Chapter

Practicing Response Surface Designs in Textile Engineering: Yarn Breaking Strength Exercise

Nefise Gönül Şengöz

Abstract

Predicting properties of end product from known properties of raw material is an important part of quality control in manufacturing. Main concept in this research is to reach a specified property of end product from known properties of raw material by attaining response surface designs with feasible region. The Ne20–19.21 T/inch yarn breaking strength (response, desired value 450 cNs) is acquired from cotton fiber properties (variables). The relationship between response and variables are obtained in response surface drawings and contour plots. The area showing the desired value in contour plots are colored in lilac and are intersected to obtain the feasible regions. By reading backwards from the feasible region borders, the variable value ranges are reached which will give the desired value of the response is obtained. When this information to start the yarn production is ready, the cotton lots containing these fiber property value ranges will be bought or from raw material in hand we will be read which yarn breaking strength will occur at the end of production. It was concluded that response surface designs with feasible region are quick, practical, and effective tools, provide valuable results, contribute a lot to quality control, and are beneficial in textile quality control.

Keywords: design of experiments, response surface design, feasible region, central composite design (CCD), textile, yarn, fiber, breaking strength

1. Introduction

Textile engineering comprises manufacturing of apparel and home textiles used in daily life together with technical textiles. Nevertheless which kind of textile it is, from the point of view of textile production, quality control is very important in entire of them. The product has to possess properties in accordance to the areas where that textile product will be used and have to be welcomed by the people using them. In order to end up with a textile product with the properties preferred in the area of its usage, at the very beginning, the raw material chosen has to conform such properties to achieve the preferred properties at the end product. Quality control is performed in raw material, in every step of production downstream, and in the end product to guarantee the preferred properties of the end product keeping them in tolerances via various statistical methods. It should also be indicated here that quality control gained more importance in due time with the shortage of raw material, and lowering the costs because of high competitiveness in the market.

To succeed the end product to own the preferred properties, the properties of the raw material and the semi-products, production steps and machine setting are all very important and needs to be known in detail since they totally affect the properties of the end product. On the other hand, many research is practiced in textile engineering to predict the preferred properties of the end product from the known properties of the raw material and semi-products in the production downstream. The known properties are generally called variables and the predicted property is called a response(s) (**Figure 1**). Many distinct evaluative quality control tools in graphical, statistical, mathematical, and simulation methods are developed to investigate the relationships between variables and response(s). To name a few of these methods are histograms, data charts, analysis of variance, regression, correlation, control charts, artificial neural networks, discriminant analysis, principal component analysis, varimax, design of experiments, etc.

The statistical method Design of Experiments (DoE) evaluates the variable data which affects the response data by taking into consideration the variations in the variable data assuming to reflect the variation in the response data. Multiple variables can be worked and their effects on the response are obtained together with the important interactions between the variables. The purpose in using DoE is to determine the optimum variable values for the examined response. With the key concepts blocking, randomization and replication, DoE can reach the response in less time and is less costly in material and energy consumption, ensures quality in the product and reduces the need for inspection in quality control. DoE *are expressed by particular subgroups like* screening designs, and response surface designs, full factorial designs, fractional factorial designs, optimal designs, latin hypercube designs, quasi-random designs, mixture designs, discrete choice designs, space-filling designs, nonlinear designs, Taguchi designs, and augmented designs. Response surface design is applied in this research [1–10].

Response Surface Designs are a set of advanced DoE techniques in which the cause-and-effect relationships between known variables and response(s) are searched by a series of designed experiments to attain an optimized response(s) for robust manufacturing conditions. This modeling and analysis of problems method was introduced by George E. P. Box and K. B. Wilson in 1951 or around. Response surface designs are available for continuous factors, cover second-degree polynomial models, and consequently provide approximation, easy estimation and application even when variable data is small. There are two main types of response surface designs, Central Composite Designs (CCD) and Box–Behnken Designs. In this research, CCD is preferred because they can fit a full quadratic model, they are usually used when the plan of the design is appropriate for sequential experimentation, and they imply information from a factorial experiment. They have 5 levels/factor and they can include runs when all the variables are at their extreme settings [4, 5, 11–14].

If the response is "y" and variables are "x_1", "x_2", ..., "x_k" and deviation is "e", then the response is generally expressed by Eq. (1):

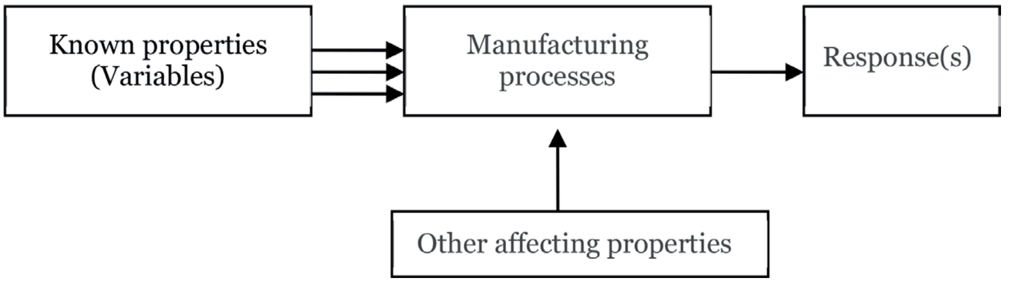

Figure 1.
Variables to response(s).

$$y = f(x_1,, x_2,, \ldots x_k) + e \tag{1}$$

A linear model with two variables can be written as Eq. (2):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + e \tag{2}$$

where; Y is the response for X_1 and X_2 variables, X_1X_2 term for interaction between X_1 and X_2, β's for regression coefficients, β_0 for the response of Y when both variables are zero; *e* is the experimental error; and for three variables (Eq. (3)):

$$\begin{aligned} Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 \\ + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 + e \end{aligned} \tag{3}$$

where; Y is the response for X_1, X_2, and X_3 variables, $k(k-1)/2 = 3*2/2 = 3$ two-way interaction terms and 1 three-way interaction term, and β_0 for the response of Y when all variables are zero. When the data are analyzed, all the unknown β parameters are calculated and the coefficients of the X terms are tested to determine which ones are significantly different from zero; response surface designs are usually approximated by a second-order regression model because the higher-order effects are usually unimportant. A second-order regression model (full quadratic) for k number of variables for central composite design (CCD) can be written as Eq. (4):

$$\begin{aligned} Y = \beta_0 + \beta_1 X_1 + \ldots \beta_k X_k + \ldots \beta_{11}{}^2 X_1{}^2 + \ldots \beta_{kk}{}^2 X_k{}^2 \\ + \beta_{12} X_1 X_2 + \ldots \beta_{k-1,k} X_{k-1} X_k \end{aligned} \tag{4}$$

where; Y is the response for k number of variables, does not include three-way interaction terms but adds three more terms to the linear model, which are: $\beta_{11}X_{21} + \beta_{22}X_{22} + \beta_{33}X_{23}$ It should be noted that a full model contains many interaction terms of X^2's but in general these terms are not included and most DoE soft wares remove them out of the model; the quadratic terms model the curvatures in the response which is mapping a region of a response surface indicating how changes in variables affect a response variable; allows the levels of variables that optimize a response variable; and, determines the operating conditions to produce the product with preferred properties [3, 15–19].

The visual outputs of response surface designs are curved response surface drawings (**Figure 2**) and contour plots (**Figure 3**). They contribute to better interpretation of the behavior of the response and to clearly notice the conditions around the optimum response. Contour lines show the similar heights of x_1-x_2 couples at the same response value. In a response surface design study, both the response surface drawing and the contour lines support to understand the trend of a response in different values of variables effecting it.

A further approach to response surface designs is the feasible region.. If there are more than one response, then the different response surface drawings are put on top of each other and their intersection area is the feasible region which optimizes both response variable's values as seen in **Figure 4**. In this research, feasible regions are studied from another point of view where different contour plots of variable couples are superposed to provide the response value range covering them all. The variables' values are read backwards from the feasible region to reach the desired response. The variable values guarantee the desired response at the end of the production. So, the concept explained above to start with raw material possessing properties which

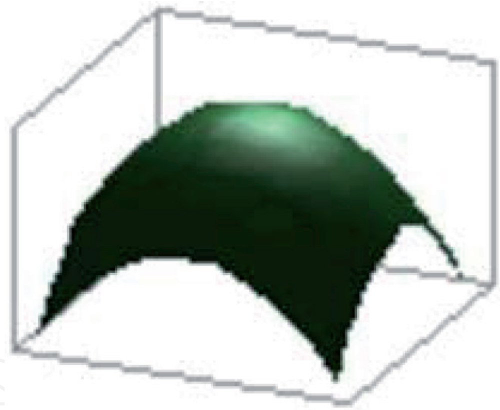

Figure 2.
Example of curved response surface drawing [13].

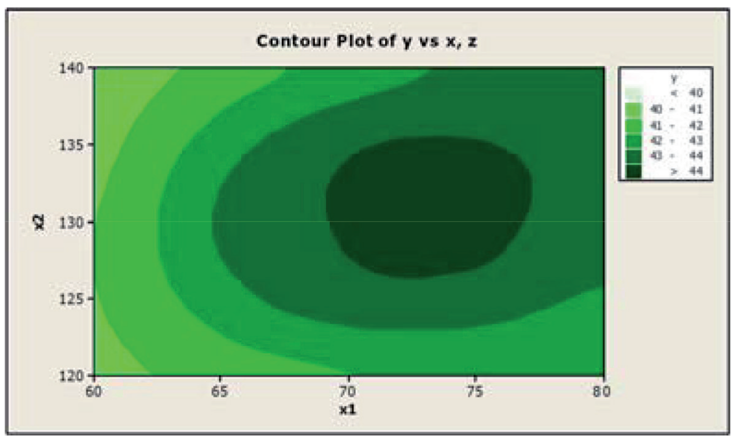

Figure 3.
Example of contour lines [25].

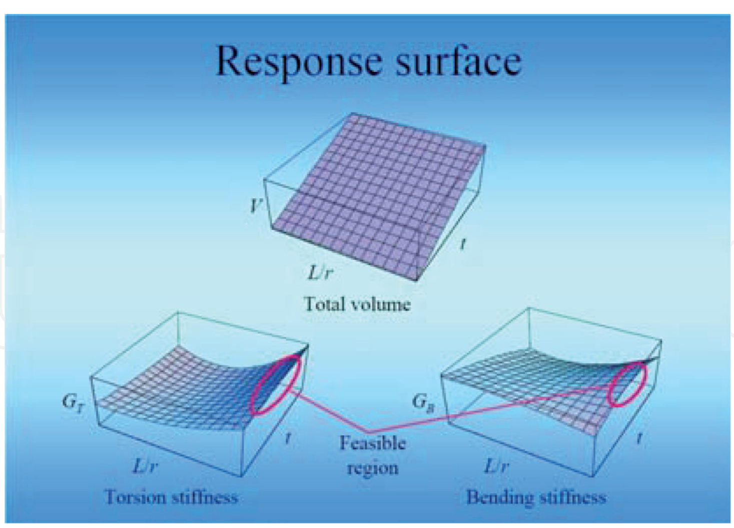

Figure 4.
Feasible region to optimize two response variable's values [25].

will end up with the desired property will be succeeded. This overall information demonstrates that response surface designs are quick, practical, and effective tools for both manufacturing and quality control. Response surface designs are used in many industries like mechanical, automotive, medical, chemical, electronics, etc., but very few in textile engineering, and none in textile quality control, except our previously published article, where response surface design with feasible region was applied to yarn irregularity property, now it is applied to yarn breaking strength property [5, 20–25].

2. Material and method

Textile production downstream mainly consists of fibers, yarns, fabrics, and confection; finishing may well be in every step. Fibers may be natural (cotton, wool, etc.) (**Figures 5**-**7**) or man-made (polyester, polyamide, etc.) (**Figure 8**) and have properties like length, fineness, breaking strength and breaking elongation, elasticity, maturity, regain, trash, oil content, color, static electricity, etc. Yarns may be spun from one kind of fiber, being 100% or blends of different fibers, may be spun in different techniques (ring, Open-End, etc.) (**Figure 9**) and have properties like count (in Ne, tex, etc. units) and twist (in T/inch or T/m unit) which are adjusted on the spinning machine, and breaking strength and breaking elongation, elasticity, abrasion resistance, moist content, oil content, irregularity, hairiness, static electricity, etc. which are outcomes relative to various variables. To provide a short information, some properties mentioned above are specified here: Yarn irregularity is a measure of deviation of fibers' orientation in the yarn from the orientation in the ideal yarn, which is expressed as the mean linear irregularity (U% unit) or coefficient of variation of the yarn mass (CVm% unit). Breaking strength for fibers and yarns is the maximum tensile force measured during the strength test which is expressed as BForce in cNs unit. Yarn

Figure 5.
Cotton boll [26].

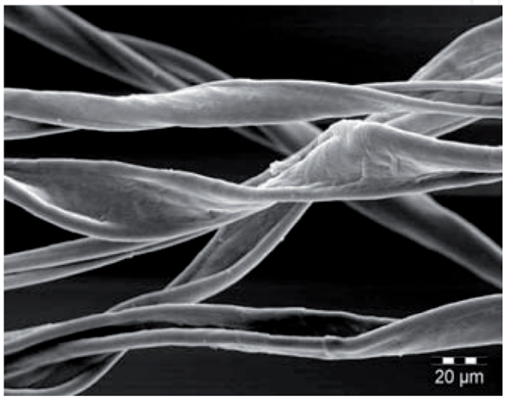

Figure 6.
Cotton fiber [27].

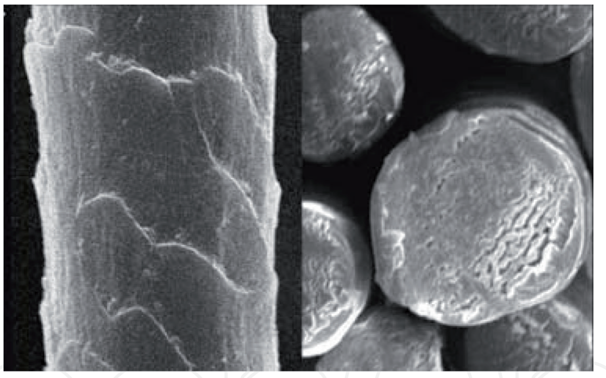

Figure 7.
Wool fiber [28].

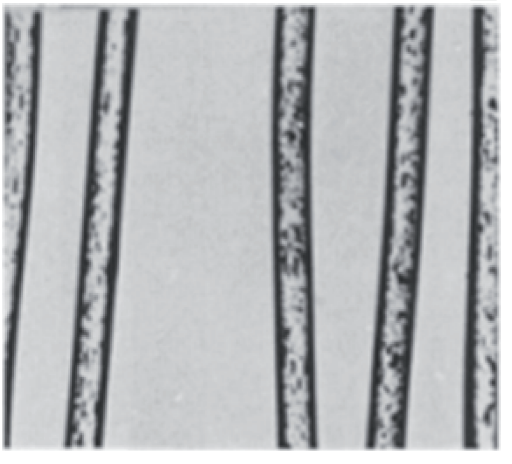

Figure 8.
Polyester fiber [29].

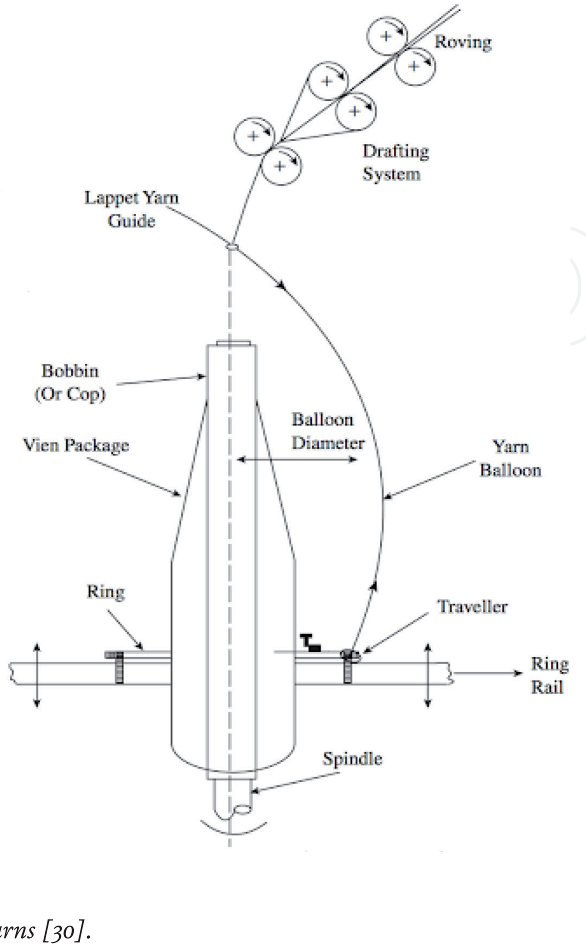

Figure 9.
Ring spinning technique of yarns [30].

breakages have many different causes like raw material, machine settings, climate conditions, human factors, etc., so it needs to be known before starting the production.

In this research, response surface designs with feasible region are applied to yarn breaking strength data which are considered as the response and fiber properties forming the same yarn are considered as the variables. The data for yarn breaking strength and fiber properties are real production data obtained from a company producing 100% cotton yarn in Uşak-Turkey. The fiber properties are fineness/micronaire index (Mic), maturity index (Mat), length (Len), fiber length uniformity index (Unf), short fiber index (SFI), fiber breaking strength (Str), fiber breaking elongation (Elg), moisture content (Moist), reflectance (Rd), yellowness (b), trash count (Tr_Cnt) and trash % area (Tr_Area), being twelve different ones. The lower the micronaire index (Mic) value the fibers are fine, the higher the Mic value the fibers are coarse. The higher the maturity index (Mat) value the cotton fibers constitute more cellulose layers in their cross-section. The higher the fiber length uniformity index (Unf) value the length distribution of the fibers in a lot are close to each other, in other words, the length difference is small. The lower the short fiber index (SFI) value the fiber lot contains less amount of short fibers. The higher the yellowness (b) value the cotton fibers are more mature. The trash count (Tr_Cnt) is the amount of trash counted on the measuring screen and is proportional with the lot, the trash % area (Tr_Area) is the area of the measuring screen the trash occupies and is proportional with the lot. In both Tr_Cnt and Tr_Area, and the rest length (Len), fiber breaking strength (Str), fiber breaking elongation (Elg), moisture content (Moist) and reflectance (Rd) the higher values indicate that property possesses high results in the tests.

The tests to obtain fiber property values were carried out in Uster®HVI Spectrum apparatus (**Figure 10**) in 20 ± 2 °C, 65 ± 2% relative humidity standard atmospheric conditions in the laboratory of the factory. The cotton fiber lots are from Adana region in Turkey. The production downstream is blowroom, carding, I.drawing, II.drawing, roving and ring spinning machines The yarn is 100% cotton, carded, ring spun, count Ne20, twist 19,21 turns per inch (T/inch), and in bobbin form. The yarn properties are irregularity (%U, %CVm), imperfections (Thin50, Thick50, Neps200), hairiness (H), yarn breaking strength (BForce), yarn breaking elongation (Elongation), tenasity (Rkm), work to break (Bwork), etc. The tests to obtain yarn breaking strength values were carried out in Uster Tensorapid 3 apparatus (**Figure 11**) which is used in the regular measurements of the factory. In this apparatus, breaking strength (BForce) in cNs unit, breaking strength (Tenacity) in cN/tex (Rkm) unit, breaking elongation (Elong) in %, and work to break (BWork) in cN.cm unit were also obtained but the yarn breaking strength (BForce) in cNs is processed with 114 repeats in this research. Yarn breaking strength testing is given in **Figure 12** and a yarn at break is seen in **Figure 13**.

Figure 10.
Uster®HVI Spectrum apparatus [31].

Figure 11.
Uster Tensorapid 3 apparatus [32].

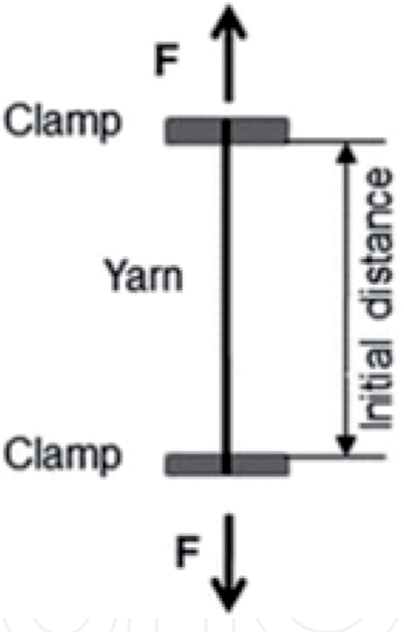

Figure 12.
Yarn breaking strength testing [33].

Figure 13.
A yarn at break [34].

Similar data of fibers and yarn was used in our previous research [25] where the yarn irregularity property in U% unit was studied via response surface designs with feasible region, but in this research yarn breaking strength property is studied which is different from our former article.

DOI: http://dx.doi.org/10.5772/intechopen.96518

	Mic	Mat	Len	Unf	SFI	Str	Elg	Moist	Rd	b	Tr_Cnt	Tr_Area
Mean	4,9781	0,9203	29,4522	85,5337	7,0765	30,3041	9,6827	7,9306	67,3531	8,2459	54,2449	1,5232
SD	0,1377	0,0130	0,4465	0,7832	0,4681	1,0551	0,289	0,8858	1,7809	0,4424	12,4504	0,3567
%CV	2,766	1,417	1,516	0,916	6,615	3,482	2,984	11,169	2,644	5,365	22,952	23,42

Table 1.
Means, SDs and CV% of fiber properties [25].

		%U	%CVm	H	Thin50	Thick50	Neps200	BForce	Elongation	Rkm	BWork
	Mean	11,28400	14,46330	6,01670	1,75000	216,91700	285,16700	442,74700	5,25630	14,99270	626,86300
Bobbin	SD	0,22695	0,34045	0,28067	1,87430	66,99100	150,88520	24,01450	0,46158	0,81246	79,31180
	%CV	2,011	2,354	4,665	107,103	30,883	52,911	5,424	8,781	5,419	12,652

Table 2.
Means, SDs and CV% of yarn properties [25].

The values for twelve fiber properties mentioned above consist of 98 different lots in bales with 5 repeats each. In this research, values in means are processed in order to get rid of the small differences between the lots, not to decline the power of response surfaces. The overall means, standard deviations and constant of variations are given in **Table 1**.

The values for yarn breaking strength consists of 30 lots in bobbin form with 10 repeats each. The values in means are also processed in order to get rid of the small differences between the lots, not to decline the power of response surfaces. The overall means, standard deviations and constant of variations are given in **Table 2**. Yarns given in **Table 2** are produced from the fibers given in **Table 1** in the factory from which the real production data are obtained.

The response (BForce of %100 cotton carded yarn) and variables (cotton fiber properties) are summerized in **Table 3**.

To elaborate the response and the variables considered for the experiments, they are implemented to **Figure 1** as seen in **Figure 14**. The main goal is to predict a property of the end-product (response) from the known properties of the raw material (variables), where in this research yarn breaking strength (BForce, marked bold) is the response and the fiber properties are the variables. This information will help the manufacturer to be aware of what will be reached at the end-product with the known properties of the raw material before starting production, so will conduct the factory more efficiently.

Response surface designs with feasible region which are regarded as satisfactory tools in textile quality control are applied in MINITAB program with central composite

Response	**Variables**										
BForce	Mic	Mat	Len	Unf	SFI	Elg	Rd. b	Tr_Cnt	Tr_Area	Str	Moist

Table 3.
Summary of the Response and the Variables.

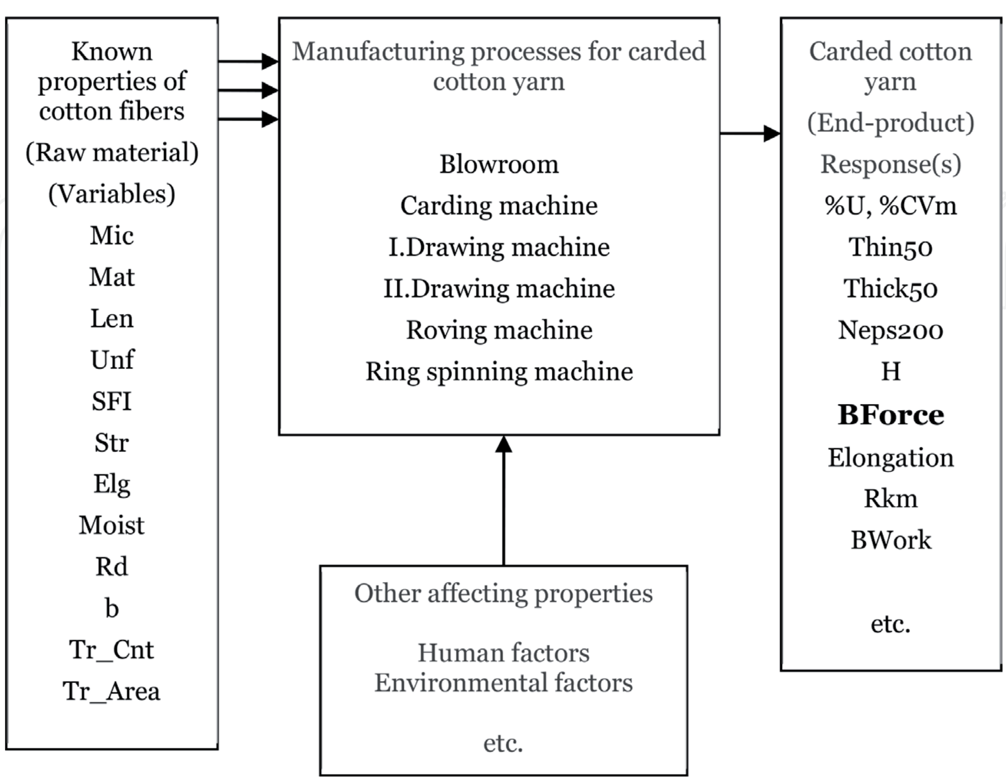

Figure 14.
Implemented variables to response(s).

Response Z axis	**X axis variable versus Y axis variable being a different one every time**			
BForce	Mic - Mat	Mic - Len	Mic - Unf	Mic - SFI
	Mic - Elg	Mic - Rd	Mic - b	(Seven combinations)
	Mic - Tr_Cnt	Mic - Tr_Area	Mic - Str	
	Mic - Moist	(Four combinations)		
	Totally eleven combinations			

Table 4.
Combinations for response surface drawings and contour plots.

design (CCD) method to obtain the relationship between the response (BForce) and the variables (fiber properties). The response is located in the Z axis, one variable (Mic) in the X axis and another variable in the Y axis, the variable in the Y axis being a different one every time. Eleven combinations of response surface drawings in 3D and contour plots are obtained and the combinations are listed in **Table 4**.

The area in the contour plots conforming greater than 450 cNs are colored in lilac and afterwards, the colored contour plots are put on top of each other by one

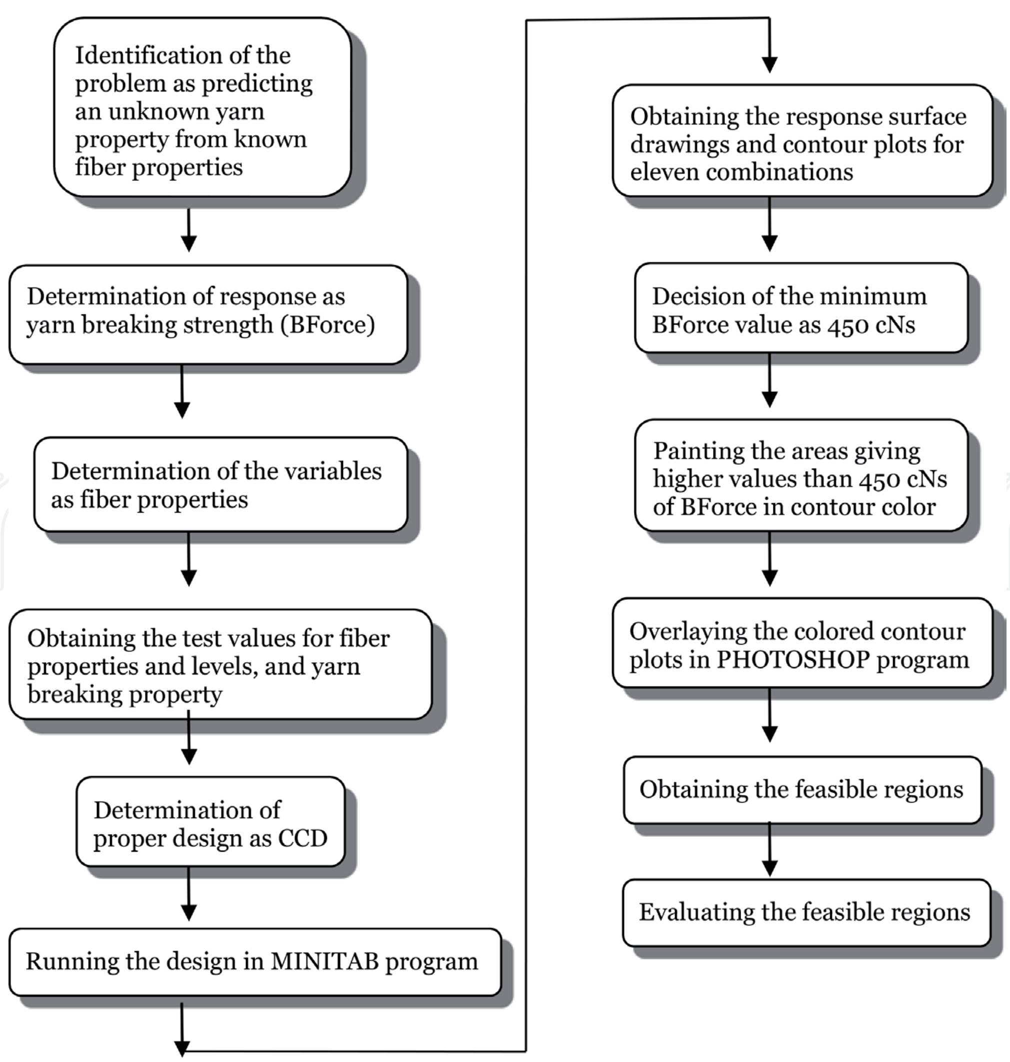

Figure 15.
The flow chart of the steps of the experimental study followed.

by in PHOTOSHOP program and the intersection of the lilac colored areas are noted as the intersection of the desired areas, where finally the borders of the feasible region is acquired and it is painted in red color. The feasible region is where the same greater than 450 cNs BForce (yarn breaking strength) values' areas are found for the most number of combinations because two feasible regions formed: One for the seven combinations in **Table 4** and the other for the four combinations in the same table. By reading backwards from the feasible regions to the BForce response in the response surface drawings and contour plots, the value range of the fiber properties which conform the yarn breaking strength higher than 450 cNs BForce values are determined adequately. The same study can be done for other yarn properties, say in a computer program for example, and all of their combination would give the fiber properties suitable for the desired yarn properties required in the end product.

A visual observation always provides better knowledge about a process [21, 35, 36]. To accentuate the concept of this research, the steps of the experimental study followed is summerized as a flow chart in **Figure 15**.

3. Results and discussion

The results of response surface designs, applied to yarn breaking strength and the properties of fibers forming the same yarns, which consists of response surface drawings, contour plots, lilac colored contour plots, and feasible regions are given in this section and are discussed.

Yarn breaking strength (BForce) is taken as the response and response surface design with feasible region is applied as variables of cotton fiber properties which are fineness/micronaire index (Mic), maturity index (Mat), length (Len), fiber length uniformity index (Unf), short fiber index (SFI), fiber breaking strength (Str), fiber breaking elongation (Elg), moisture content (Moist), reflectance (Rd), yellowness (b), trash count (Tr_Cnt) and trash % area (Tr_Area). Eleven combinations formed which are Mic-Mat, Mic-Len, Mic-Unf, Mic-SFI, Mic-Str, Mic-Elg, Mic-Moist, Mic-Rd, Mic-b, Mic-Tr_Cnt, and Mic-Tr_Area. Response surface drawings (**Figures 16** and **17** I. Colomns) and contour plots (**Figures 16** and **17** II. Colomns) are obtained for all eleven combinations.

In the contour plots, the different shades between contour lines implicate different value ranges for yarn breaking strength (**Figures 16** and **17** II. Colomns) and it is noticed that all the eleven combinations have an area of contour line conforming yarn breaking strength higher than 450 cNs except combinations for Mic-Mat and Mic-Elg. being 448 cNs. Since the difference is small and the t-test gave $p = 0{,}741$ meaning the difference is insignificant, the desired yarn breaking strength value (response BForce) is taken as greater than 450 cNs for the response surface design with feasible region in this research. The condition of being 450 cNs is also tested with the mean value for BForce being 442,747 cNs in **Table 2** which creates a normal distribution curve. $p = 0{,}155$ is obtained which is statistically insignificant and also proves that the data used is distributing normal.

In **Figure 16**, the response surface drawings in the I. Colomn, the contour plots in the II. Colomn, and the lilac colored contour plots in the III. Colomn are given for the seven combinations of eleven ones which are Mat, Len, Unf, SFI, Elg, Rd., and b versus Mic. In **Figure 17**, the response surface drawings in the I. Colomn, the contour plots in the II. Colomn, and the lilac colored contour plots in the III. Colomn are given for the four combinations of eleven ones which are Tr_Cnt, Tr_Area, Str, and Moist versus Mic. In **Figure 18**, the feasible region acquired by superposing the lilac colored contour plots in **Figure 16** III. Colomn is seen in red color, and, in **Figure 19**, the

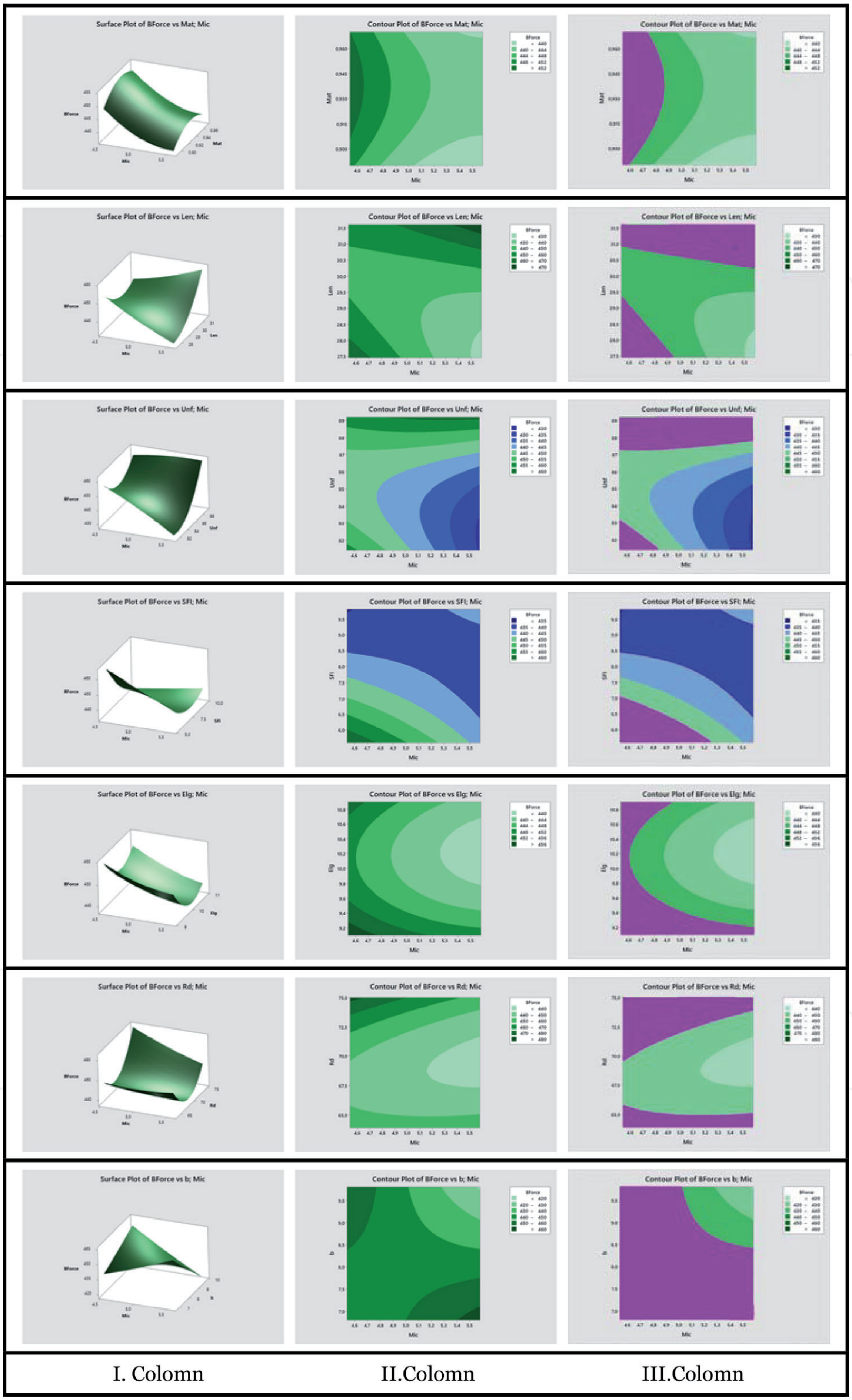

Figure 16.
BForce as response and Mic, Mat, Len, Unf, SFI, Elg, Rd., and b as variables, seven combinations.

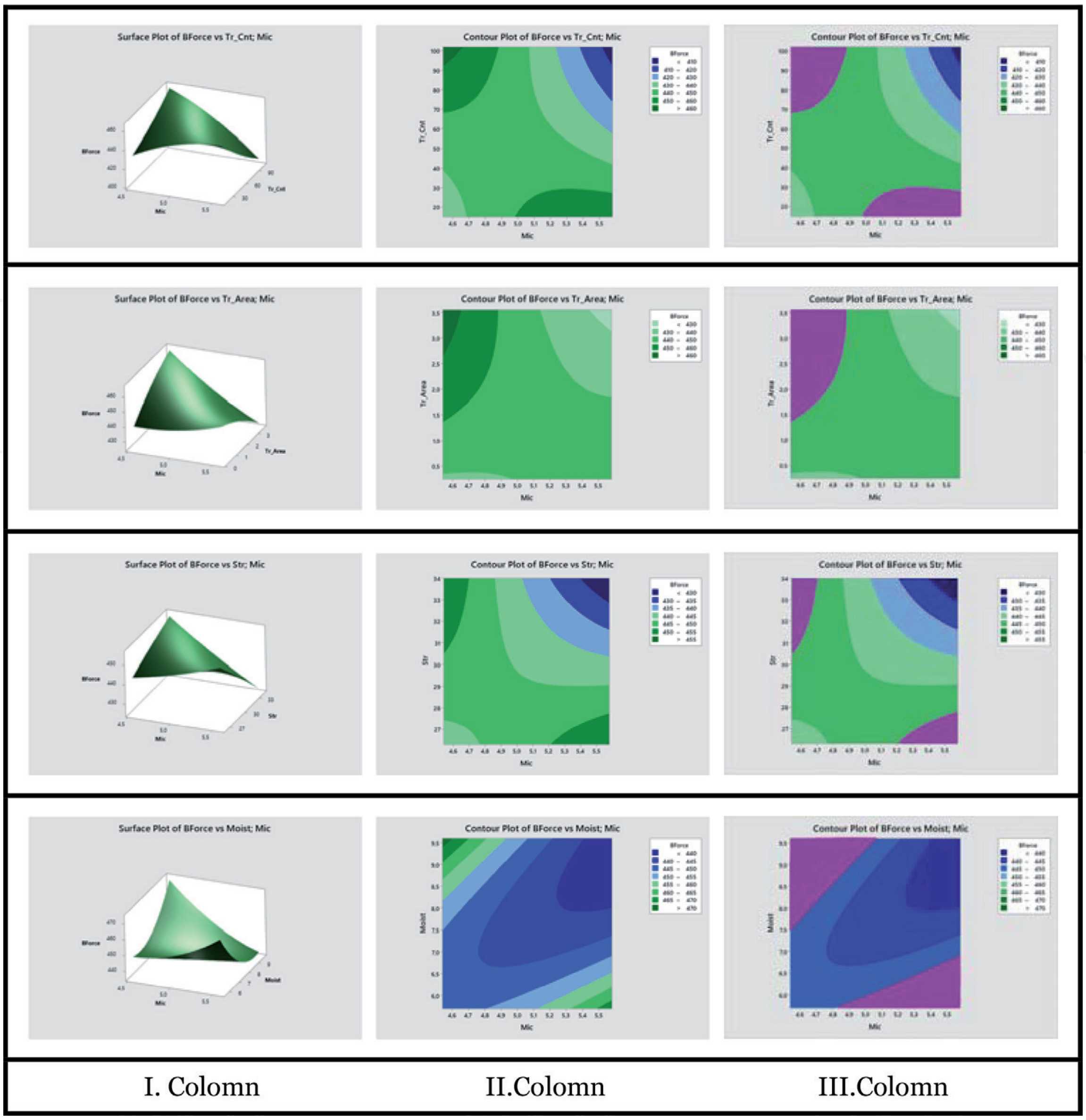

Figure 17.
BForce as response and Mic, Mat, Tr_Cnt, Tr_Area, Str, and Moist as variables, four combinations.

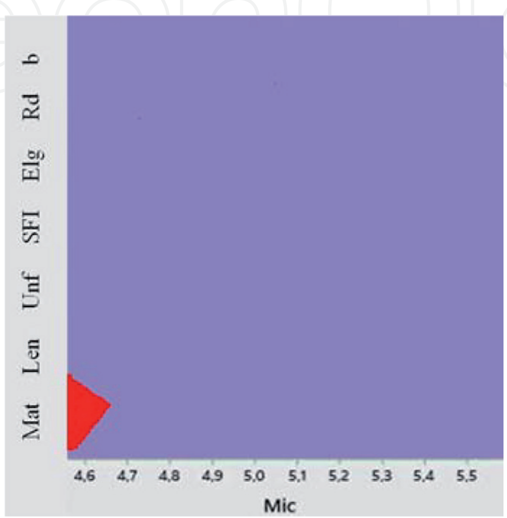

Figure 18.
Feasible region for BForce as response of seven combinations.

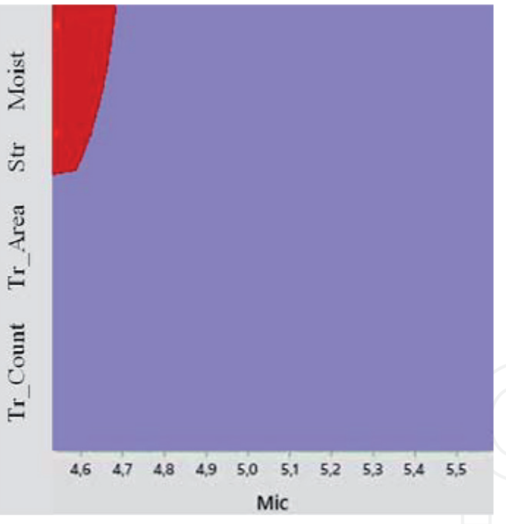

Figure 19.
Feasible region for BForce as response of four combinations.

feasible region acquired by superposing the lilac colored contour plots in **Figure 17** III. Colomn is seen in red color, both conforming yarn breaking strength higher than 450 cNs. Two feasible regions formed because when all the colored contour plots were put on top of each other there occurred to be two regions. To get a better understanding of the feasible regions, they are separated into two figures.

Examining the I. Colomns of **Figures 16** and **17**, it can be discussed that the behavior of each eleven combination is different from each other. This means each fiber property has a different influence on the yarn breaking strength, while one has an increasing impact at its high values the other possesses a decreasing one or increasing impact at both high and low values the other a decreasing one. General speaking; the curvature of response surface looks downwards in five combinations which are Mic-Mat, Mic-b, Mic-Tr_Cnt, Mic-Tr_Area, and Mic-Str, while upward looking curvature of response surfaces are in six combinations which are Mic-Len, Mic-Unf, Mic-SFI, Mic-Elg, Mic-Rd, and Mic-Moist. The downwards looking curvatures indicate high values of yarn breaking strength at their top sections, the upwards looking curvatures indicate high values of yarn breaking strength at their side sections. The relationship between the fiber properties outgiving downwards and upwards curvatures needs to be discussed. The downwards curvatures come from fiber properties fineness, maturity index, yellowness, fiber breaking strength, trash count, and trash % area. The first four properties are dependent on agricultural factors so it is reasonable to behave similar in their curvatures. The last two properties are dependent on harvesting factors and they also behave the same as agricultural factors. The relationship between the agricultural factors and the harvesting factors is another aspect of investigation aroused in this research. The upwards curvatures come from fiber properties fineness, length, fiber length uniformity index, short fiber index, fiber breaking elongation, reflectance, and moisture content. All properties except moisture content are dependent on agricultural factors so it is reasonable to behave similar in their curvatures. However, the opposite curvature behavior than the downwards curvature needs to be investigated. Moisture content property is dependent on storing and transporting factors. The relationship between the opposite observed agricultural factors and the storing and transporting factors is also another aspect of investigation. Another discussion of the response surface drawings is the attitude of the edges of the curvatures. The shape, length, height, inclination, and deflection of the curvatures seem to be important and should be evaluated. These arguments aroused in this research and will be analyzed in imminent investigations.

Examining the II. Colomns of **Figures 16** and **17**, it can be discussed that these impacts can apparently be seen in different shades of color in which different yarn breaking strength values are specified. Considering both the response surface drawings and the contour plots, it is attained that yarn breaking strength is higher than 450 cNs when;

- Cotton fiber maturity (Mat) is inbetween 0,908–0,967 and cotton fiber fineness (Mic) is less than 4,63; meaning that cotton fibers are mature and fine;

- Cotton fiber length (Len) starts to get longer than 30.02 mm and cotton fiber fineness is higher than 4,5, and, length starts to get shorter than 29,38 mm and fineness is less than 4,94; meaning that long and fine to coarse cotton fibers, and, short and fine cotton fibers have the similar impact on both sides;

- Cotton fiber lot uniformity (Unf) starts to increase at 87,2 and cotton fiber fineness is higher than 4,5, and, uniformity is less than 83,1 and fineness is less than 48,4; meaning that uniformity other than 83,1–87,2 range with fine to coarse cotton fibers have the similar impact on both sides;

- Cotton fiber lot short fiber index (SFI) is less than 7,0 and cotton fiber fineness is less than 5,25; meaning that cotton fiber lots should contain less short fibers and be fine;

- Cotton fiber elongation (Elg) is inbetween 9,1–10,9 and cotton fiber fineness is higher than 4,5; meaning that cotton fibers should elongate and be fine unless coarse as in the middle of the contour plot;

- Cotton fiber reflectance (Rd) starts to increase at 69,5 and less than 65,8 and cotton fiber fineness is higher than 4,5; meaning that cotton fibers should possess reflectance other than 65,8–69,5 range and be fine unless coarse as in the middle;

- Cotton fiber yellowness (b) is other yellownesses that start to increase at 8,48 and cotton fiber fineness is higher than 5,02; meaning that cotton fibers should be slightly yellow and fine to coarse;

- Cotton fiber lot trash count (Tr_Cnt) starts to increase at 68 and cotton fiber fineness is less than 4,87, and, trash count starts to decrease at 28 and fineness is higher than 4,98; meaning that trash count other than 28–68 range with fine and coarse cotton fibers, respectively, have the similar impact on both sides;

- Cotton fiber lot trash % area (Tr_Area) is higher than 1,4 and cotton fiber fineness is less than 4,89; meaning that cotton fiber lots should contain rather high trash % area and be fine;

- Cotton fiber breaking strength (Str) starts to increase at 30.5 cNs and cotton fiber fineness is less than 4,69, and, fiber breaking strength starts to decrease at 27,8 cNs and fineness is higher than 5,21; meaning that strong and fine, and, less strong and coarse cotton fibers have the similar impact on both sides;

- Cotton fiber moisture content (Moist) starts to increase at 7,5 and cotton fiber fineness is less than 4,92, and, fiber moisture content starts to decrease at 6,76 and fineness is higher than 4,8; meaning that normal to high moisture and fine cotton fibers, and, less moisture and coarse cotton fibers have the similar impact on both sides.

The information the feasible regions provide is achieved by reading backwards from the feasible regions in **Figures 18** and **19**. For each variable (fiber properties), the feasible region borders are corresponded with that variable's scale in the contour plots one by one and the value ranges of the variables are determined. The results are given in **Table 5**. Cotton fiber lots retaining fiber properties within these ranges will reach to yarn Ne20–19.21 T/inch having yarn breaking strength higher than 450 cNs.

The results obtained is discussed in two different points of view:

- In a factory where cotton Ne20–19.21 T/inch ring spun yarn is produced, cotton lots have to be supplied and then the fiber properties have to be tested and results obtained. Then, the new fiber property results have to be crosschecked with the fiber properties given in **Table 5** and see if they fall in between these ranges. If they do, this means the Ne20–19.21 T/inch yarn which will be produced from those lots will possess a breaking strength higher than 450 cNs. If some of them do not fall in between these limits, then we have to read backwards from **Figure 18** or **Figure 19** to figure out what the yarn breaking strength (BForce) will be in the new produced yarn;

- In a factory where cotton Ne20–19.21 T/inch ring spun yarn is produced, cotton lots will be ordered with the property value ranges in **Table 5**, and cotton bales possessing these properties will be bought. In order to do so, there has to be a system in the country where every cotton bale will have its fiber property test results stuck on them in a central warehouse, so the sales of the bales will be according to the values in the factory's order, the bales possessing these features will be chosen and sold to the factory. Furthermore, lots with much better fiber properties can be ordered.

In this research, one yarn property (breaking strength-BForce) is studied while yarn irregularity property (U%) was studied in our previous work [24, 37] however the same work can be done for different yarn properties such as tenacity (cN/tex; Rkm), breaking elongation (%), yarn irregularity (CVm%), hairiness (H Index), product of yarn count and tenacity multiplication (CSP), constant of variation of count (CV_C%), constant of variation of twist (CV_{Twist}%) constant of variation of tenacity ($CV_{Tenacity}$%), and imperfections (thin places, thick places, neps (piece/

	Variable	Range
From **Figure 16**	Mic	4,58 – 4,69
	Mat	0,890 – 0,908
	Len	27,5 – 28,25
	Unf	81,5 – 82,9
	SFI	5,5 – 6,41
	Elg	8,83 – 9,42
	Rd	64,17 – 66,2
	b	6,88 – 7,4
From **Figure 17**	Tr_Cnt	68,9–100
	Tr_Area	2,25 – 3,00
	Str	31,22 – 34,00
	Moist	8,18 – 9,5

Table 5.
Range of fiber properties for reaching yarn Ne20–19.21 T/inch breaking strength higher than 450 cNs.

km)), comparisons of these properties, ring and rotor yarns, fabric properties, different machine settings, etc. The variables can be chosen from the point of view of the important properties and it can be worked with less or more effecting variables to perform feasible regions. When choosing the effecting variables, the opposite can be done, so that the yarn properties can be the effecting variables, a fiber property may be the response variable, and the feasible regions can be accomplished vice versa, the concept being knowing what will be reached at the end before starting the production, therefore the advantages of this work is obvious. The originality of this concept is that if all this work will be incorporated into a computer program for statistical quality control, then the same research will be done for every different yarn property and for every fiber lot arriving the factory. New feasible regions will occur in due time, when the factory will make different settings in machines or renew machines in production downstream they will compare the changes in the feasible regions and conclude if the new ones help for better or worse. The developed computer program can also be used in many different industrial applications which will yield to more developed evaluative comments for the feasible regions in due time.

4. Conclusions

In industry, it is important to predict a specific property of an end product from the known properties of raw material. There are many statistical methods for prediction in literature but response surface designs with feasible region is not benefitted much, even it is an effective and versatile tool in prediction. In this research, the concept of using response surface designs with feasible region is accomplished in textile engineering quality control and is concluded that response surface designs with feasible region is important from the point that it is a quick, practical, and comprehensive tool for predicting properties of an end product from the raw material.

Yarn breaking strength property is studied by response surface designs with feasible region and this property is predicted from the fiber properties, fibers the raw material forming the yarn. The data used in this research is obtained from a company producing 100% cotton yarn in Uşak-Turkey, the company bought the cotton lots from Adana-Turkey, and the company carries out these measurements regularly during their daily production, so the important point here is that real production data are used and is guaranteed that the results achieved from this research will be suitable for production.

MINITAB program is used obtain response surface drawings and contour plots where response is the 100% cotton yarn breaking strength (BForce) and the variables are cotton fiber properties, fineness/micronaire index (Mic), maturity index (Mat), length (Len), fiber length uniformity index (Unf), short fiber index (SFI), fiber breaking strength (Str), fiber breaking elongation (Elg), moisture content (Moist), reflectance (Rd), yellowness (b), trash count (Tr_Cnt) and trash % area (Tr_Area), revealing the relationship between the yarn breaking strength and fiber properties, yarn in bobbin form. The desired value of yarn breaking strength is decided higher than 450 cNs. After obtaining the response surface drawings and contour plots, the areas in contour plots conforming desired values higher than 450 cNs were marked in lilac color, the colored contour plots were put on top on each other in PHOTOSHOP program, the intersecting area of gave the two feasible regions which are marked in red. Then, the borders of the feasible region is read backwards by corresponding the feasible region with that variable's scale in the contour plot for each different cotton fiber property. This procedure concludes the determination of the range of values of fiber properties which will reach to yarn Ne20–19.21 T/inch having the desired value higher than 450 cNs for the response yarn breaking strength.

The behavior of the response surface drawings is different in each eleven combination. It is concluded that each fiber property has a different influence on the yarn breaking strength, such as, whilst one has an increasing impact at its high values the other possesses a decreasing one, or, increasing impact at both high and low values the other decreasing, naming them downwards and upwards looking curavutures. Analyzing the downwards and upwards looking curvatures generally, it is concluded that fineness, maturity index, yellowness, fiber breaking strength, trash count, and trash % area have curvatures looking downwards, the first four being dependent on agricultural factors and the last two dependent on harvesting factors. Both agricultural and harvesting factors having similar effect on response, yarn breaking strength. On the other hand, fineness, length, fiber length uniformity index, short fiber index, fiber breaking elongation, reflectance, and moisture content have curvatures looking upwards, all except moisture content are dependent on agricultural factors, moisture content depends on storing and transporting factors. In this case both agricultural, and, storing and transporting factors having similar effect on response, yarn breaking strength. The reason why some conclude in downwards look and some conclude upwards look needs further research. Besides, the behavior of the edges of the curvatures such as their shape, length, height, inclination, and deflection are divergent and demand research in detail. Future research will be continued on the relationships between the agricultural, harvesting, storing, and transporting factors, the opposite manner of the curvatures, attitude of the edges of the curvatures, which all aroused in this research.

The information provided by the feasible region is evaluated in two different ways; first, the fiber property results of a new arriving cotton fiber lot to the factory can be compared with the value ranges of fiber properties achieved for yarn Ne20–19.21 T/inch yarn breaking strength higher than 450 cNs in this research and conclude if the desired value for yarn breaking strength will be achieved at the end of yarn production, conversely if the value ranges do not match, the new yarn breaking strength can also be determined by reading backwards from the feasible region; and the second, when ordering cotton fiber lots to the factory, to give the limits of cotton fiber properties and buy the cotton bales encompassing those values from a central warehouse, which needs a new system of cotton fiber trade in the country.

Response surface designs with feasible region serve to the main goal of predicting a property of the end-product (response) from the known properties of the raw material (variables), where in this research 100% cotton yarn breaking strength (BForce) is exercised the response and the cotton fiber properties forming the yarn are the variables, in our previous research yarn irregularity property (U%) was exercised. The information acquired by response surface designs with feasible region will help the manufacturer to be aware of what yarn breaking strength will be reached at the end-product with the known properties of the raw material cotton fibers while they are still in the bales before starting yarn production, so will run the factory more efficiently, will yeild less waste, will achieve less costs and higher profit, have better relationships with customers, will have positive effects on the economy of the country and the world. The same work can be done for all different properties of textiles where the variables can be chosen from the point of what is aimed at the end products, being responses. Further work will be done to achieve these goals, also by chosing different desired values. On the other hand, working response surface designs in textile engineering quality control is an original concept, and will be incorporated into a computer program for statistical quality control, and this will give the opportunity to get response surface drawings and contour plots and feasible regions for every different yarn property and for every fiber lot arriving the factory, as well as in different fields of textiles, leading to standardization at the far end, also to be convenient to be utilized in many different industry branches.

Acknowledgements

The author gratefully acknowledges the data provided by Kaynak İplik A.Ş.-Uşak-Turkey.

Author details

Nefise Gönül Şengöz
Usak University Engineering Faculty Textile Engineering Department, Bir Eylül Kampüsü, Uşak, Turkey

*Address all correspondence to: nefisegonul.sengoz@usak.edu.tr

References

[1] Antony J. Design of Experiments for Engineers and Scientists. 1st ed. Great Britain: Elsevier Science & Technology Books; 2003. 190p.

[2] JMP 8 Design of Experiments Guide. 2nd ed. Cary, North Carolina: Sas Publishing; 2009. 273p.

[3] Box G E P, Hunter J S, Hunter W G. *Statistics for experimenters: design, discovery and innovation*. Hoboken, New Jersey: Wiley; 2005. 633p.

[4] Dean A, Morris M, Stufken J, Bingham D. Handbook of Design and Analysis of Experiments. Boca Raton: CRC Pres; 2015. 924p.

[5] Montgomery D C. Introduction to Statistical Quality Control. 4th ed. New York: Wiley; 2001. 796p.

[6] Design of Experiments. [Internet]. Available from http://www.mathworks.com/design-of-experiments. [Accessed: 2020-11-03]

[7] What is DOE? Design of Experiments Basics for Beginners. [Internet]. Available from https://www.sartorius.com/en/knowledge/science-snippets/what-is-doe-design-of-experiments-basics-for-beginners-507170. [Accessed: 2020-11-03]

[8] What is Design of Experiments (DOE)? [Internet]. Available from https://asq.org/quality-resources/design-of-experiments. [Accessed: 2020-11-05]

[9] Design of experiments. [Internet]. Available from https://en.wikipedia.org/wiki/Design_of_experiments. [Accessed: 2020-11-06]

[10] Design of Experiments – A Primer. [Internet]. Available from https://www.isixsigma.com/tools-templates/design-of-experiments-doe/design-experiments-%E2%90%93-primer/. [Accessed: 2020-11-06]

[11] Response surface methodology. [Internet]. Available from https://en.wikipedia.org/wiki/Response_surface_methodology. [Accessed: 2020-11-18]

[12] Box-Behnken Response Surface Methodology. [Internet]. Available from https://www.theopeneducator.com/doe/Response-Surface-Methodology/Box-Behnken-Response-Surface-Methodology. [Accessed: 2020-12-02]

[13] Response Surface Methodology. [Internet]. Available from https://support.minitab.com/en-us/minitab/18/help-and-how-to/modeling-statistics/doe/supporting-topics/response-surface-designs/response-surface-central-composite-and-box-behnken-designs/. [Accessed: 2020-12-02]

[14] Lesson 11: Response Surface Methods and Designs. [Internet]. Available from https://online. stat.psu.edu/stat503/book/export/html/681. [Accessed: 2020-12-02]

[15] Bradley N. The Response Surface Methodology [thesis]. South Bend, USA: Indiana University; 2007.

[16] Response surface designs. [Internet]. Available from https://www.itl.nist. gov/div898/handbook/pri/section3/pri336.htm. [Accessed: 2020-11-19]

[17] What is experimental design? [Internet]. Available from https://www.itl. nist.gov/div898/handbook/pri/section1/pri11.htm. [Accessed: 2020-12-13]

[18] DOE Contour Plot. [Internet]. Available from https://www.itl.nist.gov/div898/handbook/eda/section3/eda33a1.htm. [Accessed: 2020-12-18]

[19] Design. [Internet]. Available from https://www.theopeneducator.com/doe/Response-Surface-Methodology/

Design-Response-Surface-Methodology. [Accessed: 2020-12-18]

[20] Koç B, Kaymak-Ertekin F. Response Surface Methodology and Food Processing Applications. Ege University Food Faculty Articles. 2013;32(8):1-8.

[21] Aydar A Y. Utilization of Response Surface Methodology in Optimization of Extraction of Plant Materials. IntechOpen. 2018. http://dx.doi.org/10.5772/intechopen.73690

[22] Bozacı E. Investigation of Biosurfactant Usage in Raw Wool Scouring by Response Surface Methodology. Tekstil ve Konfeksiyon. 2017;27(4):382-392.

[23] Tetteh E K, Rathilal S. Application of Magnetized Nanomaterial for Textile Effluent Remediation Using Response Surface Methodology. Materials Today Proceedings. 2020. https://doi.org/10.1016/j.matpr.2020.03.827

[24] Kusuma H S, Mahfud M. Response Surface Methodology for Optimization Studies of Microwave-assisted Extraction of Sandalwood Oil. J Mater Environ Sci. 2016;7(6):1958-1971.

[25] Şengöz N G, Arslan P. Response Surface Designs in Quality Control: Yarn Irregularity Exercise. Tekstil ve Konfeksiyon. 2017;27(3):289-299.

[26] Textile Study Center Online Library for Textile Engineering. [Internet]. Available from https://textilestudycenter.com/properties-of-cotton-fibers/. [Accessed: 2021-01-02]

[27] Asian Textile Studies. [Internet]. Available from http://www.asiantextilestudies.com/cotton.html. [Accessed: 2021-01-02]

[28] Wool Fiber. [Internet]. Available from https://www.google.com/search?q=wool+fiber+longitudinal+view&tbm=isch&ved=2ahUKEwjSn5LGsZHuAhXVIRoKHSJiBNkQ2-cCegQIABAA&oq=wool+fiber&gws_lcp=CgNpbWcQARgCMgIIADICCAAyAggAMgIIADIECAAQHjIECAAQHjIECAAQHjIECAAQHjIECAAQHjIECAAQHjoECAAQQ1DXo0ZYnL1GYPfORmgAcAB4AIABlAGIAc8FkgEDMi40mAEAoAEBqgELZ3dzLXdpei1pbWfAAQE&sclient=img&ei=x_X6X5KgA9XDaKLEkcgN&bih=1297&biw=1621&rlz=1C1AOHY_trTR709TR710#imgrc=gRwApDApRfr1aM. [Accessed: 2021-01-06]

[29] Khan A, Abir N, Rakib M A N, Bhuiyan E, Howlader MR. A Review Paper on Textile Fiber Identification. IOSR Journal of Polymer and Textile Engineering. 2017;04:14-20. DOU:10.9790/019X-04021420

[30] Ring spinning technique of yarns. [Internet]. Available from https://www.google.com/search?q=breakage+of+yarn&rlz=1C1AOHY_trTR709TR710&tbm=isch&source=iu&ictx=1&fir=B0GZ5iqOyrR_nM%252C-NYiJqzV6b6emM%252C_&vet=1&usg=AI4_-kR2Mz0ipMl_iOhEAPBrLgXYsV_m0w&sa=X&ved=2ahUKEwj_qqPA65HuAhVPA2MBHa_3BZEQ9QF6BAgOEAE#imgrc=B0GZ5iqOyrR_nM&imgdii=fdPJ05-sMmsYxM. [Accessed: 2021-01-06]

[31] USTER. USTER®HVI 1000 The fiber classification and analysis system [Internet]. 2013. Available from https://www.uster.com/fileadmin/user_upload/customer/customer/Instruments-use_folder_PRODUCTS/Broschueren/en_USTER_HVI_1000_web_brochure.pdf [Accessed: 2021-01-07]

[32] USTER. USTER Tensorapid 3 Apparatus. [Internet]. Available from https://www.google.com/search?q=uster+tensorapid+3+manual&rlz=1C1AOHY_trTR709TR710&source=lnms&tbm=isch&sa=X&ved=2ahUKEwj_s8PNxpHuAhWutIsKHc-AAQQQ_AUoAXoECBUQAw&biw=1621&bih=1297. [Accessed: 2021-01-07]

[33] Yarn breaking strength testing. [Internet]. Available from https://www.google.com/search?q=yarn+breaking+strength+clamps&tbm=isch&ved=2ahUKEwi7jYu0vZHuAhUHM-wKHeGzB5IQ2-cCegQIABAA&oq=yarn+breaking+strength+clamps&gs_lcp=CgNpbWcQA1DTyQRYmOUEYKHqBGgBcAB4AIABdogBwgaSAQMyLjaYAQCgAQGqAQtnd3Mtd2l6LWltZ8ABAQ&sclient=img&ei=NgL7X7uaGYfmsAfh556QCQ&bih=1297&biw=1621&rlz=1C1AOHY_trTR709TR710. [Accessed: 2021-01-07]

[34] A yarn at break. [Internet]. Available from https://www.google.com/search?q=yarn+breaking&tbm=isch&ved=2ahUKEwju9YmS7JHuAhXEgqQKHSwKAC8Q2-cCegQIABAA&oq=yarn+break&gs_lcp=CgNpbWcQARgB MgQIABATMgQIABATMgQIABATMgQIABATMgQIABATUKyyAVjruQFg-98BaABwAHgAgAF1iAHZApIBAzAuM5gBAKABAaoBC2d3cy13aXotaW1nwAEB&sclient=img&ei=NzP7X67-IcSFkgWslID4Ag&rlz=1C1AOHY_trTR709TR710. [Accessed: 2021-01-08]

[35] Güvercin S, Yıldız A. Optimization of Cutting Parameters Using The Response Surface Method. YTU Sigma J Eng & Nat Sci.2018; 36 (1):113-121.

[36] Sağbaş A, Yılmaz F B, Altınışık F. RSM Tekniği Uygulanarak Derlin Malzemesinin Optimum Aşınma Değerinin Tahmin Edilmesi. In: Proceedings of the TİMAK – Tasarım İmalat Analiz Kongresi; 26-28 April 2006; Balıkesir. İstanbul: TİMAK; 2006. p. 170-176

[37] Arslan P. Interpretational Analysis for Yarn Quality Control [thesis]. Uşak: Uşak University; 2011. Supervisor: Asist.Prof.Dr.N.Gönül Şengöz.