-related characteristics under the contact methods. But, as far as the tactile responses are concerned, all the low-stress mechanical characteristics directly or indirectly stimulate the touch pressure roughness and other mechanoreceptors of human skin [10-16].

The measurement, quantification, and analysis of surface roughness have been the subject of many kinds of research works, due to the difficult part of these parameters in the selection of suitable fabric for diverse technical and clothing end-uses fabrics. Many types of research have focused on the measurement of fabric surface properties by objective and subjective methods. In recent years, there is technological advancement in the realism, accuracy, and predictive capabilities of equations and tools for the theory and simulation of materials or products. Predictive modeling has now become a powerful tool that can also deliver real value through application and innovation to different industries. It forms an essential part of the research and development effort of many of the world's leading organizations and can be incredibly valuable for businesses. Using modeling, it is possible to identify the effective aspects of plain-woven fabric structure on surface roughness and also discover the way that they influence the property of surface roughness of plain-woven fabrics. Used in a combination of good analysis and experimentation, materials modeling can drive progress, saving time, cost, effort, and resources. The results obtained from the model are tangible, available quickly, and have project relevance.

Most of the researchers were focused on experimental methods for characterizing the surface roughness of fabrics but, their focus on modeling the roughness of a commonly used plain-woven fabric is limited, and hence most industries are suffering from knowing the level of surface roughness of their product. In this research, a linear regression model was developed based on the geometrical parameter of fabrics. Thereby the designers in the weaving looms can design plain-woven and various types of woven fabrics with specific surface roughness; simply by applying changes in fabric structural parameters "(such as weft yarn density and weft yarn linear density)" and laboratory personnel can simply calculate the surface roughness of given fabrics by identifying structural parameter and using the regression model equations. The model is a guide to selecting a suitable fabric for various end uses and a way to test and predict the surface roughness of any kind of woven fabric.

2. MATERIAL AND METHOD

2.1 Material

A. Fiber

The fiber which was used in this research work was 100% cotton and the fiber-specific characteristics properties from USTER HVI 1000 were mentioned in tabular form as shown in Table 1.

B. Fabrics

Plain-woven fabrics, nine 100% cotton, were produced with different yarn and fabric structural parameters by Picanol air-jet loom. As indicated in Table 2, the fabric properties were modified by using three different weft densities (PPC) and three different weft yarn linear densities (weft count), while the other factors such as warp density, warp count, tension, speed, and relative humidity (RH%) percent remained constant. The warp tension force is 1.58KN and the speed of the loom is 550 RPM. The fabrics were then

Table 1. Properties of cotton fiber

Fiber source	SCI	Mst [%]	Mic	Mat	UHML [mm]	SF [%]	Str [g/tex]	Elg [%]
Metema	102	8.0	4.65	0.86	28.8	10.5	23.8	7.3
Awash	110	8.9	4.72	0.87	28.65	8.0	23.1	6.4
Metema	93	8.8	4.21	0.85	28.76	8.9	21.9	6.6
Awash	110	8.7	4.49	0.86	28.59	8.2	22.2	7.0
Metema	88	7.8	4.60	0.86	28.57	11.1	20.5	6.9
Awash	105	7.8	4.50	0.86	27.33	7.4	22.8	7.0
	102	8.4	4.53	0.86	28.45	9.0	22.4	6.9

Table 2. Constructional parameters of plain-woven fabric

Fabric code	Weave type	Warp density (Ends/cm)	Warp count (tex)	Weft density (Picks/cm)	Weft count (tex)
FK_1	Plain	24	29.5	18	14.76
FK_2	Plain	24	29.5	21	14.76
FK_3	Plain	24	29.5	24	14.76
FK_4	Plain	24	29.5	18	29.5
FK_5	Plain	24	29.5	21	29.5
FK_6	Plain	24	29.5	24	29.5
FK_7	Plain	24	29.5	18	42
FK_8	Plain	24	29.5	21	42
FK_9	Plain	24	29.5	24	42

subjected to a combination pretreatment process. The chemicals used were sodium hydroxide 3%, hydrogen peroxide 4%, sodium silicate 2%, wetting agent 0.5%, EDTA 0.5 (% owf), and 10:1 liquor ratio. The fabric is treated at 90 0C temperature for 1:30 hr. at a machine speed of 40 m/min jigger machine (Mesdan-Lab model) was used.

2.2 Experimental design

Central composite design (CCD) is an efficient technique for experimentally exploring relationships between investigated factors and system response. Central composite design experiments need a minimum number of trials for estimating the main effect, require a smaller number of runs, and allow sequential experimentation, which provides flexibility and time-saving in running the experiment and analysis [17, 18]. The experiment has 8 non-center and 5 center points and the total run is 13 with five replications as shown in Table. 3.

2.3 Experimental procedure

Five test specimens 20.0 × 20.0 cm are prepared for measuring surface roughness by Kawabata Evaluation System (KES-FB4) from each produced sample and conditioned at 65 ± 2% relative humidity and 20 ± 2°C for a minimum of 24 hr. before testing according to ASTM-D1776 practice for conditioning and testing textile materials. The data were statistically analyzed and evaluated using the Design-Expert software analysis of variance (ANOVA) was done.

Table 3. The experimental design with two factors and three levels.

Code	Run	Factor 1	Factor 2	Response 1
		Count (tex)	Density (Picks/cm)	SMD
FK_2	1	14.76	21	1.315
FK_5	2	29.5	21	1.906
FK_8	3	42	21	2.321
FK_1	4	14.76	18	1.389
FK_5	5	29.5	21	1.906
FK_5	6	29.5	21	1.906
FK_9	7	42	24	2.321
FK_5	8	29.5	21	1.906
FK_4	9	29.5	18	2.137
FK_5	10	29.5	21	1.906
FK_3	11	14.76	24	1.113
FK_6	12	29.5	24	1.520
FK_7	13	42	18	2.566

2.4 Developing an empirical model

There are several statistical approaches are available nowadays to researchers to analyze multiple outcomes or informants. With multiple informants, researchers can jointly model the associations between factors (count and density) and response (surface roughness) using a linear regression modeling approach available in standard software packages [18, 19] The actual equations are derived from the coded equations after the coded equations have been determined. The coded equations are determined first, and the actual equations are derived from the coded equations. The actual equation for each term (factors) was obtained from the coded equation by being replaced with its coding formula as shown in Equation (1) [17-19].

$$X_{coded} = \frac{X_{actual} - \bar{X}}{\frac{X_{High} - X_{Low}}{2}} \qquad (1)$$

Where X_{coded} coded values of Surface Roughness, X_{actual}: is the actual value of Surface Roughness, $\bar{X}$: the mean values of Surface Roughness, X_{High} the maximum values of Surface Roughness, and X_{Low}: the minimum value of Surface Roughness.

There should be some assumptions made in order to obtain a valid and trustworthy model for the prediction and evaluation of the surface roughness of plain-woven fabrics, even though various parameters affect the surface roughness of woven fabrics.

Assumptions

The characteristics of all fibers are the same.

The fabric is produced with a constant tension force.

The fabric is produced with the same warp count and density.

The experimental results of surface roughness from the forming trials performed according to the matrix by central composite are tabulated in Table 3 by Response 1. These values are fed to the Design-Expert software for developing the surface roughness of the fabric by only considering the count and density of the plain-woven fabric as shown in Equation (2).

$$SMD = \beta_0 + \beta_1 A(Count) + \beta_2 B(Density) \text{ ....(2)}$$

2.5 Model validity test

It is necessary to check the fitness of the linear regression model to ensure that it gives an acceptable approximation to the true values and verifies that none of the least-squares regression assumptions are violated. Proceeding with the exploration and optimization of a fitted response surface will likely give poor or misleading results unless the model provides an adequate fit [17, 18].

2.6 Model test

A plain fabric consisting of different structural parameter which has different weft densities and weft counts were used for the model test against surface roughness measured values by KES-FB4. Structural parameter analysis (density and count) was done for the fabrics which are used for model validation purposes. The count of weft yarn from the fabric is measured according to ISO 7211-5; the density of weft yarn will be measured by using ISO 7211-2 standard. Finally, the average value of each measurement was used for calculating the surface roughness of the fabrics by developing the SMD model equation by Equation (2). The surface roughness of the fabrics was also measured by the Kawabata KES-FB4 instrument. Finally, the calculated and the measured value were checked for their correlations by plotting graphs.

3. RESULTS AND DISCUSSION

3.1 Effects of count and density on the surface roughness

Surface roughness data sets are normally distributed, as illustrated in Figure 1, and were obtained from the KES-fb4 in Table 2 under the response column. From the box plot in Figure 2, it is observed that the collected data have no out layers either an upper limit or lower limit. This implies that the collected data are normal and can be used for further statistical analysis.

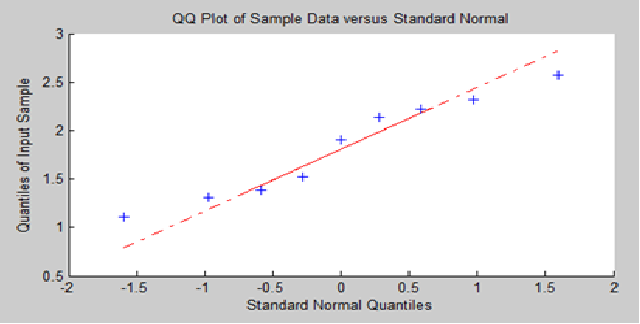

Figure 1. The quantile-quantile plot of the input data Vs. standard normal

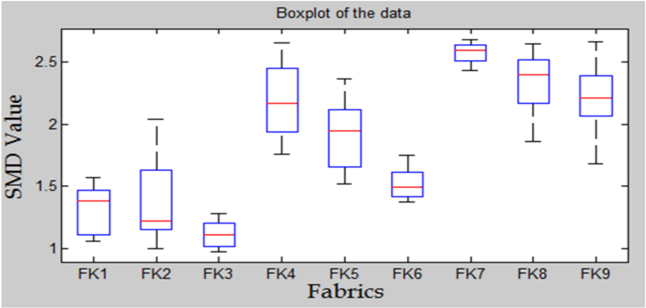

Figure 2. The box plot of the collected data set

ANOVA results of the linear models presented in Table 4 indicate that the model can adequately be used to describe the surface roughness of the fabrics based on the fabric parameters such as count and density of weft yarn. The F-value is 166.83 ($P < 0.0001$) which implies that the model is significant for surface roughness. An F- value this large could occur due to noise only 0.01 percent of the time. A P-value is a measure of the test's significance [19, 20]. If the P-value is less than 0.05 (P 0.05), the model terms in the linear model equation are significant. Both the model terms weft count and weft density and their interactions (count X density) are statistically significant at 95% of the confidence interval since they have a P-value of 0.0001, 0.0002, and 0.0331 respectively. The Predicted R^2 of 0.9407 is in reasonable agreement with the Adjusted R^2 of 0.9651; i.e., the difference is less than 0.2, which ensures a satisfactory adjustment of the model to the experimental data.

A smooth fabric surface provides a bigger contact area with the human body, while a rougher fabric surface has less contact area when it gets in contact with the human body [4, 16]. The effect of weft yarn count on surface roughness values of fabrics was observed in that surface roughness values increase with weft yarn count (coarser), while it decreases as the weft yarn gets finer and finer as shown in Figure 3. Also, the surface smoothness of the fabrics increases as the pick density of the fabrics increases, and the surface roughness of the fabric increases as the weft thread density decreases as shown in Figure 3. This was because as the thread density of weft yarn increases the pick and valley on the fabric surface decreased which resulted in the interlacement of warp and weft yarns [10, 22, 23].

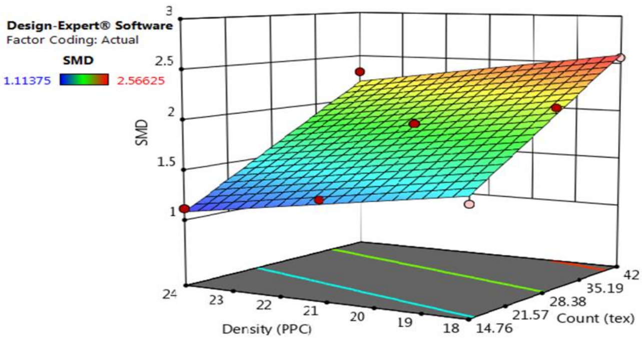

Figure 3. The effects of both density and count on the surface roughness of the fabric

3.2 Model equation for surface roughness

The actual model equation was developed by using surface roughness values of the nine samples which were measured by the KES-FB4 instrument. The equation in terms of actual factors (count and density) can be used to make predictions about the response (surface roughness) for given levels of each factor. Here, the levels of each factor should be stated in the original units for each factor in the linear model equations. This equation can be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is at the center of the design space as shown in Equation (3).

$$SMD = +1.98837 + 0.041492 * \text{Count} - 0.063241 * \text{Density}. \qquad (3)$$

3.3 Model validity test

The model validation test was done by checking the correlation between the measured data obtained from the experimental method (KES-FB4) and the calculated (estimated) data obtained from the developed actual model equations SMD as shown in Equation (3). As it is shown in Figure 4, the proposed model equation can properly correlate the experimentally measured data from (KES-FB4) at the confidence interval of 95% (R^2 of 0.97). The model efficiency was tested by using three different fabrics which are not used for the model equation extraction. The fabric's properties were studied and identified the weft density and count by using the ISO 7211-5 and ISO 7211-2 standard.

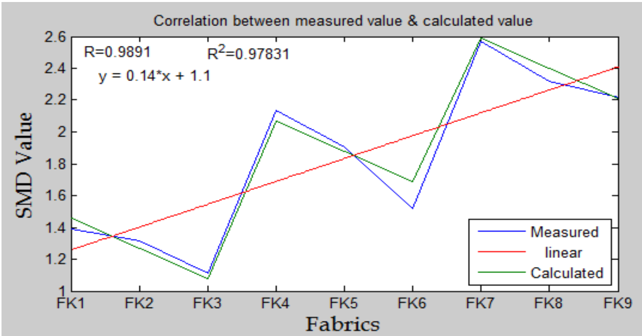

Figure 4. The correlation between the measured SMD values by KES-FB4 and the calculated SMD value by the model equation

3.4 Model test

The fabric properties which were used for the model test which was 100% cotton half-bleached and the parameter of construction were shown in Table 5. The correlation between the surface roughness values from KES-FB4 and the surface roughness values from the developed model equation were found to strongly correlate at the 95% degree of freedom as shown in Figure 5. The model can be used for the prediction and evaluation of plain-woven and other woven fabrics which are hundred percent cotton fabrics.

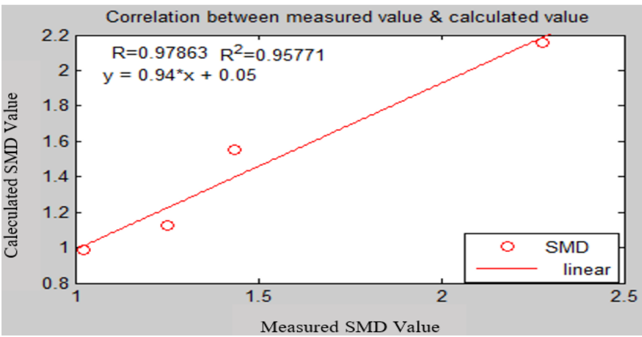

Figure 5. The correlation between the measured SMD values by KES-FB4 in X-direction and calculated SMD value by model equation in Y-direction for model testing

Table 4. ANOVA table for the linear model

Source	Sum of Squares	df	Mean Square	F-value	p-value	Decision
Model	2.14	3	1.07	166.83	P < 0.0001	Significant
Count	1.92	1	1.92	299.98	P < 0.0001	Significant
Density	0.2160	1	0.2160	33.69	P < 0.0002	Significant
Count*Density	0.0004	1	0.0004	6.35	P < 0.0331	Significant
Residual	0.0641	10	0.0064			
Lack of Fit	0.0641	6	0.0107			Not-significant
Pure Error	0.0000	4	0.0000			
Cor Total	2.20	12				

Table 5. Fabrics parameters for model test

Fabric code	Weave type	Warp Density (Ends/cm)	Warp count (tex)	Weft density (Picks/cm)	Weft count (tex)	Measured (SMD)	Calculated (SMD)
MT_1	Plain	32	28	32	28	1.25	1.1264
MT_2	Plain	20	20	20	20	1.437	1.5533
MT_3	Plain	21	36	21	36	2.277	2.1540
MT_4	Plain	28	18.5	28	18.5	1.023	0.9859

4. CONCLUSION

Even though different structural parameters affect the surface properties of the fabrics, it is possible to control the surface behavior of the fabric with the developed model equations. The surface roughness of plain-woven fabric was mainly affected by weave type, thread density, weft, and warp linear density. The weft count and density were used for the model equation which can be used for the prediction and evaluation of the surface roughness of plain-woven fabric. The model is statistically significant and can adequately be used to describe the surface roughness of the fabrics. The surface roughness increases with count increases and the surface roughness decrease as the density of the weft thread increases. To produce fabrics with smooth surface qualities, both yarn density and weft yarn fineness should be increased. The model was validated and tested the correlation between measured by KES-FB4 and calculated by the developed model equation revealed that the model was strongly correlated with the confidence interval of 95% (R^2 of 0.95). This study needs further research and investigation since it does not only count and density affect the surface properties of woven fabrics there are many factors even in both the warp and weft direction of the woven fabrics.

REFERENCES

1. K. A. Beyene, E. K. Gebeyehu and B. F. Adamu, "The effects of pretreatment on the surface roughness of plain-woven fabric by the Kawabata Evaluation System," Textile Research Journal, 2022, pp. 1-9, 00405175221139322.
2. Ashdown, S., Improving body movement comfort in apparel, in Improving comfort in clothing. 2011, Elsevier. p. 278-302.
3. Roy Choudhury, A.K., P.K. Majumdar, and C. Datta, 1 - Factors affecting comfort: human physiology and the role of clothing, in Improving Comfort in Clothing, G. Song, Editor. 2011, Woodhead Publishing. p. 3-60.
4. Pense-Lheritier, A.-M., et al., Sensory evaluation of the touch of a great number of fabrics. Food quality and preference, 2006. 17(6): p. 482-488.
5. Atalie, D. and G.K. Rotich, Impact of cotton parameters on sensorial comfort of woven fabrics. Research Journal of Textile and Apparel, 2020. 24(3): p. 281-302.
6. Akgun, M., The effect of fabric balance and fabric cover on surface roughness of polyester fabrics. Fibers and Polymers, 2013. 14(8): p. 1372-1377.
7. Mao, N., Y. Wang, and J. Qu. Smoothness and roughness: Characteristics of fabric-to-fabric self-friction properties. in The Proceedings of 90th Textile Institute World Conference. 2016. The Textile Institute.
8. Akgun, M., B. Becerir, and H.R. Alpay, The effect of fabric constructional parameters on percentage reflectance and surface roughness of polyester fabrics. Textile Research Journal, 2012. 82(7): p. 700-707.
9. Classen, E., 3 - Comfort testing of textiles, in Advanced Characterization and Testing of Textiles, P. Dolez, O. Vermeersch, and V. Izquierdo, Editors. 2018, Woodhead Publishing. p. 59-69.
10. Beyene, K.A. and S. Gebeyaw, The effects of yarn and fabric structural parameters on surface friction of plain-woven fabrics. Research Journal of Textile and Apparel, 2021. 25(.4): p. 210-218.
11. Beyene, K.A. and V. Sampath, Modeling Surface Roughness for prediction and evaluation of Bed-Sheet woven Fabric. CTA-2019, 2019: p. 42.
12. Beyene, K. A., Mengie, W., & Korra, C. G., Effects of weft count and weft density on the surface roughness of 3/1 (Z) twill woven

fabric. Research Journal of Textile and Apparel, ahead-of-print(ahead-of-print). https://doi.org/10.1108/RJTA-08-2021-0104

13. Beyene, K. A., & Kumelachew, D. M., An investigation of the effects of weave types on surface roughness of woven fabric. Textile Research Journal, 2022. 92(14-15).

14. Beyene KA. 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 Feb 22.

15. Beyene KA, Korra CG. Modeling for the Prediction and Evaluation of the Crimp Percentage of Plain Woven Fabric Based on Yarn Count and Thread Density. Tekstilec. 2022 Jan 1;65(1).

16. Kawabata, S. and M. Niwa, Objective Measurement of Fabric Mechanical Property And Quality. International Journal of Clothing Science and Technology, 1991. 3(1): p. 7-18.

17. Myers, R.H., et al., Response surface methodology: a retrospective and literature survey. Journal of quality technology, 2004. 36(1): p. 53-77.

18. Raissi, S. and R.-E. Farsani, Statistical process optimization through multi-response surface methodology. World Academy of Science, Engineering and Technology, 2009. 51(46): p. 267-271.

19. Normand, S.-L.T., Some old and some new statistical tools for outcomes research. Circulation, 2008. 118(8): p. 872-884.

20. Chihara, L., Introduction to Linear Regression Analysis. The American Mathematical Monthly, 2002. 109(7): p. 681.

21. Greenland, S., Valid p-values behave exactly as they should: Some misleading criticisms of p-values and their resolution with s-values. The American Statistician, 2019. 73(sup1): p. 106-114.

22. Becerir, B., M. Akgun, and H.R. Alpay, Effect of some yarn properties on surface roughness and friction behavior of woven structures. Textile Research Journal, 2016. 86(9): p. 975-989.

23. Kayseri, G.Ö., N. Özdil, and G.S. Mengüç, Sensorial comfort of textile materials. Woven fabrics, 2012: p. 235-66.