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Optimizing Spinning Variables to Reduce the Hairiness of Rotor Yarns Produced from Waste Fibres Collected from the Ginning Process

Abstract
In this paper, various variables of the rotor spinning system were optimised to produce cotton yarn from ginning waste with the lowest hairiness level. Using the Taguchi method, the effect of rotor parameters (diameter and speed), the navel type, the opening roller speed and yarn linear density on the level of yarn hairiness was investigated. The raw materials used in this investigation were cotton fibers and cotton waste collected from ginning machines. Yarns were produced from three different waste proportions (65%, 50% & 35%). The present study of the influence of ginning waste on the hairiness of open-end yarn indicated that for all the yarns produced with different waste proportions, the rotor diameter and navel type are the most influential factors. Moreover the results show that the opening roller speed does not seem to exert a substantial influence on the hairiness of spun yarns. For the rotor yarns optimum spinning conditions were determined in order to obtain the lowest hairiness level.

Key words: c*otton wastes, ginning process, rotor spinning, yarn hairiness, Taguchi method.*

Introduction

Nowadays, according to the end uses desired, rotor yarn can be spun from cotton waste using high twist values. This is such a good way of recycling waste from mills that no other spinning system exists that enables this economical application. As a rule, raw material should be selected in such a way as to build a balance between raw material cost and yarn characteristics desired. Many researchers [1, 2] have discussed the reuse of recovered fibres in the spinning process.

Hairiness is one of the most important yarn characteristics affecting weaving, knitting, dyeing and finishing processes in textiles. Yarn hairiness is expressed in terms of the number or length of fibres directed outwards from the yarn surface. The parameters of fibres and machines for all production stages are known to have an influence on yarn hairiness. When, as a consequence of technological advances, machine speeds are increased and high productivity is required, yarn hairiness becomes a very undesirable parameter, which should be measured and controlled. Different studies have been carried out to reduce yarn hairiness [3]. Furthermore the effects of the material and machines on yarn hairiness, as well as measurement methods for hairiness have been studied by numerous authors [4 - 8].

All those studies discussed the effect of cotton fibres and fibres recovered from the blowing and carding processes on yarn hairiness. In this investigation, we studied the effect of selected rotor spinning parameters on the hairiness of yarns produced with three different ratios of fibres collected from the ginning process. In order to estimate the optimum process conditions and to examine the individual effects of each of the controllable factors on a particular response, Taguchi's experimental design was used [9].

Experimental

The raw materials were cotton fibres and cotton waste collected from ginning machines. Cotton fibres were chosen for all mixtures with secondary raw material of different proportions (65%, 35% and 50%). We measured the cotton and waste fibre properties using a Spinlab 900 according to the ASTM Standard Test Method for Measurement of Cotton Fibres by High Volume Instruments (HVI), ASTM D4605, with a total of four samples taken for evaluation. A statistical summary of raw fibre property measurements is included in ***Table 1***. Blending was carried out after carding at the first passage in the drawing frame. The second passage was used to improve the homogeneity of the blending. A statistical summary of sliver property measurements is included in ***Table 2***. Slivers were used to produce yarns with three different linear densities - 49.2 tex, 36.9 tex and 29.5 tex on an Elitex rotor-spinning

Table 1. *Summary of fibre properties.*

Fibre properties	Waste cotton	Cotton
Fibre tenacity, cN/tex	23.2	27.1
Fibre elongation, %	6.6	6.7
Mean length by weight, mm	21.77	23.90
CV length by weight, %	1.94	1.91
Short fibre content by weight, %	11.1	7.0
Maturity index	0.81	0.82
Micronair	4.29	4.38
UQL (upper quartile length by weight), mm	27.19	28.89

Table 2. *Summary of sliver properties.*

Yarn code	Fibre content, %		1st Drawing passage		2st Drawing passage	
	Cotton	Waste	Linear density, ktex	CVm%	Linear density, ktex	CVm%
CW63	65	35	2.90	9.92	3.35	10.82
CW55	50	50		8.69		9.11
CW36	35	65		8.88		9.36

__Table 3.__ Machine setting of rotor spinning.

Parameters	Descriptions
Rotor diameter, mm	48, 54, 66
Rotor speed, r.p.m.	41000, 47000, 53000
Twist, t.p.m	775, 911, 1008
Opening roller type	OK40 (for cotton fibres)
Opening roller speed, r.p.m.	9800, 8400, 7350
Navel type	(steel) ; 8 flutes, 4 flutes and without flutes
Delivery speed, m/min	52.4 m/min
Yarn linear density, tex	49.2, 36.9, 29.5

__Table 4.__ Experimental design (L_{27}).

RUN	P1 Yarn count, tex	P2 Rotor speed, r.p.m.	P3 Opener speed, r.p.m.	P4 Rotor diameter, mm	P5 Navel type
1					A
2		41000	9700	54	B
3					C
4					A
5	49.2	48000	8400	66	B
6					C
7					A
8		53000	7350	48	B
9					C
10					B
11		41000	8400	48	C
12					A
13					B
14	36.9	48000	7350	54	C
15					A
16					B
17		53000	9700	66	C
18					A
19					C
20		41000	7350	66	A
21					B
22					C
23	29.5	48000	9700	48	A
24					B
25					C
26		53000	8400	54	A
27					B

machine. The setting of the machine is shown in ***Table 3***.

In order to estimate optimum process conditions and to examine the individual effects of each of the controllable factors on a particular response, Taguchi's experimental design was used. This experimental design involves using orthogonal arrays to organise the parameters affecting the process and the levels at which they should be varied. The controllable factors considered in this research were the rotor diameter and speed, the opening roller speed, the navel type and yarn linear density. We chose the orthogonal array L_{27} ,shown in ***Table 4***, because it required only twenty-seven runs for combinations of five controllable factors varied at three levels. The yarns produced with three rotor diameters, and three different rotor speeds, opening roller speeds and navel types were tested for yarn hairiness. ***Figure 1*** shows the three different navel types used in this investigation.

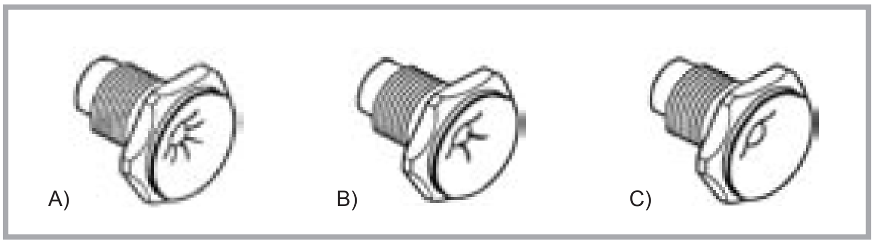

Figure 1. *Different navel types: A) 8 flutes, B) 4 flutes, C) without flute.*

Samples were kept in standard testing conditions for 24h prior to testing. Variations were to be expected within individual yarn bobbins, hence the first few meters were discarded. In addition, samples were taken at various locations in the yarn bobbins. The yarn hairiness was the response in our study. For each sample, a 500 m length of yarn was tested on a Zweigle G 566 hairiness tester at a yarn speed of 50 m/min to obtain the number of hairs per meter, and the number of hairs exceeding 3 mm was measured. Thirty tests were necessary to obtain average yarn hairiness values.

Results and discussions

Level average analysis was adopted to interpret the results. This analysis is based on combining the data associated with each level for each factor. The difference in the average results for the highest and lowest average response is the measure of the effect of that factor. The greatest value of this difference is related to the largest effects of that particular factor [4]. The results of the different spun yarns (WC63, WC36 and WC55) produced by rotor spinning are given in ***Tables 5***.

To facilitate the yarn hairiness analysis, we used the statistic 'delta', defined as the difference between the high and low effect of each factor using DOE Wisdom statistical software. A classification can be made to determine the most influential factor. The study of yarn hairiness is a smaller-the-better problem, and optimum spinning conditions are determined by selecting the levels that show the lowest average responses in ***Tables 5***. As mentioned earlier, the study selected is a smaller-the-better problem, and optimum spinning conditions are determined by choosing the levels that show the highest average responses in ***Tables 5***. Considering this principle, the levels recommended are summarised in ***Table 6***.

According to the level average analysis (***Table 5***), for cotton-waste (35/65) spun yarns, the rotor diameter has the largest effect on yarn hairiness; the factor navel type is second, followed by the factor linear density, factor rotor speed and factor opening roller speed.

For cotton-waste (50/50) spun yarns, the factor rotor diameter shows the strongest effect; the factor navel type is second, followed by the factor yarn linear density, rotor speed and opener speed. For cotton-waste (65/35) spun yarns, the dominant parameters that influence the quality index are the rotor diameter, navel type, rotor speed, yarn linear density and opening roller speed.

The effect of the yarn linear density and rotor diameter on yarn hairiness for all yarns produced with different waste proportions is shown in ***Figure 2***. The results show that the rotor diameter influences hairiness, which grows as the rotor diameter increases. According to ***Table 6***, the lowest hairiness value is obtained when the smallest rotor diameter is used. This finding is supported by Manich *et. al* [3], who reported that one of the factors that chiefly affects hairiness is the degree of friction between the yarn and parts of the rotor as the yarn leaves the collecting groove to come out of the nozzle. It seems logical that the larger the rotor diameter, the higher the friction will be, which, in turn, will result in greater hairiness.

The effect of yarn linear density and navel type on yarn hairiness for all the yarns produced with different waste proportions is shown in ***Figure 3*** (see page 24). The hairiness values of the rotor yarns were affected directly by navel properties; minimum hairiness values were obtained by using a navel which has no flutes, and maximum values were obtained by using a 4 flute-navel. These results can be attributed to deformation in the yarn caused by its rough surface. The fluted insert affected yarn properties differently; when it is added to a grooved

Table 5. *Response table for rotor spun yarns of cotton/waste.*

Spun yarn	Factors	Average response value of each level Mean hairs exceeding 3 mm in 1 meter of yarn					Optimum level
		I	II	III	Delta	Rank	
cotton/waste 35/65	P1 (linear density)	-12.395	-11.0726	-11.212	1.1829	3	II
	P2 (rotor speed)	-11.904	-11.9294	-10.765	1.163	4	III
	P3 (opener speed)	-11.633	-11.4823	-11.564	0.151	5	II
	P4 (rotor diameter)	-11.695	-12.9529	-10.032	2.920	1	III
	P5 (navel type)	-11.166	-12.5222	-10.991	1.530	2	III
cotton/waste 50/50	P1 (linear density)	-11.880	-10.678	-11.364	1.208	3	II
	P2 (rotor speed)	-11.540	-11.747	-10.575	1.171	4	III
	P3 (opener speed)	-11.153	-11.650	-11.126	0.497	5	III
	P4 (rotor diameter)	-11.607	-12.885	-9.4367	3.448	1	III
	P5(navel type)	-11.117	-12.338	-10.474	1.864	2	III
cotton/waste 65/35	P1 (linear density)	-11.960	-10.844	-11.400	1.116	4	II
	P2 (rotor speed)	-11.626	-11.797	-10.613	1.183	3	III
	P3 (opener speed)	-11.281	-11.452	-11.470	0.189	5	I
	P4 (rotor diameter)	-11.569	-13.276	-9.3588	3.917	1	III
	P5 (navel type)	-11.321	-12.062	-10.820	1.241	2	III

Table 6. *Optimum level of control factors for rotor spun yarns.*

Spun Yarns	Optimum level for each factor				
	Linear density, tex	Rotor speed, r.p.m.	Opener speed, t.p.m.	Rotor diameter, mm	Navel type
Cotton/waste (35/65)	36.9	53000	8400	48	C
Cotton/waste (50/50)			7350		
Cotton/waste (65/35)			9700		

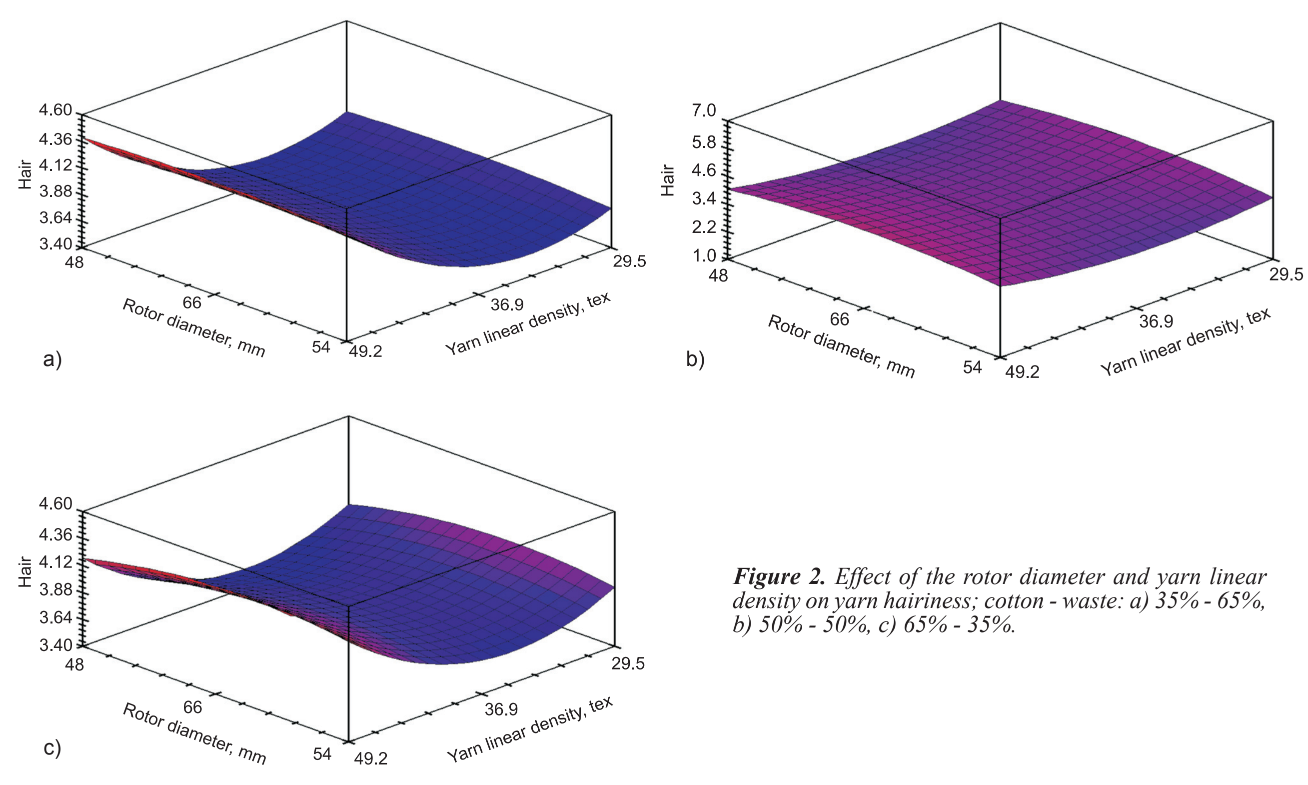

Figure 2. *Effect of the rotor diameter and yarn linear density on yarn hairiness; cotton - waste: a) 35% - 65%, b) 50% - 50%, c) 65% - 35%.*

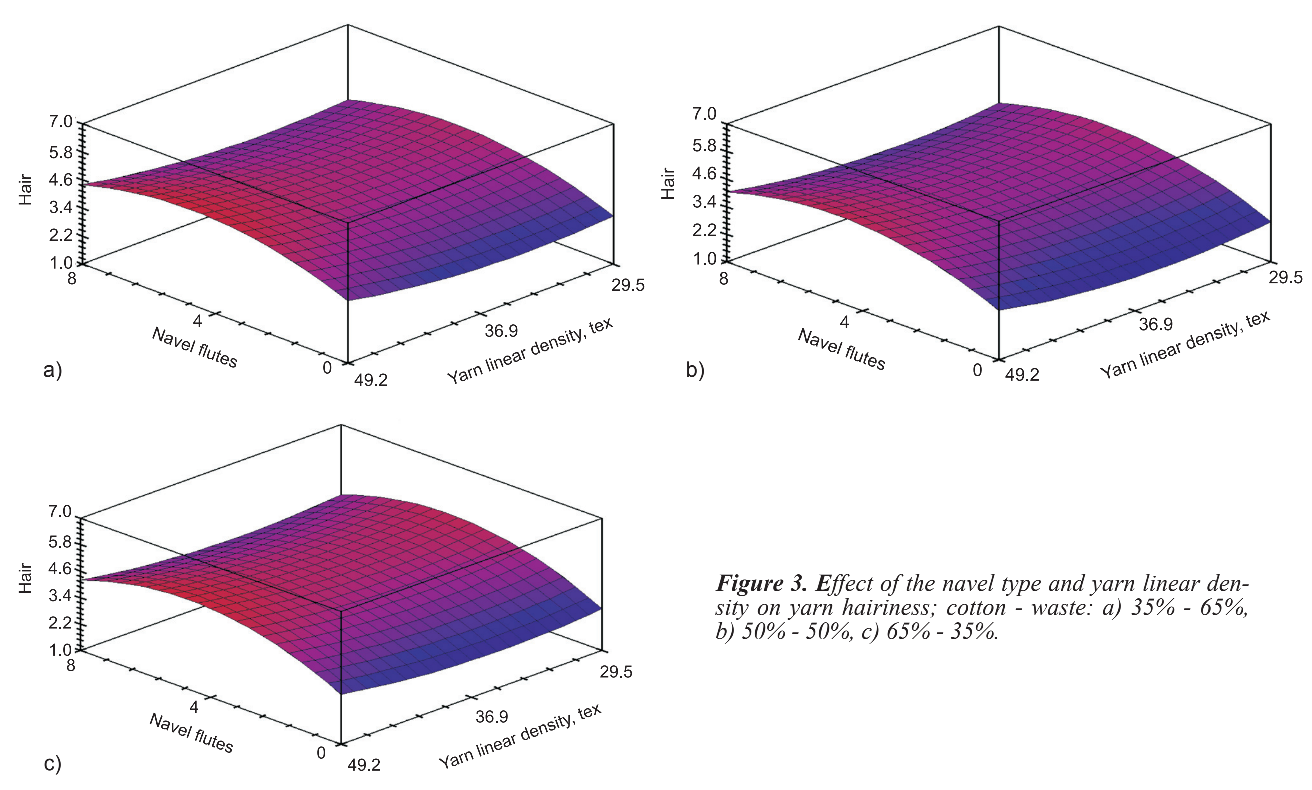

Figure 3. *Effect of the navel type and yarn linear density on yarn hairiness; cotton - waste: a) 35% - 65%, b) 50% - 50%, c) 65% - 35%.*

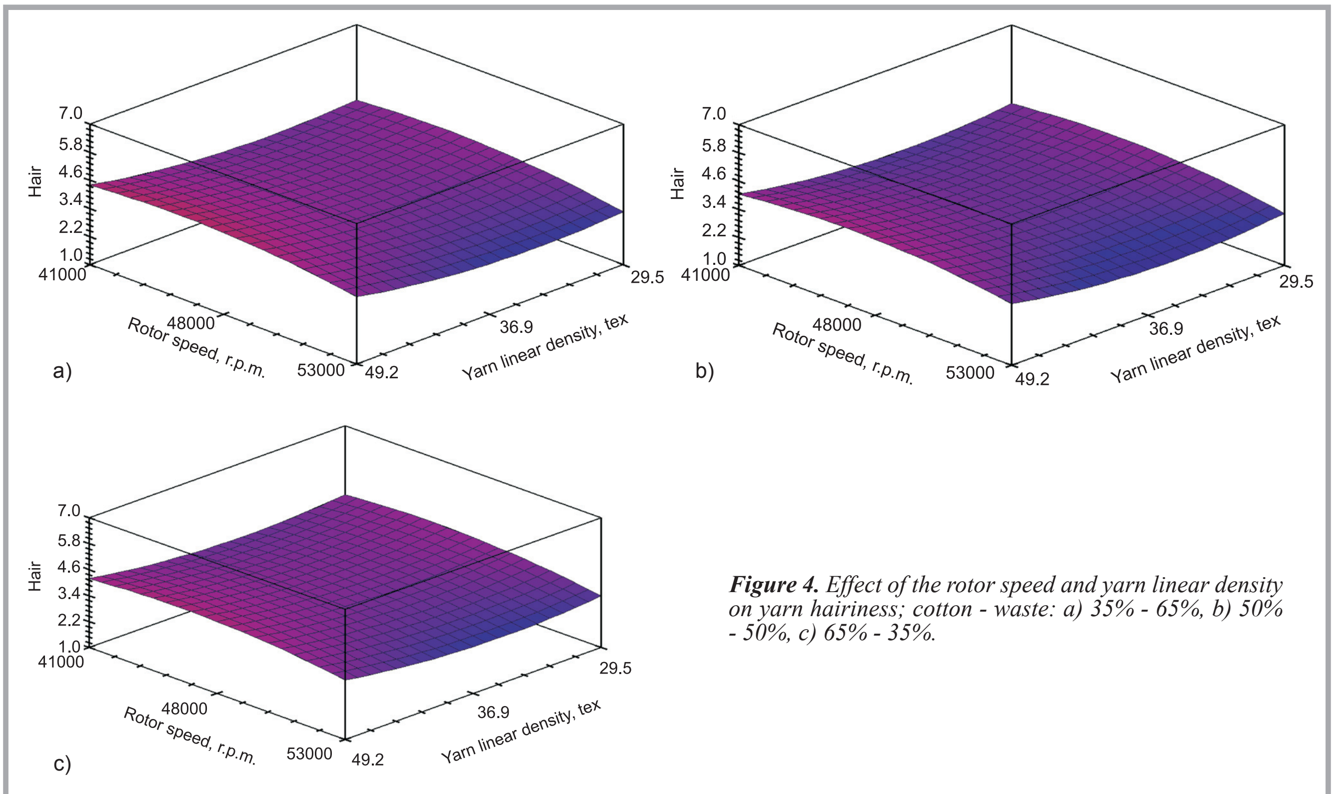

Figure 4. *Effect of the rotor speed and yarn linear density on yarn hairiness; cotton - waste: a) 35% - 65%, b) 50% - 50%, c) 65% - 35%.*

navel, it primarily affects the surface's characteristics, and consequently the hairiness values of the yarn [7]. The greater deformation caused by using a 4 flute-navel, compared with an 8 flute-navel, is due to the deeper grooves of the 4 flute-navel.

The effect of the yarn linear density and rotor speed on yarn hairiness for all the yarns produced with different waste proportions is shown in ***Figure 4***. The rotor speed influences hairiness i.e. when the rotor speed increases, the hairiness grows. This phenomenon could be explained by the fact that as the rotor speed increases, the friction time of the yarn in the sector between the collecting groove and the exit will be less, which will entail a smaller number of hairs raised from the nucleus of the yarn, some of which will tend to be longer, although this effect will

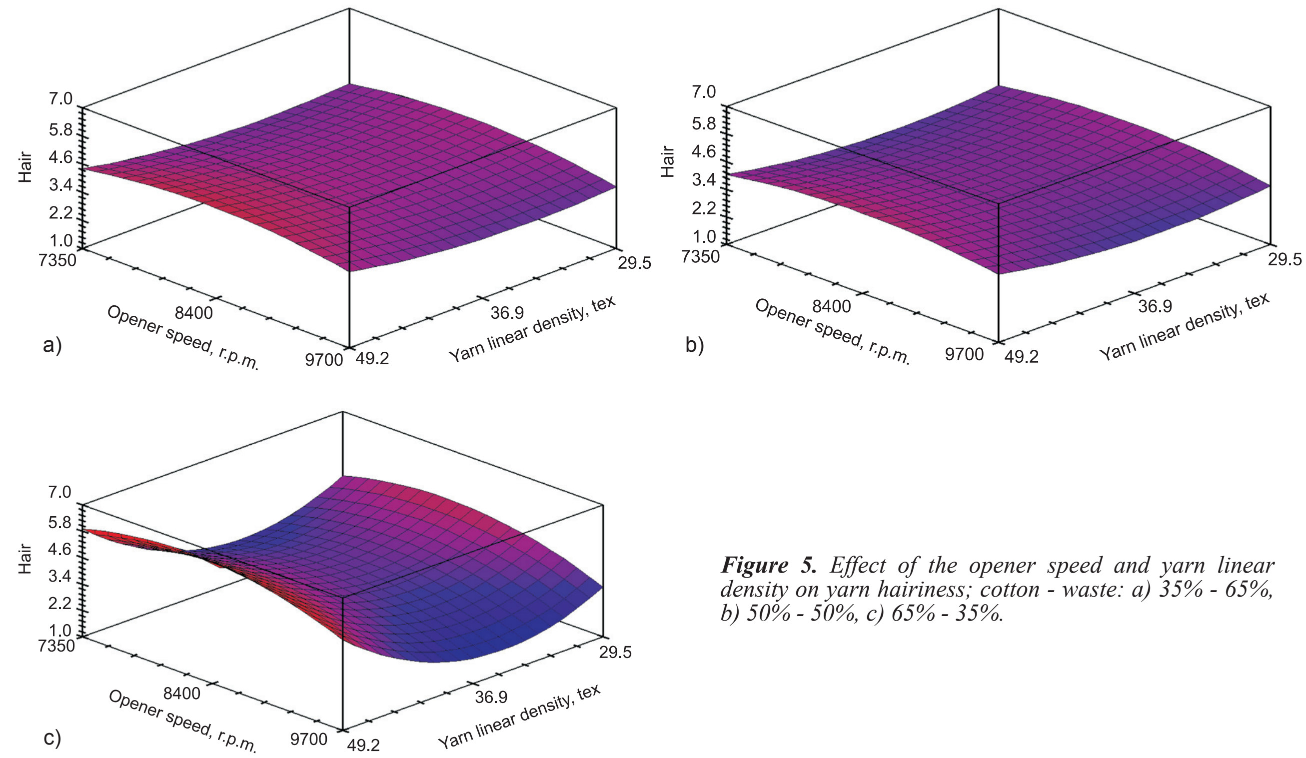

Figure 5. *Effect of the opener speed and yarn linear density on yarn hairiness; cotton - waste: a) 35% - 65%, b) 50% - 50%, c) 65% - 35%.*

not essentially modify the mean-length value of the protruding ends [5].

The effect of the yarn linear density and opening roller speed on the yarn hairiness for all the yarns produced with different waste proportions is shown in ***Figure 5***. The findings show that the opening roller speed has the lowest effect on yarn hairiness. These results are also proved by the findings reported by Vila *et. al* [5]. Their investigations showed that the opening roller speed does not seem to exert a substantial influence on the hairiness of spun yarns.

Manich *et. al* [4] concluded that the linear density of the yarn always influences the hairiness in the same sense as conventional yarn, that is to say, the great the linear density (tex) , the higher the hairiness. However, the results of this investigation show that the minimum yarn hairiness level was achieved for 36.9 tex-yarn.

The influential parameter for yarn hairiness is the raw material (fibres), as expected. Empirical studies show that yarn hairiness can be attributed to fibre properties. It has been well reported that fibres of higher fibre length can reduce yarn hairiness; therefore, spun yarns produced with a lower waste proportion have less hairiness, which can be seen in ***Table 6*** for yarns produced from cotton-waste (65% - 35%).

Conclusions

The present study of the influence of ginning waste on the hairiness of open-end yarns indicates that for all the yarns produced with different waste proportions, the rotor diameter and navel type are the most influential factors. Moreover the results show that the opening roller speed does not seem to exert a substantial influence on the hairiness of spun yarns. However, the rotor diameter and rotor speed influence hairiness, which grows as the rotor diameter and rotor speed increase. Furthermore, the hairiness values of the rotor yarns were directly affected by navel properties; minimum hairiness values were obtained by using a navel which has no flutes, whereas maximum values were obtained using a 4 flute-navel.

Using the Taguchi method, the findings show that the rotor diameter has the largest effect on yarn hairiness for cotton-waste (35/65) spun yarns; the factor navel type is second, followed by the factor linear density, factor rotor speed and factor opening roller speed.

For cotton-waste (50/50) spun yarns, the factor rotor diameter shows the strongest effect; the factor navel type is second, followed by the factor yarn linear density, rotor speed and opener speed. For cotton-waste (65/35) spun yarns, the dominant parameters that influence yarn hairiness are the rotor diameter, navel type, rotor speed, yarn linear density and opening roller speed. Moreover, the findings show that spun yarns produced with lower waste proportions have less hairiness.

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