Response Surface Methodology for Optimisation of Parameters in High Micronaire Value Cotton Fibre

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Abstract
The spinning consistency indexes obtained from high volume instrument testing are more reliable in recent years for deciding the spinning limit of cotton fibres. The main objectives of this study were to investigate the application of Response Surface Methodology (RSM) in determination of optimum value of spinning consistency index (SCI) for high micronaire value of cotton variety. High micronaire value variety of Gagat was used in this experiment. Initially, five level combination coded value was applied to determine the effects of the independent variables such as micronaire, maturity index and UHML on the spinning consistency index, and the experimental design by Response Surface Methodology (RSM) was obtained for spinning consistency index at different micronaire, maturity index and UHML. The determination coefficient R^2 was 92.16% meaning that the experimental data were acceptable. The relationships between the response SCI and the predictors, Micronaire and Len are significant. The relationship between the response SCI and the predictor Mat is not significant. It was observed that regression model is significant and lack of fit strengthens the model. It was found that the spinning consistency index (56) could be optimised at the optimum condition at micronaire value of 8.14, maturity index 1.03 and UHML of 23 mm.

I. INTRODUCTION

Based on the cotton outlook October 2018 report, it was stated that world 2018-19 cotton area and production are projected at 32.9 million hectares (81.20 million acres) and 122.0 million bales. The global percentage of cotton production is nearly 2% less than that of 2017-18. Among all crops produced in India, Cotton constitutes the largest amount of production; expected projection of cotton fibre production is 28.7 million bales of cotton in 2018-19, which was 1 percent less than the production in 2017-18 [3].

In order to maximise the usage of coarse cotton varieties for producing medical textile, the high micronaire value varieties were selected, which offer a low spinning consistency index and short fibre length. The HVI method is mostly used to determine cotton fibre properties.

According to Cotton Corporation of India, the price of coarse cotton varieties such as Bengal desi/Assam comilla is Rs 44,108/per candy with staple length less than 22 mm and micronaire value range 5-7. These coarse cotton varieties are not used for spinning yarn and hence, these varieties can be used in alternative applications such as medical textiles. Coarse cotton varieties are widely used in surgical cotton. The hybrid Gale cotton varieties are widely used in this research work. Spinning consistency index indicates the spinning limit of cotton fibres. The (SCI) responses obtained by HVI method are influenced by fibre parameters, namely: micronaire value, Maturity, UHML, UNF, SFI, Strength, Elongation, Rd and Plus B. Therefore, it is very important to determine the optimization of these parameters, which will affect the measurement of the SCI values of high micronaire value cotton varieties in order to know their feasibility for medical textiles such as surgical cotton. The research design used in this study is central composite design of Response Surface Methodology of Minitab 16 Statistical software. Response Surface Methodology is a mathematical and statistical technique useful for improving, developing and optimizing processes [8]. It is possible to observe the interaction effect of the independent parameters on the response by using Response Surface Methodology.

II. MATERIAL AND METHOD

The data used in this research is obtained from a cotton breeder producing different varieties of cotton fibre in Saloo district Wardha, Maharashtra. The cotton breeder produces these hybrid cotton varieties during three consecutive seasons. The key point is that the cotton fibre samples used in this research were collected directly from the farm and immediately put through the ginning process at the same place. The standard atmospheric conditions in the laboratory of the factory are 20±20C, 65±2%RH. Uster HVI Spectrum apparatus is used in the regular measurements to obtain cotton fibre properties which are micronaire (Mic), maturity index (Mat), length (Len), fibre length uniformity index (Unf), short fibre index (SFI), fibre strength (Str), elongation (Elg), moisture content (Moist), reflectance (Rd), yellowness (b), trash count (Tr_Cnt) and trash % area (Tr_Area) [4].

Different male and female are used in this research to produce Gale hybrid varieties of cotton fibre. Measurements of cotton fibre properties were carried out using an HVI instrument operating in the HVI mode. The data was entered into the minitab 16 software and studied for the response surface designs with feasible region. The results achieved from this research will be suitable for the production of medical textile products such as surgical cotton. Total 58 cotton varieties collected from the farm with variations in fibre properties and their means, standard deviations and constant of variations are mentioned in Table 1. In order to show that response surface designs with feasible region, Spinning Consistency Index (SCI) is considered as response variable and HVI results of fibres (Mic, Mat, Len, Unf, SFI, Str, Elg, Moist, Rd, b, Tr_Cnt, and Tr_Area) as effecting factors.

Table 1: Mean, Standard deviation, CV % of the Gale variety Fibre properties

	Mic	Mat	Length	Unf	SFI	Str	Elg	Moist	Rd	Plus b
Mean	6.1760	0.95655	22.058	81.507	9.702	27.414	5.850	7.579	73.357	9.010
Std. deviation	0.7132	0.02857	1.241	1.489	0.896	3.238	1.014	1.188	2.997	0.976
CV %	11.55	2.99	5.63	1.83	9.24	11.81	17.33	15.67	4.09	10.83

Optimisation of spinning consistency index involved the combination of RSM with central composite design (CCD). Since there are large numbers of variables controlling the spinning consistency index, a few mathematical models are required to represent the process. Rather than including all the parameters, these models have to be developed using only significant parameters that influence the spinning consistency index of cotton fibres. Therefore, in order to achieve this, the data were subjected to analysis of variance (ANOVA). RSM and second-order CCD for three variables [7] were Micronaire b1, Maturity b2, and fibre length (UHML) b3. Besides, five level combination coded value - α, -1, 0, +1, and + α (Table 2) [5] was applied to determine the effects of the independent variables on the spinning consistency index.

Table 2: Design of experiment for coded factor

Variables	Levels				
	α	-1	0	1	α
Mic (b1)	4.29	5.20	6.27	7.13	8.14
Mat (b2)	0.89	0.93	0.96	1	1.03
Len (b3)	27.05	23.57	22.49	21.87	18.55

Table 3: Experimental design suggested by MINITAB software Version 16

Run order	Mic (b1)	Mat (b2)	Len (b3)
1	6.27	0.96	22.49
2	5.20	0.93	21.87
3	7.13	0.93	21.87
4	7.13	0.93	23.57
5	5.20	1.00	21.87
6	6.27	0.96	22.49
7	7.13	1.00	23.57
8	6.27	0.96	22.49
9	7.13	1.00	21.87
10	5.20	1.00	23.57
11	6.27	0.96	22.49
12	5.20	0.93	23.57
13	6.27	1.03	22.49
14	4.29	0.96	22.49
15	8.14	0.96	22.49
16	6.27	0.89	22.49
17	6.27	0.96	22.49
18	6.27	0.96	18.55
19	6.27	0.96	22.49
20	6.27	0.96	27.05

The spinning consistency index was obtained by following three parameters chosen - micronaire value (µg/inch), Maturity Index and fibre length (UHML in mm).

III. RESULTS & DISCUSSION

Optimization of SCI Using RSM (Response Surface Methodology)

Analysis of RSM Model of SCI is done with the help of Minitab software 16. The data processing was also done using software Minitab 16, and the results can be seen in Table 4.

Results in Table 4 shows that the predicted responses and highest actuals were 136 and 136.869 respectively at factors whereby micronaire (µgm/inch) was 6.27, Maturity index was 0.96 and UHML (mm) was 27.05. Meanwhile, the predicted responses and lowest actuals were 34 and 31.549 respectively at factors in which micronaire (µgm/inch) was 6.27, Maturity index was 0.96 and UHML (mm) was 18.55.

Table 4: Comparison of factors between predicted (FITS) and actual (Y) responses

Run order	Test variables			RESPONSE (SCI)	
	Mic	Mat	UHML	Y	Fits
1	6.27	0.96	22.49	106	91.511
2	5.20	0.93	21.87	91	100.707
3	7.13	0.93	21.87	56	64.657
4	7.13	0.93	23.57	91	91.782
5	5.20	1.00	21.87	88	95.836
6	6.27	0.96	22.49	106	91.511
7	7.13	1.00	23.57	91	92.045
8	6.27	0.96	22.49	91	91.511
9	7.13	1.00	21.87	54	60.704
10	5.20	1.00	23.57	108	109.898
11	6.27	0.96	22.49	88	91.511
12	5.20	0.93	23.57	108	110.554
13	6.27	1.03	22.49	88	82.808
14	4.29	0.96	22.49	118	110.882
15	8.14	0.96	22.49	54	51.144
16	6.27	0.89	22.49	91	86.498
17	6.27	0.96	22.49	88	91.511
18	6.27	0.96	18.55	34	31.549
19	6.27	0.96	22.49	88	91.511
20	6.27	0.96	27.05	136	136.869

Table 5: Optimisation of spinning consistency index of high micronaire by estimated regression coefficients of second-order polynomial model

Term	Coefficient	SE Coefficient	t	p
Constant	96.1848	3.498	27.499	0.000
MIC (b1)	-26.7264	4.877	-5.481	0.000
MAT (b2)	-1.1025	4.879	-0.226	0.826
LEN (b3)	51.4289	6.107	8.421	0.000
MIC*MIC (b1*b1)	-11.3612	7.507	-1.513	0.161
MAT*MAT (b2*b2)	-6.8585	7.455	-0.920	0.379
LEN*LEN (b3*b3)	-11.2027	7.511	-1.492	0.167
MIC*MAT (b1*b2)	0.9160	12.960	0.071	0.945
MIC*LEN (b1*b3)	43.0846	31.920	1.350	0.207
MAT*LEN (b2*b3)	10.5378	31.894	0.330	0.748
	R-Sq = 92.16% R-Sq(adj) = 85.11%			

Table 5 shows that the linear factors such as fibre length UHML (mm) (b3) indicated positive coefficients and micronaire (b1), Maturity index showed negative coefficients. Square factors such as MIC*MIC (b1*b1), MAT*MAT (b2*b2), LEN*LEN (b3*b3) indicated negative coefficients. Quadratic or interaction factors such as MIC*MAT (b1*b2), MIC*LEN (b1*b3) and MAT*LEN (b2*b3) shows positive coefficients respectively. Analysis of response surface regression [2] was performed and results of estimated regression coefficients of second-order polynomial model for optimisation of SCI for high micronaire value cotton are shown in Table 5. Referring to Table 5, the second-order polynomial model equation for SCI optimisation was given in the equation:

Y = 96.1848-26.7264 b1 -1.1025 b2 + 51.4289 b3 -11.3612 b1b1 -6.8585 b2b2 -11.2027 b3b3 + 0.9160 b1b2 + 43.0846 b1b3 + 10.5378 b2b3 ------ (1)

Where: b1 = micronaire (µgm/inch), b2 = Maturity index, b3 = UHML(mm),Y = SCI.

R^2 (R-Sq) describes the amount of variation in the observed responses that is explained by the model. The coefficient of determination (R^2) and the significance of lack-of-fit indicate the fitness and adequacy of the model. For coarse cotton varieties, the coefficient of determination R^2 which was calculated to be 92.16% of variability in the response could be explained by the model. The closer the R^2 value to unity, the better the empirical model fits the actual data. The model explains 7.84% variability in the observed response value. Probably, 7.84% of the total variations would be due to other factors which were excluded in the model. The adjusted R^2 represents a rectified value for R^2 after excluding unnecessary model terms. In this study, the adjusted R^2 (85.11%) was close to the R^2 (92.16%) value. The higher the adjusted R^2 implies better the model. The relationships between the response SCI and the predictors, Mic (P = **0.000**) and Len (P = **0.000**) are significant. The relationship between the response, SCI and the predictor, Mat (P = **0.826**) is not significant because the p-value is higher than the pre-selected α-level. A commonly used α-level is 0.05.

Table 6: ANOVA for optimisation of SCI of high micronaire value cotton fibre

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**f**	**p**
Regression	9	10080.5	10080.5	1120.05	13.07	0.000
Residual Error	10	857.3	857.3	85.73		
Lack-of-Fit	5	453.8	453.8	90.75	1.12	0.450
Pure Error	5	403.5	403.5	80.70		

The p value defined the probability of the factors having significant or not significant effect on the response. The RSM model signifies better fit to the experimental data when the f value was large and the p-value is less than 0.05. Regression is further broken into different orders of terms in the model - linear, square and interaction. Based on the above discussion, the high f and low p values with 13.07 and 0.000, respectively indicate that the regression model found in this study was very significant [Table 6]. The test for lack of fit was also calculated by Minitab software 16. The lack of fit test assesses the fit of your model. If the p-value is less than your selected α-level, evidence exists that your model does not accurately fit the data. Lack of fit explains the variation in the data around the fitted model. Table 6 shows the results of the lack of fit and it was found that the f and p values for the lack of fit were 1.12 and 0.450, respectively. Besides, the absence of any lack of fit (p>0.05) also strengthened the reliability of the models. Thus, it exhibits that the model was fitted well to the experimental data.

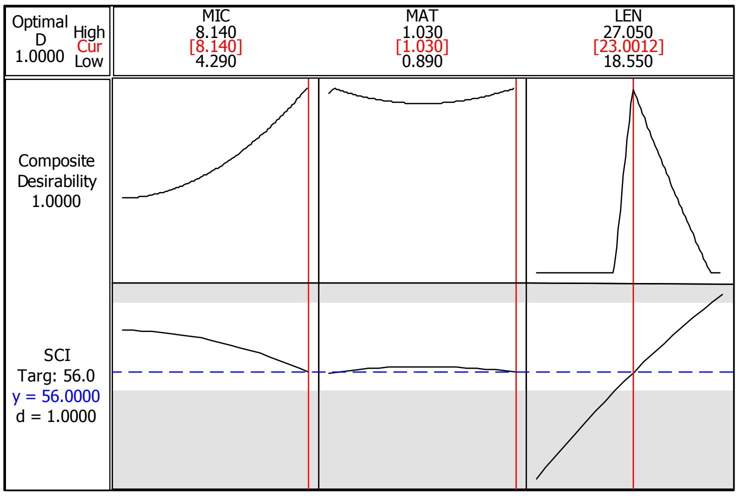

Fig. 1 (a): Response optimiser for target goal at optimum condition

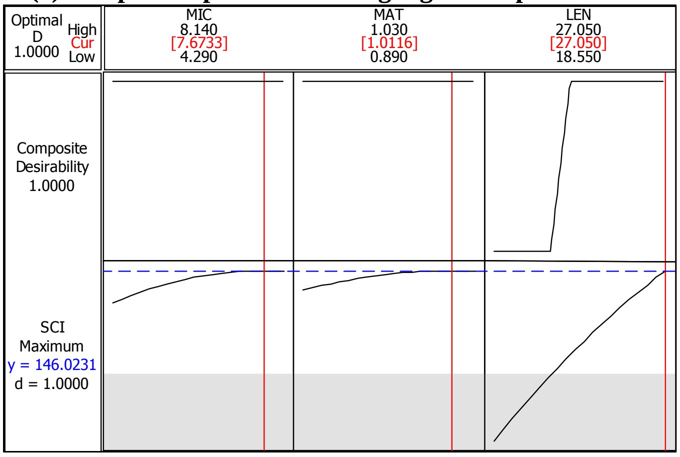

Fig. 1 (b): Response optimiser for target maximum at optimum condition

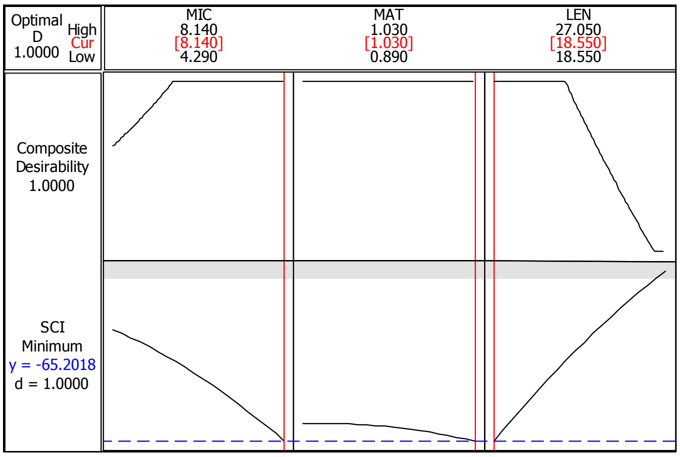

Fig. 1 (c): Response optimiser for minimum goal at optimum condition

Fig 1(a) shows that the target goal of SCI (56) for optimum conditions with micronaire of 8.14, Maturity index of 1.03 and UHML (mm) of 23.002, and maximum of SCI Fig 1(b) for optimum conditions with micronaire of 7.67 Maturity index of 1.01 and UHML (mm) of 27.050 were feasible to be carried out. Meanwhile, for minimum goal Fig 1(c) at optimum condition with micronaire of 8.14, Maturity index of 1.03 and UHML (mm) of 18.55 was not feasible to be carried out.

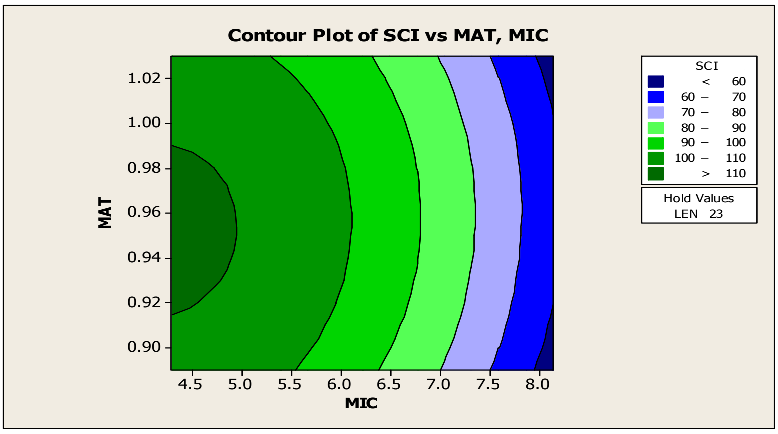

Fig. 2: Contour plot of SCI at feasible optimum condition; Micronaire of 8.14 µg/inch, Maturity index of 1.03 and UHML of 23 mm (holding value: UHML of 23 mm)

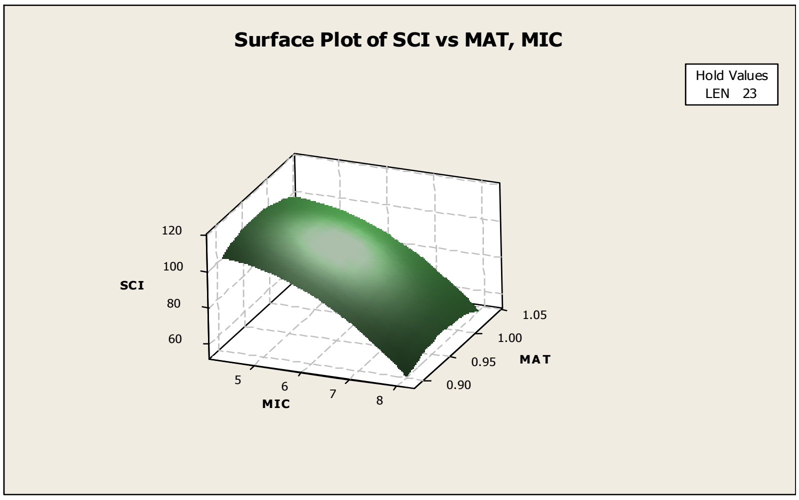

Fig. 3: Surface plot of SCI at feasible optimum condition; Micronaire 8.14 µg/inch Maturity index 1.03 and UHML 23 mm (holding value: UHML 23 mm)

The 2D contour plots and 3D surface plots [10] of SCI for high micronaire value at feasible optimum condition are shown in Fig. 2 and Fig. 3 respectively; they present the Micronaire µg/inch.
Maturity index and UHML mm. 2D contour and 3D surface plots were defined as the graphical representatives of the regression equation and describe the function of two factors at a time while holding other factors at a fixed level. The plots illustrate the values for Micronaire and Maturity index while holding the value of UHML at 23 mm.
The contour plots indicate that the lowest SCI is obtained when micronaire levels are high and maturity index levels are high. This area appears at the upper & bottom right corner of the plot. The surface plot also shows that the lowest SCI is obtained when micronaire levels are high and maturity index levels are high. In addition, you can see the shape of the response surface and get a general idea of SCI at various settings of micronaire and maturity index.

IV. CONCLUSION

The RSM could be effectively used to optimize the process parameters in complex processes using the statistical design of experiments. The coefficient R^2 (92.16%) was high, thus the experimental data was acceptable. Optimum value for spinning consistency index for high micronaire cotton fibre variety had been determined. It was found that spinning consistency index could be optimised at the Micronaire of 8.14 µg/inch, Maturity index of 1.03 and UHML of 23 mm. It was also found that the difference between the verification and predicted values was small. The lack of fit exhibits that the model was fitted well to the experimental data. The contour plots indicate that the lowest SCI is obtained when micronaire levels are high and maturity index levels are high.

V. REFERENCES

[1]. Myers, Raymond H., Andre I. Khuri, and Geoffrey Vining. "Response surface alternatives to the Taguchi robust parameter design approach." The American Statistician, Vol. 46(2), 1992, 131-139.
[2]. Üreyen, M. E. and Kadoğlu, H., "Regressional Estimation of Ring Cotton Yarn Properties from HVI Fibre Properties", Textile Research Journal, Vol. 76(5), 2006, 360-366.
[3]. S. Sonawane, P.W. Chandurkar, Prafull P. Kolte, P.P. Raichurkar, Role of developed card technology in the improvement of yarn quality, Melliand International, Vol. 24(3), 2018, 122-125.
[4]. Nefise Gonul Sengöz, Pınar Arslan "Response surface designs in quality control: yarn irregularity exercise", Textile and Apparel, Vol. 27(3), 2017, 289-299.
[5]. Athijayamani, A. Ganesamoorthy, R. Loganathan, K.T. Sidhardhan, S., "Modelling and Analysis of the Mechanical Properties of Agave Sisalana Variegata Fibre / Vinyl Ester Composites Using Box-Behnken Design of Response Surface Methodology", Journal of Mechanical Engineering, Vol. 62(5), 2016, 273-280.
[6]. Md. Khalilur Rahman Khan, Habibur Rahman, "Study of Effect of Rotor Speed, Combing-Roll Speed and Type of Recycled Waste on Rotor Yarn Quality Using Response Surface Methodology", IOSR Journal of Polymer and Textile Engineering, Volume 2(1), 2015, 47-55.
[7]. Hasanuzzaman, Pranab K. Dan and Sanghita Basu, "Optimization of ring-spinning process parameters using response surface methodology", The Journal of The Textile Institute, Vol. 106(5) 2014, 510 -522.

[8]. Muhammad Bilal Qadir, Zulfiqar Ali Malik, Usman Ali, Amir Shahzad, Tanveer Hussain, Amir Abbas, Muhammad Asad, Zubair Khaliq, "Response Surface Modelling of Physical and Mechanical Properties of Cotton Slub Yarns", AUTEX Research Journal, Vol. 18(2), 2018, 173-180.
[9]. S. Sathiyamurthy, A Syed & S Jayabal, "Predication and optimization of mechanical properties filled coir polyester composite using ANN and RSM algorithms", Indian Journal of Fiber & Textile Research, Vol. 38(3), 2013, 81-86.
[10]. Ghanim, A.N., "Application of Response Surface Methodology to Optimize Nitrate Removal from Wastewater by Electro coagulation", International Journal of Scientific & Engineering Research, Vol. 4(10), 2013, 1410-14016.
[11]. Bok Choon Kang, Shin Woong Park, Hyun-Jin Koo, and Sung Hoon Jeong, "A Simplified Optimization in Cotton Bale Selection and Laydown", Fibers and Polymers, Vol.1 (1), 2000, 55-58.
[12]. MINITAB User's Guide 2: Data Analysis and Quality Tools Release 13 Feb, 2000.
[13]. Jambur H.R., Kolte P.P., Nadiger V.G., Daberao A.M., "Effect of Machine Variables on Rotor Yarn Properties", Journal of the Textile Association, Vol. 78(6), 2018, 377-383.