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Analysis of Ring Spun Yarn Wickability Using the Post-Hoc Test

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Abstract
Yarn wickability achieves high thermo-physiological comfort. Therefore, this paper aimed to investigate yarn wickability and analyze statistically factors affecting yarn wicking performance. Methodology consists of testing wicking height for ring spun yarn produced from three levels of fibre types and twist factors at two levels of doubling. Statistical tools such as ANOVA, T-test and Post-hoc tests analyzed the impacts on wicking heights. Findings showed that the Post-hoc test represented the variation between groups more accurately than ANOVA. Furthermore, a comparison of Bonferroni Alpha with T-test p-values revealed that yarn wicking was significantly affected by interactions of fibre type, doubling, and twist level.

Keywords
wickability, ring spun yarns, ANOVA, Post hoc test, Bonferroni alpha.

1. Introduction

Wicking is defined as a capillary-driven spontaneous transfer of a liquid into a porous substance [1, 2]. Wickability also indicates the ability to maintain capillary flow. Wettability, on the other hand, describes the initial performance of a yarn or fabric in contact with liquid [3, 4]. There are many factors that affect yarn wickability, such as the yarn count, yarn structure, twist level, number of ply yarns as well as fiber type and fiber properties. Hitherto, most studies on this have investigated the effect of plying parameters on the wicking height of yarn. For example, Lu et al. [5] compared the wicking properties of ring and compact-siro ring spun staple yarns of polyester staple fibers. Results revealed that the wicking property was significantly affected by the twist level for both two yarn types, where the wicking height increases by using a low twist coefficient. In addition, the compact-Siro spun yarn showed better wicking properties than staple yarns. Wang et al. [6] investigated the wicking performance of polyester filament yarns by evaluating the effects of the twist level, monofilament cross-sectional shape and texturing on the yarn wicking height. The results showed that by increasing the twist level, the wicking height ascends until reaching the maximum height, and then descends. Furthermore, it was noticed that the wicking height of the ply low-stretch yarn is the largest among all tested yarns under the same twist level. Hajiani et al. [7] investigated the wicking performance of nylon 6.6 nanofiber yarns by studying the effect of the twist rate. The capillary rise was measured by adding a pH sensitive dye to the yarn inter-structure, and an analysis was made of the color alteration of the nanofiber yarn structure caused by the shift occurring in pH during the capillary rise of distilled water. The results illustrated that the addition of pH-sensitive dye has no significant effect on the average nanofiber diameter and wicking behavior of yarns. Furthermore, by increasing the nanofiber yarn twist, the average equilibrium wicking height and capillary rise rate coefficient decreased because of the reduction in the continuity and size of capillaries. Li et al. [8] studied the wicking performance for cotton and wool yarns. Results showed that the twist level and ply number of yarns affected yarn wicking performance for cotton yarns. For wool yarns, better wicking behavior was found for the yarn containing the coarsest fiber diameter. According to a comparison of results between the treatment methods for synthetic continuous filament yarns and natural staple yarns, the prewash treatment could improve yarn wicking and plasma treatment increased the yarn wicking rate effectively for both filament yarns and staple yarns.

In addition, some studies evaluated the effect of yarn count on the wicking height of yarn. For instance, Taheri et al. [9] studied the wicking height of Lyocell ring-spun yarns, and tested samples were prepared according to different twist factors and yarn counts. Results showed that wicking height decreases with the increasing of the yarn count as a result of a reduction in the yarn diameter due to the lower number of fibers at the yarn cross section causing limited capillary space of fibers. De et al. [10] investigated the effect of yarn structure on the wicking behavior of cotton yarns such as single, plied and corded yarns at different linear densities. Results revealed that the high number of ply yarns increased the wicking height with high rates at coarser counts.

Besides these, a few researchers studied how can fiber type affects yarn wickability, such as Parveen and Lakshmi [11], who studied the effect of fiber type on the yarn wicking behavior of micropolyester cotton blended yarns. Tested samples consisted of different fiber blends of micropolyester/cotton arranged from 100% micropolyester to 100% cotton. Results indicated that 100% micropolyester has better wicking behavior. Furthermore, various studies evaluated the effect of yarn properties on the wicking height of fabrics. For example, Kaynak et al. [2] evaluated the effects of filament fineness, weft density and weave design on the wickability of filament woven fabrics by comparing the wickability of sample fabrics produced from twill and satin polyester filament woven fabrics with different weft yarns of three levels of filament fineness and two levels of weft density. Results showed that the following major factors affect fabric wickability: the fibrous structure, drying rate, water holding capacity, total porosity, pore size and pore distribution. Considering the importance of the wicking property, which indicates the degree of absorbency, dyeing performance and fabric comfort, Subramaniam and Raichurkar [12] conducted a survey of many papers measuring the wicking of yarns and fabrics. Moreover, other researchers investigated the relation between the wicking performance of yarn and the fabrics produced, such as Nyoni and Brook [13], who used a microscopic to analyze the wicking properties of nylon 6.6 continuous and textured filament yarns, commonly used for lightweight high performance woven fabrics. Furthermore, other studies evaluated the performance of fabric wickability [14-16].

According to the above survey, there is a need to test the wicking behavior of different yarns produced from different fiber types at variable plying parameters. Therefore, the objectives of this research work were, firstly, to measure the wicking height of ring spun yarn produced from three levels of fiber types at three twist levels and two levels of doubling. The second objective was to compare the values of yarn wicking heights. The final one was to analyze the significant effect of the parameters studied on wicking heights using a new technique – the Post-hoc test, which has not been applied before to test this phenomenon, as well as using ANOVA and the T test.

1.1. ANOVA and Post-hoc tests

The ANOVA test is an omnibus test that provides overall results, but statistically the variations in the means are not always significant when taken as a whole. ANOVA includes post-hoc testing as a necessary component. Statistically significant results show that not all of the group means are equal when using ANOVA to evaluate the equality of at least three group means. The findings of the ANOVA, however, do not specify which specific differences between mean pairs are significant. While limiting the experiment-wise error rate, post-hoc tests were used to investigate variations between different groups averages [17]. To evaluate the outcomes of experimental data is *post hoc*, which is Latin for "after this." The likelihood that at least one type I error will occur in a set (family) of comparisons is the foundation for these calculations [18]. Post-hoc analyses offer crucial advantages when choosing the best of the parameters studied in the research work. Furthermore, ANOVA is used to compare the group means. Hence, the greater the number of groups, the more comparison tests must be performed [17].

2. Bonferonni Correction

This multiple-comparison post-hoc adjustment is utilized when numerous independent or dependent statistical tests are run concurrently. Running numerous tests simultaneously has the drawback that with each test run, the probability of a significant result rises. The significance threshold for this post-hoc test is α/n. The correction, for instance, would be 0.0025 if you were conducting 20 tests concurrently at 0.05. Additionally, there is a power loss with the Bonferroni. This is attributable to a number of factors, including the high type II error rates for each test. In other terms, it overcorrects for type I errors [18].

3. Experimental design

3.1. Material

Table 1 shows the material specifications of the fiber type used, and plying parameters such as the twist factor (TF) and number of ply yarns (doubling). Tested samples consist of three levels of fiber type, three twist levels and two levels of doubling of ring spun carded yarn, including a 30/1 Ne count for all samples. Ring spun yarn was produced using a Rieter ring spinning machine G33 (14000 rpm). In addition, a Savio Two for One- TFO Twister at 10000 rpm was used to produce the tested yarn at a variable twist level set at three levels (2.8, 3.8, and 4.8), which correspond to low, medium, and high. The formula of calculating the twist factor is shown as Eq. 1 [19].

Table 2 shows the design of the experimental model, which consists of 18 different experiments, with six readings of the wicking height (mm), measured in each experiment.

For the English count system (Ne), the twist factor (k_e) is as follows:

$$(\boldsymbol{k}_{\mathbf{e}}) = \frac{\mathbf{TPI}}{\sqrt{\mathbf{N}_{\mathbf{e}}}} \qquad (1)$$

Where TPI is the number of turns per unit length in inch

3.2. Experimental method

The wicking property of yarns was evaluated using the longitudinal wicking 'strip' test method in accordance with DIN 53924 under atmospheric conditions of 65% ± 2% relative humidity and 27ºC ± 2ºC temperature for all the yarns [20]. An instrument developed for examining the wicking of yarns was used [11]. Yarns were set vertically and immersed in a diluted potassium chromate aqueous solution (0.5 percent, about 0.01 m high) [5, 21]. The wicking height was measured after 30 minutes to get a stable final height (mm). Six specimens of each group were tested. Statistical analyses were made to test the variation between groups' wicking heights, where the experiments consisted of two levels of doubling and three levels of the fiber type and twist factor. Therefore, one way ANOVA analysis was applied to test the overall significant effect of the fiber type and twist levels. Besides, the T-test was used to test the overall significant effect of doubling as it consists of two levels. Then, the post-hoc test was applied to analyze the actual significant effect of tested parameters by comparing

Bonferroni Alpha with the p-value test for each group. After adjusting groups to study the effect of each parameter, the number of comparisons (N) used in each comparison was equal to (3, 3, 2), which was calculated according to Eq. 2 based on the number of tested groups (n), which was equal to (3, 3, 2) for testing the significance of fiber type, twist and doubling parameters in series. Finally, the Post-hoc test (Bonferroni Method) was used. Bonferroni Alpha was calculated according to Eq.(3). Using Alpha values of ANOVA, which was equal to (0.05) in all cases, then the Bonferroni Alpha was calculated to test the real significance, equal to (0.01666, 0.01666, 0.05), of the fiber type, twist and doubling models in series.

$$N = \frac{n\,(n-1)}{2} \quad (2)$$

Where, N: number of comparison tests, n: number of tested groups

$$\text{Bonferroni corrected Alfa} = \frac{\text{ANOVA Alpha}}{N} \quad (3)$$

Where, ANOVA Alpha =0.05

Levels	Fiber type	Doubling	Twist factor T.F
1	Polyester 100%	2 ply yarns	2.8 (low)
2	Cotton100%	3 ply yarns	3.8 (medium)
3	Cotton Polyester50% 50%	……	4.8 (high)

Table 1. Material specifications

Run	Fiber Type	Doubling	TF
1	1	1	1
2	1	1	2
3	1	1	3
4	2	1	1
5	2	1	2
6	2	1	3
7	3	1	1
8	3	1	2
9	3	1	3
10	1	2	1
11	1	2	2
12	1	2	3
13	2	2	1
14	2	2	2
15	2	2	3
16	3	2	1
17	3	2	2
18	3	2	3

Table 2. Design of experimental model

4. Results and discussion

4.1. Results of wicking height

Table 3 show the outcome values of the wicking height (mm) for 2 ply and 3 ply yarns for three levels of the twist factor and fiber type. In addition, coded samples are presented according to the specification of the material tested. For example, P21 refers to ring spun yarn produced from 2 ply yarn of 100 % polyester at a low twist level (TF is 2.8). The wicking results illustrate the relationships between yarn wicking and the parameters studied for yarn samples produced from polyester, cotton and cotton/polyester fibers at two levels of doubling and three levels of twisting. By comparing the wicking height at the same twist factor versus the number of ply yarn, all samples have the same performance. Since the outcomes of average wicking heights show that the higher the number of ply yarn is, the lower the wicking height, due to less porosity, which prevents liquid transfer. In addition, at the same number of ply yarn, yarn wicking heights decrease when increasing the twist factors because of the reduction in fluid absorption in the yarn.

Doubling	2									3								
TF	**2.8**	**3.8**	**4.8**	**2.8**	**3.8**	**4.8**	**2.8**	**3.8**	**4.8**	**2.8**	**3.8**	**4.8**	**2.8**	**3.8**	**4.8**	**2.8**	**3.8**	**4.8**
Fiber type	**Polyester 100%**			**Cotton100%**			**Cotton /polyester 50% 50%**			**Polyester 100%**			**Cotton100%**			**Cotton/polyester 50% 50%**		
Group / Run	**P21**	**P22**	**P23**	**C21**	**C22**	**C23**	**CP21**	**CP22**	**CP23**	**P31**	**P32**	**P33**	**C31**	**C32**	**C33**	**CP31**	**CP32**	**CP33**
1	126	113	106	65	57	56	85	85	50	92	85	76	60	50	35	52	39	33
2	121	111	107	63	56	58	86	83	50	89	83	77	62	52	38	50	35	36
3	122	112	103	62	56	56	88	88	51	91	88	78	63	38	37	52	50	35
3	119	117	106	67	58	57	90	87	55	93	92	78	60	51	35	39	38	33
5	121	116	109	68	60	52	82	83	53	88	95	79	65	35	52	50	52	36
6	123	109	111	65	55	57	85	83	52	87	83	80	62	38	36	38	51	36
Average	***122***	***113***	***107***	***65***	***57***	***56***	***86***	***85***	***52***	***90***	***88***	***78***	***62***	***44***	***39***	***47***	***44***	***35***

Table 3. Wicking height (mm)

Groups	F	P-value	F crit
P21-C21-CP21	812.935	5.1E-16	3.682
P31-C31-CP31	166.751	5.68E-11	3.682
P22-C22-CP22	812.601	5.12E-16	3.682
P32-C32-CP32	79.571	1.03E-08	3.682
P23-C23-CP23	1077.283	6.28E-17	3.682
P33-C33-CP33	217.260	8.42E-12	3.682

Table 4. ANOVA results for the effect of fiber type on wickability

No	Comparison Groups	P-value (T test)	No.	Comparison Groups	P-value (T test)
1	P21-C21	1.25E-12	**4**	P22-C22	2.07E-10
	P21-CP21	5.25E-08		P22-CP22	1.96E-08
	C21-CP21	3.21E-10		C22-CP22	3.80E-10
2	P31-C31	6.44E-10	**5**	P32-C32	1.03E-06
	P31-CP31	5.05E-06		P32-CP32	9.50E-07
	C31-CP31	0.00156		C32-CP32	0.97083
3	P23-C23	4.80E-11	**6**	P33-C33	3.01E-05
	P23-CP23	1.86E-11		P33-CP33	1.74E-13
	C23-CP23	0.00508		C33-CP33	0.195

Table 5. Post-hoc test for the effect of fiber type on wickability

Groups	F	P-value	F crit
P21-P22-P23	35.804	3.10E-07	3.682
P31-P32-P33	25.833	1.38E-05	3.682
C21-C22-C23	33.219	2.57E-06	3.682
C31-C32-C33	69.381	2.63E-08	3.682
CP21-CP22-CP23	310.854	7.97E-13	3.682
CP31-CP32-CP33	13.081	0.000515	3.682

Table 6. ANOVA results for the effect of twist factor on wickability

No.	Comparison Groups	P-value (T test)	No.	Comparison Groups	P-value (T test)
1	P21-P22	0.00028	**4**	P31-P32	0.3754
	P21-P23	7.17E-07		P31-P32	5.24E-06
	P22-P23	0.00396		P32-P32	0.00225
2	C21-C22	8.26E-05	**5**	C31-C32	0.0015
	C21-C23	3.24E-05		C31-C33	0.00016
	C22-C23	0.39513		C32-C33	0.24159
3	CP21-CP22	0.3974	**6**	CP31-CP32	0.32861
	CP21-CP23	1.78E-09		CP31-CP33	0.00016
	CP22-CP23	1.03E-10		CP32-CP33	0.00804

Table 7. Post-hoc test for the effect of the twist factor on wickability

4.2. Results of Statistical analysis of tested parameters

4.2.1. Studying the effect of fiber type

ANOVA results show the significant effect of fiber type on the output wicking values according to the P-values shown in Table 4 for the groups compared at constant levels of twist and doubling. By comparing Bonferroni Alpha (0.016667) to the P-value- 2 tail (T test) of each group, shown in table (5), it is clear that fiber type has a significant effect for all tested groups, except groups (C32-CP32) and (C33-CP33), as the wicking heights changed imperceptibly.

4.2.2. Studying the effect of TF

ANOVA results show the significant effect of twist factor on the output wicking values according to the P-values shown in Table 6 for the groups compared with a constant fiber type and doubling level. For the data shown in Table 7, the significance of the effect of tested parameters is evaluated by comparing Bonferroni Alpha (0.016667) to the P-value- 2 tail (T test) of each group according to the planned comparison groups. However, for samples (P31-P32), (C22-C23), (CP21-CP22), (C32-C33), and (CP31-CP32), the comparison test of the influence of the twist factor is non-significant. This result was due to the effect of the interaction of the fibre type, doubling level, twist level impact yarn structure, porosity, and wickability. As a result, comparing using the Post-hoc test shows the actual variation between tested samples.

4.2.3. Studying the effect of doubling

The P-value outcomes shown in Table 8 display the overall significant effect of the doubling factor on the output wicking values for the groups of same fiber type compared at a constant twist level. By comparing p-values of the T test with

No.	Comparison Groups	P-value (T test)
1	P21 -P31	2.90E-06
	P22-P32	2.69E-06
	P23-P33	5.24E-07
2	C21 -C31	0.04836
	C22-C32	0.01172
	C23-C33	0.00423
3	CP21 -CP31	6.60E-05
	CP22-CP32	6.30E-05
	CP23-CP33	2.00E-05

Table 8. Post-hoc test for the effect of doubling on wickability

Bonferroni Alfa (0.05), it is clear that the doubling has actual significant effect on yarn wickability, since increasing the number of ply yarns decreases the yarn wicking height, due to less porosity in all tested samples of a certain fiber type and constant TF.

5. Conclusions

This study introduced a wicking height testing procedure for ring spun yarn produced from three levels of fibre types at three twist levels and two levels of ply yarns. This paper developed a new statistical analysis by comparing Bonferroni Alpha with P-values of the T-test to determine the significance of the effect of studied parameters on wicking performance. The Post-hoc test presented precisely the variation between groups, which is not clear when using ANOVA. Additionally, these comparisons showed the actual significant impact of the all tested factors on the output wicking values, where wicking performance is affected by the interaction of the fiber type, doubling level and twist level. The findings indicated that the higher the polyester percentage, the greater the wickability. Moreover, plying parameters have a negative strong impact on yarn wickability. In conclusion, it is recommended to increase polyester percentage in the blend ratio with a low twist factor and fewer ply yarns in order to improve the yarn wicking performance.

Declaration of Conflicting Interests

Author declares there is no conflict of interest.

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