This is the accepted version of the publication Yin R, Tao XM and Xu BG. Yarn and fabric properties in a modified ring spinning system considering the effect of the friction surface of the false-twister. Textile Research Journal (vol 90, no. 5-6) pp. 572-580. Copyright © 2020 (The Author(s)). DOI: 10.1177/0040517519873057

Yarn and Fabric Properties in a Modified Ring Spinning System Considering the Effect of Friction Surface of False-twister

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Abstract

This paper experimentally studies the relationship between the friction surface of a false-twisting unit and the quality of cotton yarns produced by a modified ring spinning system, with the adoption of the single friction-belt false-twister. The friction surface of the false-twisting unit, as a key twisting component, has been studied in terms of material, surface roughness, hardness and diameter, as well as the interaction between these factors and resultant yarn properties, with particular attention to yarn imperfections. Experimental results showed that the false-twisting unit with a short interactive path demonstrated significant reduction of yarn imperfections, especially yarn neps. With the optimal false-twisting unit, performances of the modified yarns and their knitted fabrics were evaluated and compared with the conventional ones.

Keywords: yarn properties, ring spinning, yarn neps, friction-belt, false-twister

1 Introduction

Spinning is a fundamental method to produce long strands from staple raw fibers of cotton, wool, flax, or other material.[1] Till now, ring spinning[2-5] still takes a leading role in yarn manufacturing industry due to its high yarn quality and flexibility in materials and yarn counts. With the increasing demand of novel features or improving qualities, many modifications based on the ring spinning system have been developed, such as Compact[6], Siro[7] and Solo[8]. Recently, a novel spinning technology, named Nu-Torque^{TM}, has been proposed by introducing a false-twisting unit into the conventional ring frame for producing low twist and soft handle single yarns.[9] Previous investigations[10-14] have demonstrated that the modified cotton yarns (Ne 7-32) and fabrics have significant advantages in terms of soft handle, similar or higher yarn strength at lower twist factor reduced by 10 to 40%, as compared with conventional ring yarns, lower residual torque and low knitted fabric spirality after washing and tumble-dry cycles. Among over ten mills using the technology, 10 to 40% increment in production rate has been achieved for cotton ring yarns with various versions of the technology. In addition, a significant average energy saving of 337 KWhr/ton was reported by Lu Thai Textile Co., Limited producing 30Ne and 1100 KWhr/ton for another mill spinning 80Ne yarns.

Driven by the excessive market demand for producing superior yarns with high-added value, it is necessary to further exploit this technique to finer count yarns. The technical dilemma lies in that severe yarn imperfections, especially for yarn neps (+140%), are generated, attributed to rearrangement of surface fibers along yarn axis due to the frictional force between the false-twisting unit and modified yarns. Although some attempts[15, 16] have been made to extend this technology to finer modified yarns (Ne 60-80) and significant merits in tenacity and hairiness were discovered as compared to conventional yarns, worse yarn imperfections were observed.

Although several parameters related to the false-twisting unit such as wrap angle and speed ratio have been incorporated for systematic investigation and optimization of finer yarn properties, as a key twisting component, the influence of friction surface of the false-twisting unit including material, surface roughness, hardness and diameter, which may also have large impinge on resultant yarn properties, were seldom been explored. Therefore, this study aims to improve the yarn imperfections for Ne 40 modified cotton yarns based on the study on the potential parameters of the false-twisting unit. The frictional coefficient and yarn twist in spinning zone of different false-twisting units were tested and the resultant yarn properties were assessed. With the optimal false-twisting unit, performances of the modified cone yarns and their knitted fabrics were evaluated and compared with the conventional ones.

2 The Modified Ring Spinning System

The breakthrough of Nu-Torque™ technology is that it provides a mean to produce low twist and low torque single ring yarns in a single step on a ring spinning machine by modifying the yarn structure. Compared with the conventional ring spinning method, the main principle of Nu-Torque™ technology is to install a false-twisting unit between the front rollers and the yarn guide in a traditional ring frame, as shown in Figure 1. In this way, when fibers pass through the nip point of the front rollers, the twist in the spinning triangle raises to a maximum value. The extreme tension variation enlarges fiber migration. In the downstream zone of the false-twisting unit, the reverse twists are immediately introduced until the final twist remaining is that of the original low twist yarn. At last, the extra twist introduced by the false-twisting unit is removed. This technology yields novel yarns with unique structure and exciting properties, such as low torque, reduced twist and relatively higher strength.

Compared with the conventional ring spinning system, more system parameters should be investigated for the modified one. Our previous work[16] has demonstrated that twist factor and speed ratio are the most significant parameters determining yarn properties, which represent the quantities of true twist and false twist, respectively. However, the yarn imperfections, especially for yarn neps (+140%) were found for high count yarns and can not be solved through the optimization of the parameters of twist factor and speed ratio. Therefore, as a key twisting component which directly contacts the yarn, further investigation of the false-twisting unit is necessary to understand the yarn formation process, and meanwhile find out a better solution for high count yarn production.

Yarn imperfections are mainly caused by rearrangement of the loose surface fibers along yarn axis. Firstly, it was found by the experiments that imperfections are occurred in the condition of adopting a low twist factor. Actually, the yarn undergoes an untwisting process on the false-twisting unit, from high twist in the entrance of the false-twisting unit to low twist in the exit. For the yarn with high-twist, the surface fibers are densely packed and many long protruding fibers are hold tightly together with the relatively low yarn tension at the entrance of the false-twisting unit, thus the friction with the false-twisting unit will not cause severe surface fiber migration, whereas for the yarn in low-twist state, the surface fibers may in a loose state and the yarn tension is in a high level, especially in cause of many long hairs protruding outside the yarn body, and the friction with the false-twisting unit will easily cause yarn surface fiber movement, which in the end evoluting into thin places, thick places, or neps on the yarn surface. Secondly, the moving directions between the yarn and false-twisting unit at their contacting area are different, resulting in frictional force along the yarn delivery direction. In the spinning process, the false-twisting unit moves transversely at a constant speed which turns the yarn, and at the same time the yarn slides across the false-twisting unit which generates sliding friction. The frictional force between the yarn and false-twisting unit can easily rearrange the loose surface fiber and generates imperfections on the yarn surface. Thirdly, the yarn transverse movement on the false-twisting unit further deteriorate yarn surface morphology and force migration of the surface fiber along the yarn axis. Yarn transverse movement deteriorates even twist distribution along yarn path, leading to weak points in the yarn, thus increases the chance of imperfection occurrence.

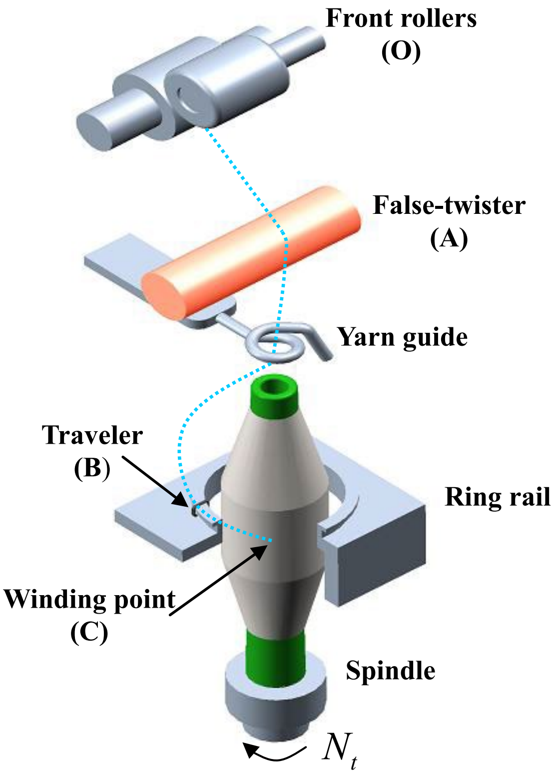


Figure 1 A schematic diagram of Nu-Torque^{TM} technology

3 Experimental Design

3.1 Materials

In this experiment, all Ne 40 single cotton yarns were spun on spinning frame Zinser 351. The combed roving of 535 tex and mass variation of 4.26% provided by the Central Textiles (Hong Kong) Ltd was used. In the spinning process, the spindle speed and total draft ratio are 13000 rpm and 36.25, respectively. Main physical properties of fiber material were tested by the Spinlab 900 and roving evenness was tested by Uster evenness tester 3. Before testing, all samples were kept under standard laboratory conditions (20°C ± 2°C and 65% ± 2% relative humidity) for at least 24 hours, and the results are listed in the Table 1.

Table 1 Fiber and roving specifications

Items	Mean Value	[CV%]
Fiber length (mm)	31.75	[1.7]
Uniformity ratio (%)	60.2	[2.3]
Fiber strength (gf/tex)	24.5	[2.6]
Elongation (%)	5.6	[3.6]
Micronaire Value	4.2	[3.6]
Roving count (tex)	535	[1.5]
Evenness (CVm%)	4.26	[6.7]

In our study, round belt has been employed as a false-twisting unit and directly contacts the yarn. Five round friction-belts with different hardness, diameter, surface morphology and material were employed for the experiments, as shown in Table 2.

Table 2 Belt specifications

Code	Hardness	Surface	Material	Diameter(mm)
85-6mm	85A	Smooth	Polyurethane	6
85-4mm	85A	Smooth	Polyurethane	4
85-3mm	85A	Smooth	Polyurethane	3
89T-4mm	89A	Texture	Polyurethane	4
40D-4mm	40D	Smooth	Polyester	4

3.2 Yarn and fabric preparation

According to previous results of factorial experiments, twist factor, speed ratio and wrap angle were confirmed as the significant parameters on yarn properties, therefore, these three parameters were selected for further study using response surface methodology. The experimental design and results of Ne 40 yarns in coded values are listed in Appendix. The optimized parameters for twist factor, speed ratio and wrap angle are 3.2, 2.0, 43°, respectively. Based on the optimized parameters, five false-twisting unit with different hardness, diameter, surface morphology and material were employed for yarn production and evaluation. The frictional coefficient and yarn twist in spinning zone of different false-twisting units were tested and the resultant yarn properties were assessed. Conventional Ne 40 yarns were also produced by using the same roving material as benchmark against the modified yarns. The twist factor of the conventional yarns was 3.6, the spindle speed was 13000 rpm and the traveler weight was Bracker 5/0. With the optimal false-twisting unit, performances of the modified cone yarns and their knitted fabrics were evaluated and compared with the conventional ones.

After spinning, all yarns in cop form were wound on cones using SAVIO winding machine E1136047 at the speed of 550m/min. The winding cleaner LOEPFE TK840 is closed so that all the yarn characteristics were kept and reflected on the fabrics. There is no waxing during the winding process.

The cone yarns were knitted to produce fabrics. Since the gauge of the flat knitting machine is E14, three cone yarns were fed together into the knitting machine in order to produce the fabrics with normal tightness. The interlock structure was adopted to balance the residual torque of the cone yarns, avoiding spirality of the resultant fabrics. The interlock knitted fabrics were produced on STOLL CMS822, and the detailed knitting parameters are displayed in Table 3. Two types of fabrics were prepared made from the conventional yarns and the modified yarns, respectively.

Table 3 Knitting parameters

Code	Yarn	Structure	Speed (rpm)	Gauge (No. of needles per 1 inch)	Tension (gf)
F-3.6C	3.6C	Interlock	200	14	2
F-3.2S	3.2S	Interlock	200	14	2

3.3Testing methods

Three cop yarns spun on three different spindles were produced for measurement. Before each testing, all samples were conditioned under standard laboratory conditions (20ºC ± 2ºC and 65% ± 2% relative humidity) for at least 24 hours, and all yarn properties measurement followed the methods as shown in Table 4. Yarn tenacity, evenness, hairiness and blackboard evenness were important properties for the yarn. Yarn breaking strength was tested by the Uster Tensorapid tester, from which fifty subtests were measured for each sample, with a testing length of 500 mm and testing speed of 5,000 mm/min. Yarn evenness was evaluated by the Uster evenness tester, from which 400 meter yarn sample was tested at a testing speed of 400 m/min. Zweigle hairiness tester was introduced for the measurement of hairiness, from which 100 meter yarn sample was adopted for each sample, at a testing speed of 100 m/min. In addition, yarn surface characteristics were evaluated by blackboard evenness according to the standard ASTM D2255. Yarns were wrapped onto a blackboard at a density of 32 turns per inch by Zweigle yarn board winder and were graded by three experts.

Table 4 Yarn tests and standards

Properties	Test Method	Test Apparatus
Tenacity	ASTM 2256-02	Uster Tensorapid 3
Evenness	Uster Standard	Uster Tester 3 Evenness Convertor
Blackboard evenness	ASTM D2255	ZweigleYarn Board Winder
Hairiness	ASTM D1423	Zweigle G566

Before testing, all fabrics were conditioned at 20±2℃and 65±2% RH for 24 hours. The properties of the interlock fabrics were examined including fabric weight, thickness, loop length, bursting strength, pilling resistance, air permeability as well as thermal properties. The fabric weight, thickness and loop length were measured according to their specific standards, and the apparatus used for each testing are listed in Table 5. Then the bursting strength of the fabrics were measured by the Instron according to the standard ASTM D6797. Three tests were measured and averaged. Fabric pilling resistance was tested by ICI pilling tester according to the standard ISO 12945-1. Four samples of each fabric with 125 x 125 mm were evaluated and averaged. The air permeability and thermal properties of the fabrics were tested by Kawabata Evaluation System (KES-F). Each property was measured 5 times and averaged.

Table 5 Fabric testing standards and apparatus

Fabric properties	Standards	Apparatus
Weight	ASTM D3776: 2013	Textile testing and quality control equipment
Loop length	BS EN 14970: 2006	TAUTEX digital crimp tester
Thickness	ISO 5084: 1997	Feather touch thickness tester
Bursting strength	ASTM D6797: 2002	Instron 4411
Pilling	ISO 12945-1: 2000	ICI pilling tester
Air permeability	KES	KES-FB-AP1 tester
Thermal properties	KES	KES-F7 Thermo lab II

4 Results and Discussions

4.1 Coefficient of friction

A device was designed for measuring the frictional coefficient, as shown in Figure 2. In this device, a Ne 40 cotton yarn with a tension close to yarn spinning tension (10 cN) was driven by a set of rotating rollers at a constant speed close to yarn spinning speed (0.2 m/s) and the yarn contacted with the stationery belt with a wrapping angle of 90 degree. The coefficient of friction can be easily obtained according to the capstan equation.

$$T_2 = T_1 e^{\frac{\pi}{2}\mu} \tag{1}$$

where T_1 and T_2 are yarn tensions before and after stationery belt, μ is the frictional coefficient of the yarn and stationery belt.

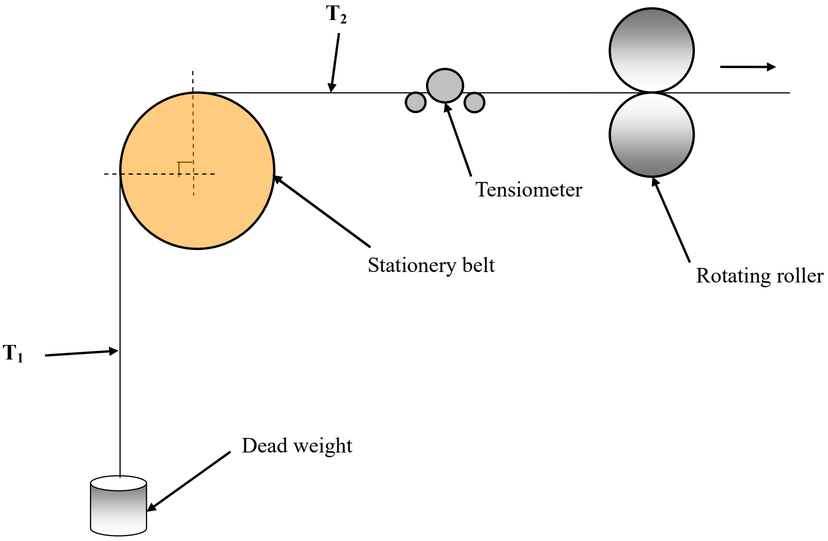


Figure 2 Schematic view of the designed device for measuring the coefficient of friction

Table 6 lists the measured coefficients of friction among five false-twisting units and Ne 40 single cotton yarn. Specifically, the false-twisting unit with hardness of 85A displays the highest value of 0.81-0.82, followed by the false-twister of hardness 40D, whereas the textured false-twister of hardness 89A shows the lowest value of 0.73. Therefore, it can be concluded that the surface roughness has the largest effect on the frictional coefficient, whereas the diameter of the false-twister has almost no influence on the frictional coefficient.

Table 6 Measured coefficients of friction

Code	Coefficient of friction	
	Mean	CV(%)
85-6mm	0.82	5.18
85-4mm	0.82	5.89
85-3mm	0.81	6.37
89T-4mm	0.73	4.20
40D-4mm	0.78	4.61

4.2 Yarn twist in spinning zone

The black-white yarn technique[17, 18] was adopted to evaluate the yarn twist above the false-twister in order to exam the false-twisting efficiency of these five belts. The Ne 40 black-white yarn was produced, and the yarn twist was captured by using the high-speed photography. The results are displayed in Figure 3, from which all the belts generate almost same amount of twists in high-twisted zone ranging from 1087-1145 turns/m, except for 85-3mm belt, which is 896 turns/m. The reason for low false twist of 85-3mm belt may result from its relatively low contacting length of the yarn and belt, which has a linear relationship to yarn diameter under the same wrap angle. Among these five belts, 85-6mm belt has the highest twist with 1145 turns/m, followed by 85-4mm belt with the twist of 1126 turns/m, whereas the values of 89T-4mm and 40D-4mm are 1104 and 1087 turns/m, respectively.

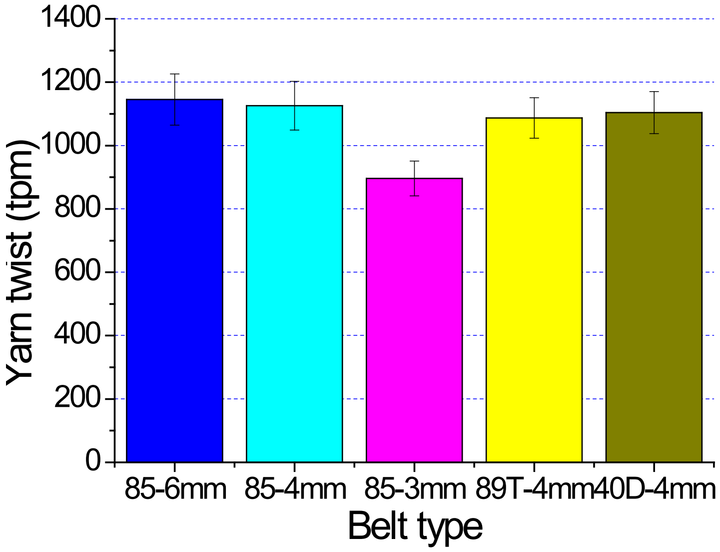


Figure 3 Yarn twists in high-twisted zone for different false-twisters

4.3 Effects of belt friction surface on yarn performances

Effects of belt friction surface on yarn performances are listed in Table 7. Comparing the yarn properties produced by belts with the same hardness of 85A but different diameters, significant differences can be found in tenacity, imperfections and hairiness. Specifically, the yarns produced by 85-6mm belt demonstrated the highest mean and minimum tenacities, comparable to the conventional ring yarns with the normal twist factor, lowest yarn hairiness values, much better than that of Conv-TF3.6 yarns, as well as highest yarn neps (+140%) values among three yarns, 51.78% worse than the Conv-TF3.6 yarns. As the diameter of the belt decreases, the yarn tenacity and hairiness also show a decreasing trend, but the yarn imperfections, especially the yarn neps (+140%), is greatly improved and the value is very close to the corresponding ring yarns. It can be concluded that the yarn impactions are significantly affected by the diameter of the false-twister, which is closely related to the interactive length of the yarn on the false-twister. As the interactive path is shortened, the surface fibers have more chances to maintain their original positions along yarn axis and resulting in a better imperfection values, meanwhile the surface fibers have less chances to wrap into the yarn body, leading to a worse hairiness and tenacity. Compared the yarns produced by the same diameter but different hardness, the yarn properties in all aspect are close to each other, which means that the belt hardness and material have almost no effect on the resultant yarn properties. Compared the yarns produced by the same diameter but different surface roughness, it can be concluded that the yarns produced by the roughness surface show a better yarn tenacity and hairiness but worse evenness and imperfections than that of the yarns made from smooth surface, which indicates that the rough belt further deteriorates local deformation of surface fibers and causes more neps. The blackboard evenness was also assessed, and the results are listed in Table 8. The results show a similar trend as the Uster evenness results, from which the yarns made from 85-3mm belt show the same grade as the conventional yarns, whereas the yarns made from 85-6mm, 85-4mm, 40D-4mm and 89T-4mm belts display half grade and one grade lower than the conventional yarns.

Table 7 Yarn performances affected by belt properties

Ne 40 yarn	Tenacity (cN/Tex) [cv%]	Mini. Tenacity (cN/Tex)	Evenness CVm% [cv%]	Thin places (-40%) [cv%]	Thick places (+50%) [cv%]	Neps (+140%) [cv%]	Hairiness (S3) [cv%]
85-6mm	17.42 [7.50]	14.70	12.88 [2.94]	134 [31.73]	31 [41.18]	340 [24.44]	469 [24.73]
85-4mm	16.84 [6.98]	14.42	12.88 [2.70]	119 [15.02]	19 [61.86]	303 [21.41]	624 [30.96]
85-3mm	16.90 [7.52]	14.28	12.82 [2.84]	104 [13.87]	21 [31.23]	248 [6.15]	846 [3.93]
89T-4mm	17.35 [7.14]	14.59	12.94 [1.93]	112 [2.24]	17 [50.26]	384 [6.83]	515 [7.41]
40D-4mm	16.96 [7.15]	14.11	12.92 [1.16]	125 [20.21]	22 [30.03]	303 [18.69]	605 [8.88]
Conv-TF3.6	17.59 [7.50]	14.23	12.71 [1.23]	110 [7.27]	34 [29.85]	224 [14.75]	1321 [27.76]

Table 8 Blackboard evenness of the modified and conventional yarns

Yarn code	Conv TF3.6	85-6mm	85-4mm	85-3mm	89T-4mm	40D-4mm
Grade	A [4.32]	B+ [5.21]	B+ [5.43]	A [5.57]	B [6.39]	B+ [7.45]

4.4 Cone yarn properties

Table 9 exhibits the physical properties of Ne 40 cone yarns made by the conventional ring spinning and modified spinning methods, coded as C-3.6C and C-3.2S, respectively. The C-3.2S yarns show a higher minimum tenacity and better yarn hairiness, comparable mean tenacity, evenness and imperfection than the corresponding C-3.6C yarns. Moreover, the snarling of the modified yarns was 25% lower than the conventional ring yarns, which could bring about softer handle feeling of the resultant fabrics.

Table 9 Properties of the cone yarns

Yarn code	Tenacity (cN/Tex) [cv%]	Mini. Tenacity	Evenness CVm% [cv%]	Thin places (-40%) [cv%]	Thick places (+50%) [cv%]	Neps (+140%) [cv%]	Hairiness (S3) [cv%]	Snarling (turns/m)
C-3.6C	17.40 [7.16]	14.76	12.97 [0.39]	122 [10.29]	33 [19.64]	243 [3.39]	1562 [9.98]	96 [10.23]
C-3.2S	17.45 [7.20]	15.01	13.07 [0.27]	121 [19.67]	25 [16.97]	269 [1.42]	1186 [9.23]	72 [8.23]

The blackboard evenness of cone yarns made by the conventional spinning and modified spinning methods are displayed in Table 9 and Figure 4, from which it could be found that the blackboard evenness of C-3.2S yarns presents the same grade with that of C-3.6C yarns, which obtains the similar results as tested by USTER3.

Table 9 Blackboard evenness of the Ne 40 cone yarns

Yarn code	C-3.6C	C-3.2S
Grade	B+ [5.32]	B+ [5.93]

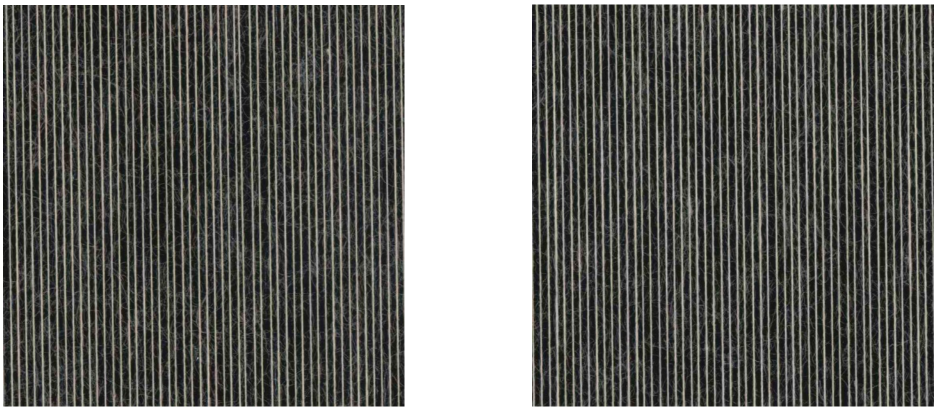

C-3.6C C-3.2S

Figure 4 Blackboard evenness of C-3.6C and C-3.2S cone yarns

4.5 Fabric Properties

The specifications of the fabrics made from C-3.6C and C-3.2S yarns are shown in Table 10, coded as F-3.6C and F-3.2s, respectively. It can be seen that F-3.6C fabrics have heavier weight but less thick and shorter loop length than the F-3.2S fabrics, and the differences are statistically significant because the p-value is below 0.05. The difference in fabric weight may be caused by the different weft densities of the two fabrics. The weft density of the conventional fabric is 1/5cm larger than the modified fabric, leading to a 1.23% higher fabric weight. The difference in loop length may also be resulted from different weft densities of the two fabrics. The difference in thickness may be ascribed to the difference in diameter of the two yarns, because the diameter of the modified yarns is about 3% larger than the conventional yarns, however the difference of yarn diameter is not statistically significant. The bulkiness of the fabrics was calculated by fabric weight and thickness, and the results indicates that the F-3.2S fabrics shows a 6.28% higher in bulkiness than that of the F-3.6S fabrics.

Table 10 Fabric specifications

Code	Weight (g/m^2)	Thickness (mm)	Loop length (mm)	Bulkiness (cm3/g)
F-3.6C	339.93 [0.40]	1.702 [2.09]	5.80 [0.12]	1.974
F-3.2S	335.57 [0.65]	1.844 [1.56]	6.17 [0.94]	2.098
t-test (p-value)	0.06	0.00	0.01	-

In order to evaluate the mechanical strength of the knitted fabrics, tests of fabric bursting strength were conducted, and the results are displayed in Table 11. The bursting strength for the F-3.6C and F-3.2S fabrics are 715.53 and 707.92 N, respectively. Although the fabrics made by the modified yarns show a slightly weaker in bursting strength than that of the fabrics made by conventional ring yarn, the two fabrics are statistically no difference since the p-value of the t-test is very close to unity.

Fabric air permeability is related to fabric bulkiness when the raw material and fabric structure are the same. It is measured by the air resistance when the air flow permeates the fabric sample in thickness direction with a flow velocity of 1m/s. The lower the permeating resistance, the better the air permeability of the fabric. Table 11 displays that the air permeability of the fabrics made from the modified yarns was 3.96% lower than that of the conventional yarns, therefore the F-3.2S fabrics had a relatively better air permeability, but the results were not statistically significant.

The thermal properties of the fabrics were tested in terms of thermal conductivity (W/m°C) and Q-max (W/cm^2). By comparing the measured data displayed in Table 11, statistical significances were found between the two fabrics. According to Table 11, F-3.2S fabrics show a 9.16% lower value in thermal conductivity than the F-3.6C fabrics, which indicates that the fabrics made from the modified yarns own a better capability of thermal insulation due to its relatively higher bulkiness. In addition, q-max measures the maximum value of heat current transferring onto the measured fabric when the heated plate touches the fabric surface. Actually, Q-max indicates the cool feeling of a person's experience when touches the tested fabric. The higher the Q-max, the cooler the feeling. As shown in Table 11, the Q-max of fabric samples for F-3.6C and F-3.2S are 0.0728 and 0.0644 W/cm^2, respectively, which implies that the fabrics made from the modified yarns have a warmer touch feeling than that of the fabrics made from the modified yarns.

Pilling is a fabric surface characterized by little pills of entangled fiber clinging to the cloth surface and giving the garment unsightly appearance, in which the pills are formed during wear and washing by the entanglement of loose fibers protruding from the fabric surface. Under the influence of the rubbing action these loose fibers develop into small spherical bundles anchored to the fabric by a few unbroken fibers. In terms of pilling grade, the higher the value, the better the fabric performance. As displayed in Table 11, the pilling grades for both fabrics have the same value of 3.75, even though the twist factor of the modified yarns have a 11.11% twist lower than that of the conventional ring yarns.

Table 11 Fabric properties

Code	Bursting strength (N)	Air resistance (KpaS/m)	Thermal conductivity (W/m°C)	Q-Max (W/cm^2)	ICI pilling grade
F-3.6C	715.53 [7.04]	0.0505 [6.16]	0.02598 [1.53]	0.0728 [4.79]	3.75 [7.71]
F-3.2S	707.92 [5.68]	0.0485 [2.66]	0.0236 [1.77]	0.0644 [1.77]	3.75 [7.71]
t-test (p-value)	0.85	0.30	0.00	0.01	1.00

5 Conclusions

In this paper, effects of friction surface of false-twisting unit on the properties of Ne 40 cotton yarns produced by the ring spinning system with single friction-belt false-twister has been carried out. The yarn imperfections generated in this system are mainly caused by rearrangement of surface fibers along yarn axis. The experiments verified that diameter of false-twister has significant impact on the yarn neps (+140%), which is closely related to the interactive path of the yarn and belt under the same wrap angle and speed ratio. It was also revealed that the belt hardness is independent of the yarn imperfections and the belt with rough surface morphology even deteriorates the situation. By comparing the properties of optimal modified yarns with that of conventional ring yarns with normal twist factor of 3.6, the optimal modified yarns with a 11.1% twist reduction apparently outweighed the conventional yarns in hairiness and slight improvements in yarn minimum tenacity and comparable yarn evenness and imperfections; whereas the mean tenacity is slightly worse than that of conventional yarns. The modified cone yarns demonstrated a higher minimum tenacity, better yarn hairiness, 25% lower snarling, same blackboard evenness, as well as comparable mean tenacity, evenness and imperfections than the corresponding conventional yarns. The knitted fabrics made from modified yarns show a 6.28% higher in bulkiness than that of the conventional yarns, resulting to a better capacity of thermal insulation and warmer feeling. Moreover, these two fabrics show similar bursting strength and same pilling grade.

Acknowledgment

This research was funded in part through a research grant from Innovation and

Technology Commission, Hong Kong Special Administrative Region (Grant number ITP/021/17TI) and a postgraduate scholarship by the Hong Kong Polytechnic University.

Appendix

Table A1 Coded and actual level for each variables of the CCD

Variables	Code	Variation levels				
		-1.682	-1	0	+1	+1.682
Twist factor	X	2.8	2.96	3.2	3.44	3.6
Speed ratio	Y	0.99	1.3	1.75	2.2	2.51
Wrap angle (o)	Z	19.82	28	45	52	60.18

Table A2 Fitted equations of Ne 40 yarns in coded values

Yarn properties	Response surface equations	R^2
Tenacity	$16.9354+1.0856X+0.3558Y+0.6229Z-0.2456X^2-0.1519Y^2$ $-0.3463Z^2-0.1713XY-0.4237XZ-0.0738YZ$	0.949
Evenness	$13.0241-0.0283X-0.0597Y+0.1781Z+0.0536X^2+0.0412Y^2$ $+0.0288Z^2+0.0675XY+0.0725XZ+0.035YZ$	0.757
Thin places (-40%)	$127.528+1.238X-2.796Y+28.41Z+7.804X^2+3.915Y^2$ $8.157Z^2+6.75XY+5.75XZ+10.5YZ$	0.836
Thick places (+50%)	$26.5947-1.3679X-2.2533Y+2.6993Z+3.5933X^2+2.1791Y^2$ $1.1184Z^2+3.125XY+0.375XZ-0.375YZ$	0.712
Neps (+140%)	$306.359-69.815X-3.574Y-11.366Z+43.745X^2+27.835Y^2$ $+24.476Z^2-5.625XY+9.125XZ-16.625YZ$	0.614
Hairiness (S3)	$497.46-185.53X-96.52Y-326.63Z+56.17X^2+75.79Y^2$ $+162.59Z^2+33.62XY+91.12XZ+66.13YZ$	0.946

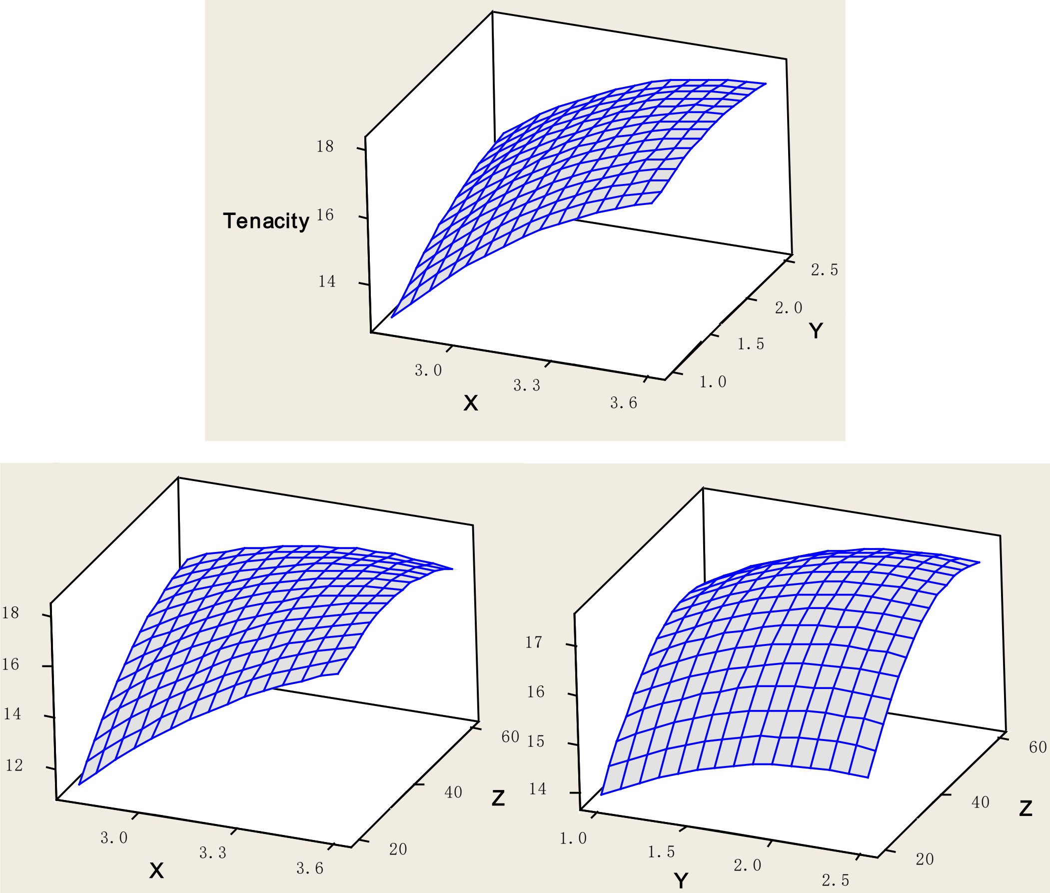
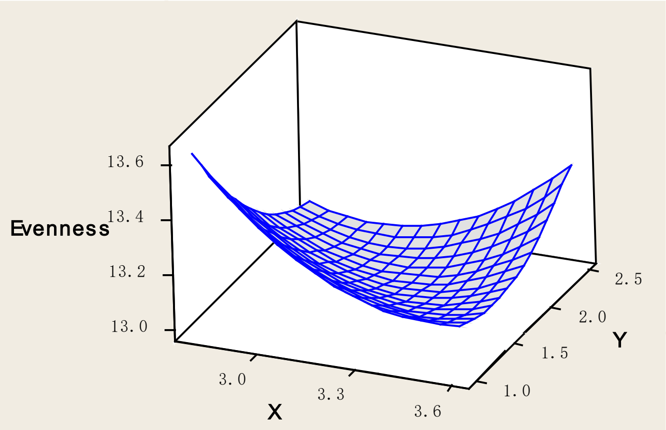


Figure A1 Effects of three factors on yarn mean tenacity



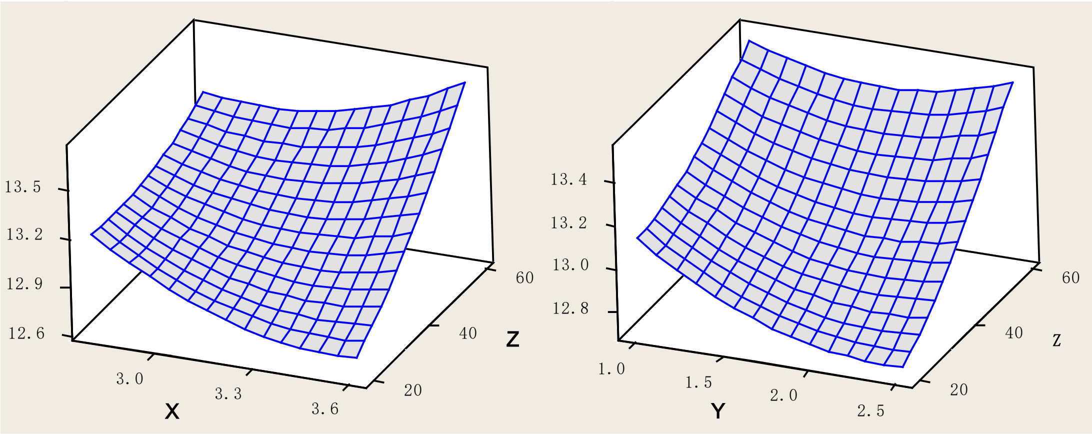


Figure A2 Effects of three factors on yarn evenness

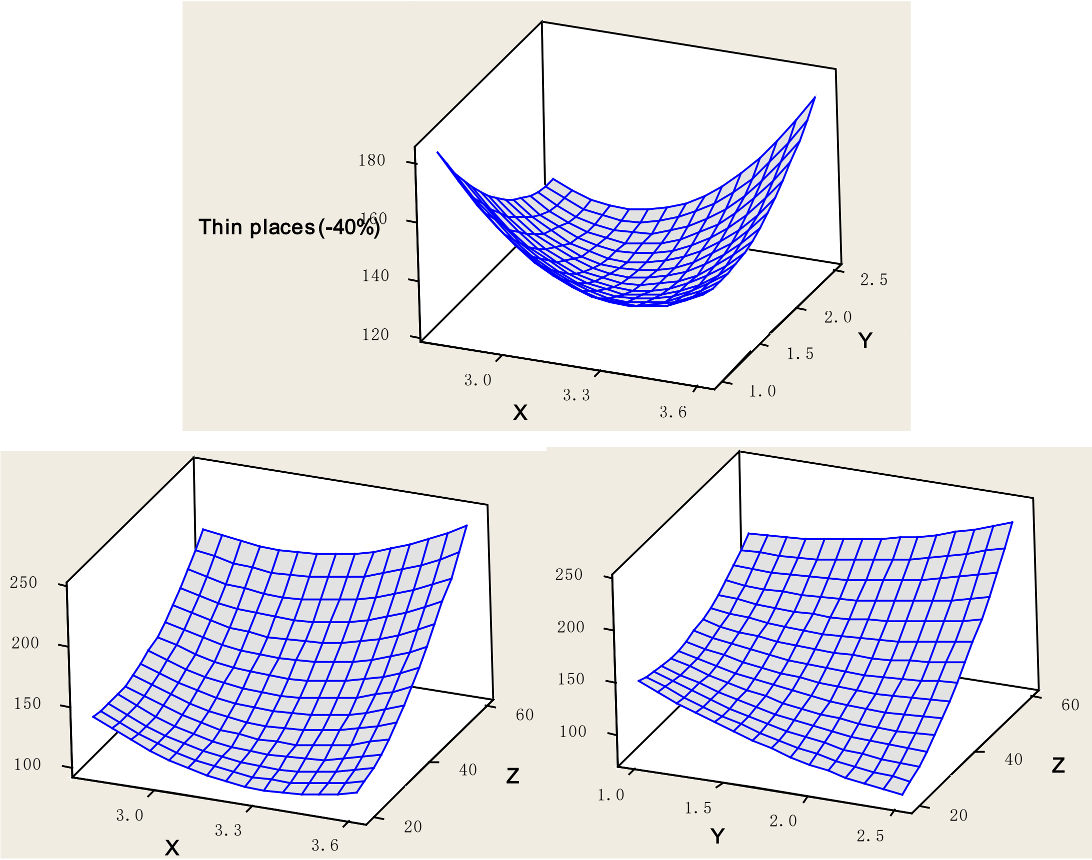


Figure A3 Effects of three factors on thin places (-40%)

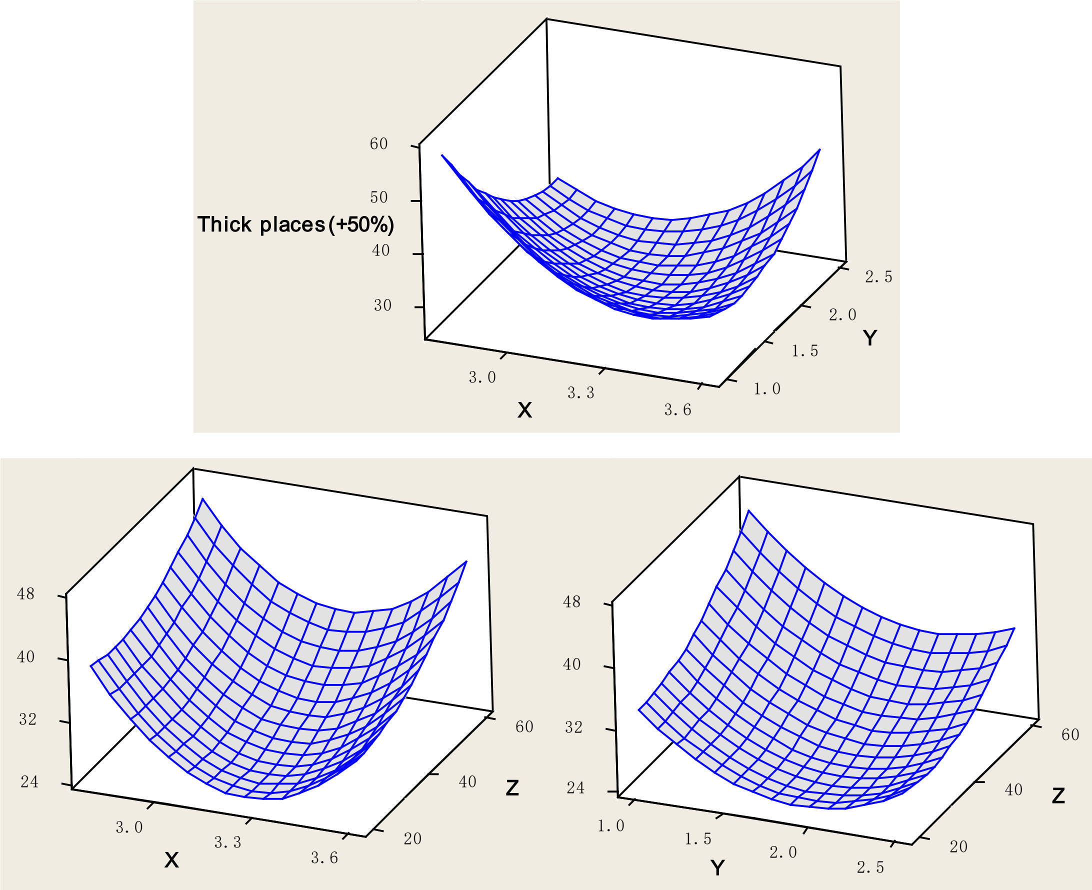
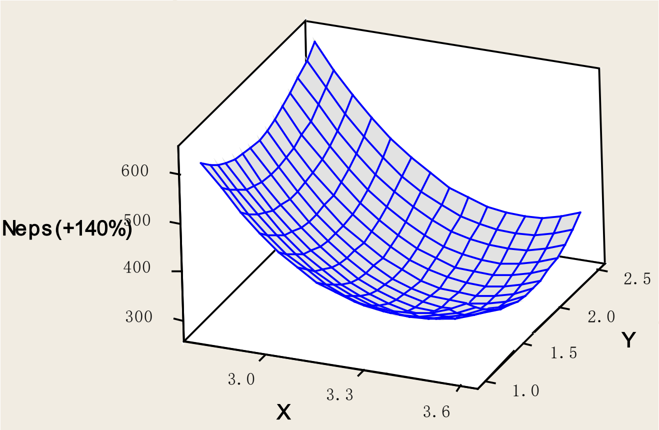


Figure A4 Effects of three factors on thick places (+50%)



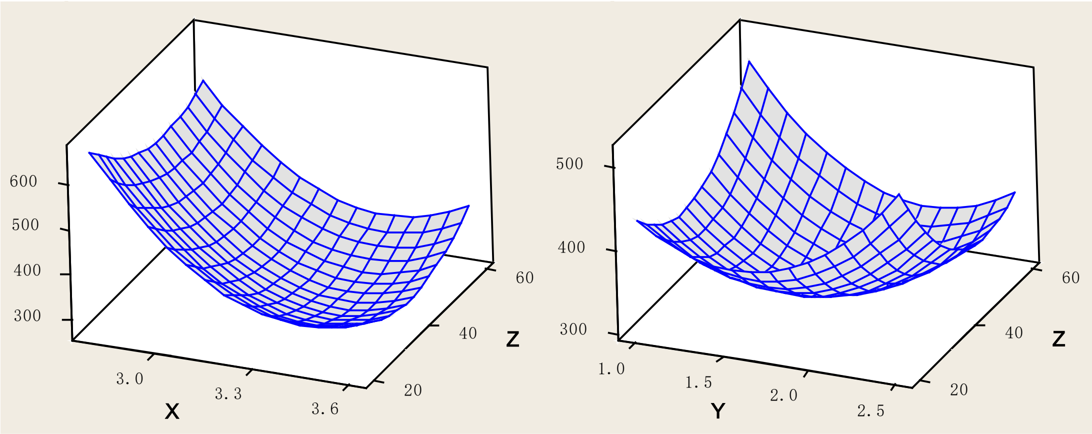


Figure A5 Effects of three factors on neps (+140%)

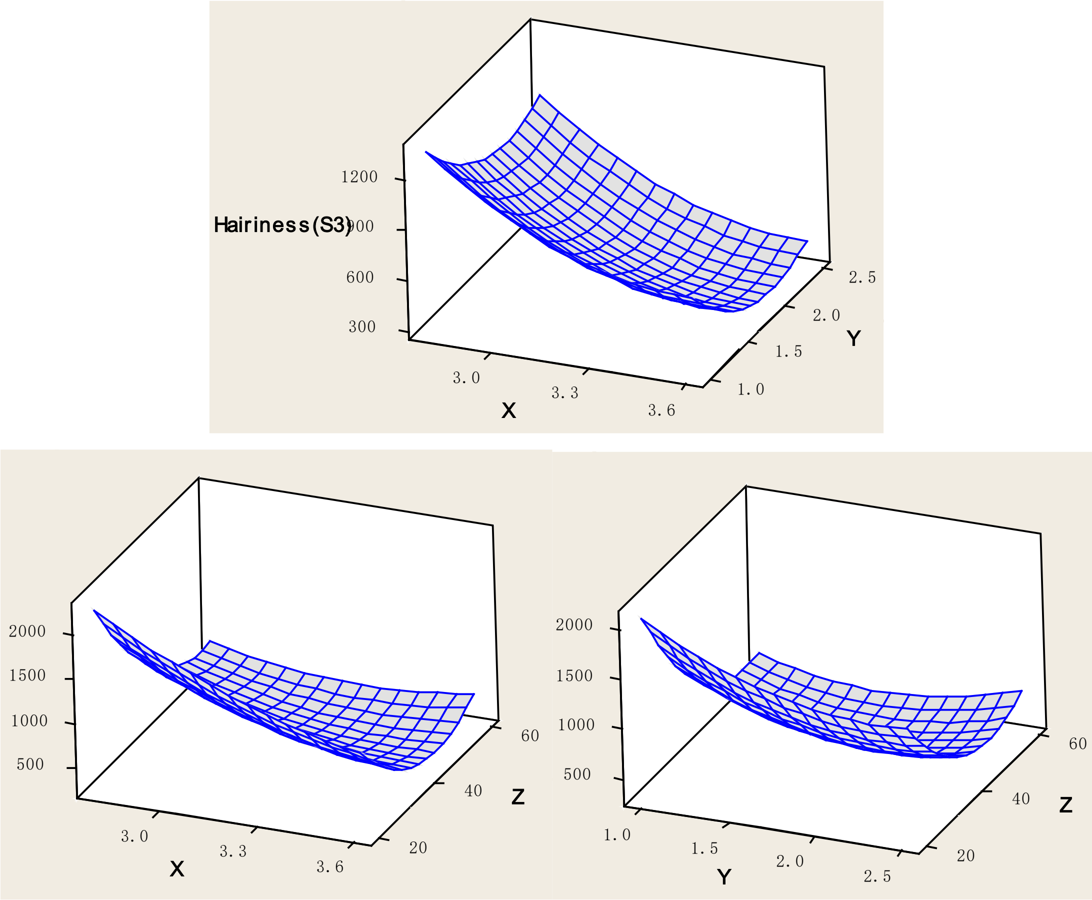


Figure A6 Effects of three factors on hairiness (S3)

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