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Research article

Assessment of the effects of the use of preconsumer cotton waste on the quality of rotor yarns

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ABSTRACT

Due to the shortage of raw fiber materials and stricter legislative conditions, it has become necessary to process even the more contaminated fiber wastes that contain only a small amount of useable fibers. Hence, this paper investigates the impact of different cleaning channels on the Rieter R37 rotor spinning machine in controlling spinning strategy and yarn quality using recovered blowroom cotton waste fibers. The study involves spinning 98-tex yarns with different cleaning channels during the spinning process, using recovered blowroom cotton waste in blends with virgin cotton processed into slivers by two methods. Qualitative indicators in the fiber-sliver-yarn line were evaluated and graphically compared. The statistical significance of the influencing factors was determined using the Generalized Anova. Additionally, the quality of the experimental samples was compared to authentic data from global production using the USTER® STATISTIC. The results underline the significant influence of fiber quality, sliver preparation method and implemented cleaning channels on the arrangement of fibers in yarn structures as evidenced by structural and mechanical parameters. In particular, the comparison with USTER® STATISTICS confirms that all yarns meet the required quality standards for selected applications, including those spun exclusively from 100 % cotton waste. Furthermore, the results demonstrate that this innovative technology enables yarn manufacturers to meet customer demands, ensure optimal yarn quality and achieve cost savings by optimizing waste removal without compromising fiber yield.

1. Introduction

The importance of recovering cotton fibers from pre and post-production cotton wastes for reuse in yarns continues to grow in line with the increasing demand for cotton yarns and the inability to meet the increased demand for cotton fibers in their entirety from natural resources, what has been proven in many scientific articles. Current studies oriented on potential areas of improvement in textile recycling and the evaluation of their impact on the textile industry from ecological and economic perspectives have been published previously [1,2,3,4,5]. These studies also emphasized the need for repeated processing or minimization of all waste types.

The innovative rotor spinning machine Rieter R37 makes it possible to influence the cleaning and extraction of waste in the production of yarn from lower quality and potentially more contaminated raw material. In order to understand better how this technology affects the quality of yarns, the bibliography and the industrial research were realized and important findings follow.

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1.1. Quality of cotton waste versus quality of yarn and final product - bibliography search

Preproduction and postproduction cotton wastes differ from virgin cotton mainly in terms of length parameters (mean length, upper half mean length, and short fiber content) its variability and mechanical parameters, and potential level of contamination (e.g., amount of dust, trash, leaves, and seed coat fragments) [6,7,8,9,10,11]. Cotton fibers recovered from preconsumer cotton waste can be adopted more easily in many spinning mills [2,6]. This is because of their low level of cyclic loading during processing and reopening from textile structures and as they experience no wearing in previous live cycles in the form of final products due to use and maintenance, resulting in good-quality cotton fibers. Another invaluable benefit of preconsumer cotton waste is the knowledge of its material composition and all technological stages leading to its generation, which simplifies the setup and implementation of the mechanical method of fiber recovery for spinning [8]. The quality of reopened fibers from preconsumer waste is influenced by fabric structure and the technology settings (number of reopening cycles, size of shaded scraps) as it is proved in Refs. [7,10–12]. Ichim and Sava evaluated spin ability of reopened cotton fibers from textile scraps of 20 %, 40 % and 60 % waste ratio by rotor spinning of count 25 tex, 29 tex and 37 tex and found out that the amount of waste significantly influenced parameters of yarns [7]. Ütebay et al. found that as the number of passages increased, the short fiber content in recycled fibers decreased, but no effect on the yarn properties was observed. It was mentioned that the rotor yarn of 29.5 tex properties deteriorated when the number of opening passages exceeded [10]. Wanassi et al. present that not only the speed of opening roller but also the rotor speed influence the quality of rotor yarn made of recycled cotton fibers and the optimal quality of recycled fibers can be obtained after 7th passage [12].

Krifa et al. concentrated to the study of the seed coat fragments impact on ring yarn of 20 tex, 27 tex and 37 tex on yarn quality. Their findings confirmed that the size and occurrence of seed coat fragments significantly negatively influence the unevenness, number of faults and strength of yarn. Moreover, they mentioned interactions of quality of fibers and fiber contamination on yarn quality [13,14]. Likewise, Jones et al. studied how seed coat neps can be effectively removed during carding from cotton to get relevant quality of yarn and verified that remaining seed coat neps caused mainly the increase of faults of 20 tex, 27 tex and 37 tex ring yarns [15]. The deterioration of unevenness and tenacity due to shorter fiber length is referred and evaluated for the 100 % cotton ring yarn of count from 10 tex to 27 tex e. g. in Refs. [16,17,18].

1.2. Impact of reused fibers and spinning line setting on quality of yarn - bibliography search

Several studies dealt with the impact of rotor spinning line setting and cotton waste reuse, for instance, from the perspective of fiber blending. Klein showed how the waste was generated during spinning processes, how differed in its quality and could be reused [8,19].

Halimi et al. as well as Hasani et al. studied the impact of waste fiber blending (spinning mill cotton waste ratio from 0 % to 100 %; ginning cotton waste ratios 35 %, 50 %, 65 %) and various rotor spinning setting on the quality of cotton yarn (count range 29.5tex - 100 tex) [9,20–22]. They concluded that the deterioration of yarn quality increased as the waste portion increased in unevenness, number of faults. Furthermore, they proved that the waste portion as well as the rotor spinning settings are significant factors influencing the quality of resulting yarns.

Additionally, Kaplan and Göktepe investigated how navel type affects the quality of 49 tex cotton yarn made of spinning mill waste [23]. They pointed out that using smooth steel and spiral navel leads to better quality of yarn. Duru et al. proved that a suitable range of opening roller speed provided an effective degree of cleaning, but the increase of opening roller speed influenced negatively strength and positively unevenness and hairiness of yarn [24]. Also Repon et al. referred, that the increase of rotor speed leads to decrease of cotton yarn faults for the yarn of 45 tex spun from 35 % of spinning mill waste [25].

Ute and Celik [26] investigated how the quality of various type of cotton waste from spinning mill influence the rotor yarns of 29.5tex made from it in waste ratios 10 %, 30 % and 50 % and concluded that the blowroom and card waste differs in the tendency of trash cleaning resulting in worse quality of yarn (worse hairiness, tenacity and number of thick and thin places). Similarly, Yilmaz et al. reported that blowroom and flat stripes cotton waste mixed with virgin cotton in blends from 0 % to 40 % affected negatively the hairiness and the number of neps of ring and rotor yarn [27].

1.3. Objectives

The investigation of bibliographic sources and surveys conducted in spinning mills, mainly in India, China, and Turkey, reveals the crucial significance of the philosophy that determines the preparation and cleaning of the fiber material in the yarn production process, especially when dealing with recycled fibers. Spinners typically use two strategies for producing yarn from fiber blends.

The first strategy aims to produce high-quality yarns that are suitable for various applications. This approach requires high-quality semi-finished products at each technological step, emphasizing well-oriented sliver structures with adequate fiber quality, consistency, and minimal unevenness for processing on rotor spinning machines. In terms of cleaning, it is preferable to completely remove impurities during the fiber preparation stage and spinning process rather than maximizing fiber yield.

On the other hand, the second spinning strategy involves processing fibrous materials to produce yarns that are tailored for a specific end purpose and prioritize fiber yield over impurity exclusion, resulting in the minimization of the elimination of good fibers. However, this approach may lead to a decline in yarn quality, especially in terms of unevenness, fault count, hairiness, and mechanical parameters. Yarns produced under this strategy may have a rustic appearance due to remaining dust and seed coat fragments, which requires careful consideration in subsequent technological steps.

Therefore, this article concentrated on an assessment of the effect of using cotton waste on the quality of rotor yarns produced on the innovative rotor spinning machine Rieter R37, offering a selection of cleaning strategies. Its motivation was to prove whether the selection of cleaning channels on the spinning unit of the Rieter R 37 rotor spinning machine leads to various yarn qualities and various trash exclusions during spinning. The purpose of this article is not to describe the technology and its advantages, but rather to describe the effect of this technology on the quality of the yarn.

It is uneasy to compare and summarize the results from the published articles due to the fact that influencing factors interact (length and contamination of fibrous material, used technology of fiber preparation and the setting of whole spinning line, construction parameters of yarns and selected final application for yarns). In many cases, the information about quality of fibrous material omitted the level of contamination, which can be crucial factor for the cotton waste from blowroom cleaners or ginning cotton waste. Moreover, the information about the contamination for every component before blending and sliver preparation is defined. It is well known that during the preparation of sliver through the processes of blending and mixing, carding and possibly doubling and drawing the major part of impurities is removed as well as the part of fibers with suitable quality to be formed into yarn. To be able to examine the amount of waste exclusion exactly and only during rotor spinning a two-step experiment was carried out. Firstly, the impact of the percentage of the used preconsumer cotton waste from 0 % to 100 % on rotor yarn quality was evaluated and next the way of sliver preparation and the used way of cleaning during spinning were evaluated. The percentage of trash excluded during spinning in relation to the proceeding fiber blend was analyzed as well. But in this case, the selected qualitative parameters were evaluated for fibrous material blends selected from slivers and for rotor yarns spun from them to extend and precise our knowledge from existing research published in the articles cited earlier. The level of contamination of fiber blends formed to sliver was compared with the level of contamination of rotor yarns, and the amount of fibers released during a yarn-on-yarn abrasion test was examined together with the number of cycles to yarn destruction caused by cyclic friction (leading to yarn abrasion) to specify how easy the shorter fibers are removed from yarn structure.

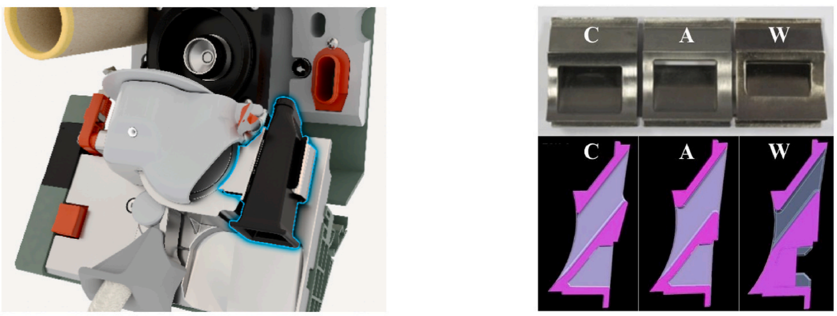
The difficulties when rotor yarns spun from waste are used for the production of areal textiles and further implemented in final products include the following: increased cotton dust level in the air during processing by weaving or knitting, together with a higher number of end breaks (causing impaired workability); troubles with uniformity of product staining related to an increased number of yarn faults given mainly by fiber neps or the presence of vegetable impurities incorporated to the yarn structure; and increased wear rate of the final product due to the easy release of fibers during use. The exact specification of used materials and methodologies follow together with results and discussion.

2. Materials and methods

The results of other scientific team showed that the amount of preconsumer spinning mill waste portion due to its lower quality and higher contamination leads to deterioration of yarn quality. The possibility of influencing the rate of trash removal is possible through the appropriate choice of the speed of the opening roller, which must be in balance with the rotor and delivery speed. The optimal range for it is technically limited and very sensitive to the length parameters of fibrous material. Also, all settings must be adjusted to match the underpressure setting to ensure that the waste is optimally extracted. First trials have been carried out by the innovated rotor spinning machine R37 and it was found, that using of various cleaning channels together with construction parameters of yarn can be used to get optimal quality of yarns for the 29.5 tex and 98 tex rotor yarns most commonly offered on the market e.g. Ref. [28,29].

2.1. Fiber preparation and spinning of rotor yarns

The innovative rotor spinning machine Rieter R 37 allows the selection of spinning strategies thanks to the changing of cleaning channels in the spinning unit. Three types of cleaning channels (A, C, and W), which differed mainly in terms of their profile, geometry and potentially surface treatment, could be used for yarn production (Fig. 1). Due to its geometry, the A channel should remove the highest amount of waste from the processed fiber material. Conversely, the W channel should allow the lowest quality fiber to be incorporated into the yarn structure with minimal waste removal during spinning. To gain a better understanding of how trash is removed through these cleaning channels during yarn production on the Rieter R 37 rotor spinning machine and how this affects yarn



a) Spinning unit b) Types of cleaning channels (C, A, and W) – front planes and side cross sections

Fig. 1. Rotor spinning machine Rieter R 37.

quality, the experiment was conducted in two steps. Firstly, yarns were spun from slivers prepared in the classical way (including doubling and drawing processes) and containing different proportions of cotton waste through the cleaning channel A. It can give us an idea how various fiber blends affect the quality of rotor yarns and how large is the amount of trash eliminated during spinning as an upper limit for the first spinning strategy (the production of excellent quality yarn for a wide range of applications). Various fibers blends from 0 % to 100 % of preproduction cotton waste (mixture of blowroom cleaners, flat stripes, and sliver remains) with virgin cotton in relevant portions were well mass blended on a mixer and then fed to a carding machine for the preparation of the same sliver count. Herein, the production of yarn was realized with the same machine settings to eliminate other factors, which can influence the results. The yarn count of 98 tex together and a twist of 421 m^{-1} were selected with respect to final use, where we expected that these yarns would be used as weft yarns for weaving (home textile, linen, and denim fabrics).

Subsequently, the second strategy (the production of yarn having optimal quality for specific final application) was verified. The only blends of 100 % preproduction cotton waste (mixture of blowroom cleaners, flat stripes, and sliver remains) were used for production of rotor yarn trough cleaning channel A, C and W. Fibers recovered from blowroom cleaners' waste usually have shorter lengths with high variability in comparison with virgin cotton, and the preparation of optimally consistent slivers only from waste can be problematic because of flouting fibers resulting in higher sliver unevenness. This phenomenon can be intensified by the repeating of doubling and drawing passages of slivers. Therefore, slivers for the second step of experiment made of 100 % preproduction cotton waste is drawn and processed by an integrated draw frame on a carding machine only (later "IDF technology"). The advantage is that the obtained data can be compared with the yarn made of 100 % preproduction cotton waste spun trough A cleaning channel from sliver, which was doubled and drawn (experiment step 1: yarn having 0 amount of virgin cotton in Table 1).

The technological specifications of the fiber blend, sliver preparation, and spinning parameters of the rotor spinning machine Rieter R37 for yarn production are summarized in Table 1.

2.2. Measurements of the fiber and yarn quality

The typical set of yarn qualitative parameters in terms of structure and mechanical indicators in line fiber–sliver–yarn were measured to evaluate the impact of the quality of fibrous materials, the way of sliver preparation, and the used cleaning channel during spinning on yarn quality. The recovered fibers from blowroom cleaners were typically highly contaminated and had relatively short fiber lengths and great variability. Thus, it was impossible to proceed with all components of cotton fiber wastes having their own specifications. Therefore, the quality of the fibrous materials was examined from all types of already prepared slivers using USTER AFIS® PRO and Tresh Tester 1000 Hollingsworth. In addition, an accurate idea of the changes in contamination from the sliver to the rotor yarn is available in terms of fiber yield and waste removal. The yarns were examined through computer tomography scanning on RIGAKU nano 3DX with a resolution of 0.5 μm, voltage of 20–50 kV, and electrical current of 30 mA to determine the distribution of trash and dust particles in the yarn structures.

The sliver quality was specified by measuring its unevenness CV_m using USTER® TESTER 5 and the yarn unevenness CV_m, the number of faults (*Thin − 40 %*, *Thin − 50 %*, *Thick + 35 %*, *Thick + 50 %*, *Neps + 200 %*, and *Neps + 280 %*), and yarn hairiness index H, together with the amount of *Trash* and *Dust counts* in yarns (sliver testing: testing speed 25 m min^{-1} and testing sliver length of 125 m; yarn testing condition: testing speed of 400 m min^{-1} and testing length of 1 km for each bobbin, 5 ×). The summation criteria of yarn hairiness S_{12} and S_3 were analyzed using ZWEIGLE G 567 (testing speed of 50 m min^{-1} and testing length of 100 m, 5 ×). The mechanical parameters in terms of yarn tenacity F and yarn breaking elongation ε were measured using an INSTRON TESTER (pretension of 0.5 $cNtex^{-1}$, testing speed of 500 mm min^{-1}, and testing length of 500 mm, 50 ×).

The yarn abrasion resistance and lint generation were measured to check whether the yarns made from fibers with shorter lengths with greater variability were easily destroyed by mechanical friction and released more fiber segments from the surface. The yarn abrasion resistance was realized using ZWEIGLE 552 (emery paper P 800, the type of abrasive grains alpha Al_2O_3, and pretension of 20 g, 60 ×), where an abrasion roller covered with abrasion material traversed in a constant rhythmic motion and constant velocity at right angles to the direction in a 15-cm range, where the tested threads were tensioned. The abrasion roller continuously rotated about

Table 1
Technological specifications of the fiber blend, sliver preparation, and spinning parameters of the rotor spinning machine Rieter R37 for yarn production.

Experiment	Step 1					Step 2		
Amount of virgin cotton [−]	**0**	**0.25**	**0.5**	**0.75**	**1**	**0**	**0**	**0**
Sliver preparation	**Classical doubling and drawing**					**IDF (integrated draw frame)**		
Cleaning channel	**A**					**A**	**C**	**W**
Sliver count T_s [tex]	5850					5850		
Nominal yarn count T_n [tex]/*Ne*	98/6					98/6		
Rotor *RPM* [min^{-1}]	70 000					70 000		
Opening roller *RPM* [min^{-1}]	9500					9500		
Draft	59					59		
Delivery speed [m min^{-1}]	164.7					164.7		
Rotor type/nozzle type	S341/UD/S-KS					S341/UD/S-KS		
Machine twist Z_n [m^{-1}]	425					425		

its own axis, and the relative yarn abrasion resistance was expressed as the number of strokes to yarn destruction per tex. The lint generation was measured using Lawson Hemphill Constant Tension Transport (testing speed of 100 m min^{-1}, input pretension of yarn 0.5 g tex^{-1}, yarn-to-yarn wrapping angle of 540°, and tested yarn length of 1000 m). The amount of separated abraded lint from a 1-km-long yarn section of the wrapped yarns was evaluated.

2.3. Formulation of assumptions and expectations

Thanks to information mentioned in previous text certain assumptions are made:

2.3.1. Experiment - step 1

✓ The blending of virgin cotton and preconsumer spinning waste can result in different quality of fiber material with different length parameters and contamination.
✓ The production of sliver with optimal consistency by classical drawing and drafting can be more problematic when the input material contains a higher proportion of waste and is highly contaminated for a final yarn count of 98 tex, where the lower sliver count is usually used in comparison with sliver used for example for yarn 29.5 tex.
✓ The production of rotor yarn from different waste ratios by cleaning channel A can show the upper limit of waste extraction during spinning and verify first strategy when the yarn quality is required to be as excellent as possible.
✓ In addition, the effect of fiber length parameters and sliver contamination level on rotor yarn quality can be investigated.
✓ The cleaning channel A in comparison to the cleaning channels C and W can cause the extraction of a higher amount of waste during spinning and it can be seen in the lower level of contamination of rotor yarn.
✓ The increased deterioration of rotor yarn quality can be expected when yarns are spun from fibrous material with higher waste content. The yarn unevenness, the number of faults and the level of yarn contamination may increase and the mechanical parameters may decrease.
✓ Comparison with previous experiments and extension of knowledge of the effect of fiber quality, including contamination, on the quality of 98 tex rotor yarn for selected applications.

2.3.2. Experiment - step 2

✓ Processing of cotton waste without adding virgin cotton is only possible if the fiber length is sufficient as a bearing component. Slivers made from this fibrous material might be more contaminated and its consistency might be problematic during its preparation.
✓ Preparation of sliver by IDF technology can help with sliver consistency and allow processing of fiber material having lower quality.
✓ The production of rotor yarns from 100 % cotton waste only by cleaning channels A and C can verify the spinning first strategy and implementation of cleaning channel W can verify spinning second strategy, where the worse quality fibrous material can be processed to yarn of optimal quality for a given narrow range of final use in fabric.
✓ The cleaning channel W should extract a lover amount of spinning waste, get better fiber yield what means the saving of input material.

3. Results and discussion

Relevant data are hereby presented in tables, and figures to show the quality of the line fiber–sliver–yarn. Because of the limited length of the article, some of the data are presented as an appendix. The description of yarn data in figures is marked with respect to the way of sliver preparation and the used cleaning channel during spinning.

Table 2
Quality of cotton fiber blends based on the measurements of samples selected from slivers.

Amount of virgin cotton [−]	0	0.25	0.5	0.75	1	0
Sliver preparation	Classical doubling and drawing					IDF
$L_{(w)}$ [mm]	21	21.7	22.7	23.1	23.6	20.8
$UQL_{(w)}$ [mm]	26.9	27.6	28.5	29.0	29.3	26.2
$SFC_{(w)} < 12.7$ [%]	17.2	15.0	12.2	11.3	9.8	16.1
$L_{(n)}$ [mm]	16.1	17	18.1	18.7	19.6	16.2
$SFC_{(n)} < 12.7$ [%]	38.2	34.7	30.0	28.1	24.1	36.3
Neps [Cnt g^{-1}]	412	289	196	138	74	429
Dust [Cnt g^{-1}]	1004	711	486	350	146	974
Trash [Cnt g^{-1}]	122	92	50	32	9	133

3.1. Quality of fiber blends

The evaluation of the quality of fibers taken from slivers showed that with the increasing proportion of virgin cotton, the fiber length ($L_{(w)}$, $UQL_{(w)}$, and $L_{(n)}$) increased, whereas the proportion of short fiber content ($SFC_{(w)}$ and $SFC_{(n)}$) and the number of *Neps*, *Dust*, and *Trash* particles decreased (Table 2). Moreover, the quality of fibers selected from the sliver that consisted only of 100 % cotton waste prepared using classical means was a bit better than the quality of the fibers selected from the sliver prepared by IDF. This might have been due to the high variability of fiber quality obtained repeatedly from cotton waste.

3.2. Quality of rotor yarns

The data had to be recalculated with respect to the yarn count to allow comparing sliver and yarn contaminations. The graphical comparison of yarn contamination by trash and dust particles and the recalculated amount of sliver contamination are shown in Fig. 2 (the classically prepared sliver was marked "sliver rec.," whereas those prepared by IDF were marked "sliver IDF rec."). Apparently, the amount of trash and dust decreased as the amount of blending portion of virgin cotton increased. The amount of contamination in the sliver was orders of magnitude higher than that in the yarn. The contamination of the sliver processed using IDF technology was a bit higher in terms of trash particles and more or less similar in terms of dust if compared with the sliver processed classically. This might have been because some particles not fixed in the sliver structure were loosened by manipulation during the doubling and drawing processes, which were shorted here. From earlier experience, most fragile plant impurities are crushed upon their passage through guiding eyelets or upon contact with the working parts of weaving or knitting machines and partially or completely released from the structure during the rewinding of yarns and their processing into fabrics.

The analysis of yarn cross-sections scanned using computed tomography validated that small dust particles, as well as plant impurities, were placed randomly in the whole volume of yarns. Sample plant impurities fixed on the yarn surface and dust particles inside the yarn structure are shown in Fig. 3. Relevant yarn cross-sections with 3D visualization are displayed. The yarn cross-section perpendicular to the *z*-axis (yarn axis direction) was, for the presentation, proportionally enlarged identically to the detail of the seed coat fragment fixed on the yarn surface in 3D visualization. Examples of dust particles inside the yarn and the seed coat fragment particle fixed close to the yarn surface were marked by red color (Fig. 3a–e). The measurement techniques used to determine yarn contamination provided information on the presence of impurities only on the surface of the yarn. The separation of impurities or their parts probably occurred mainly on or near the yarn surface because of the cohesive arrangement of fibers in the yarn structure caused by twists and frictional contacts between fibers and impurities.

The *Trash count* and *Dust count* results for the yarn spun with cleaning channel A had the lowest contamination, followed by the yarns spun with cleaning channels C and W. The contamination of the yarn from the sliver processed by IDF from 100 % cotton waste

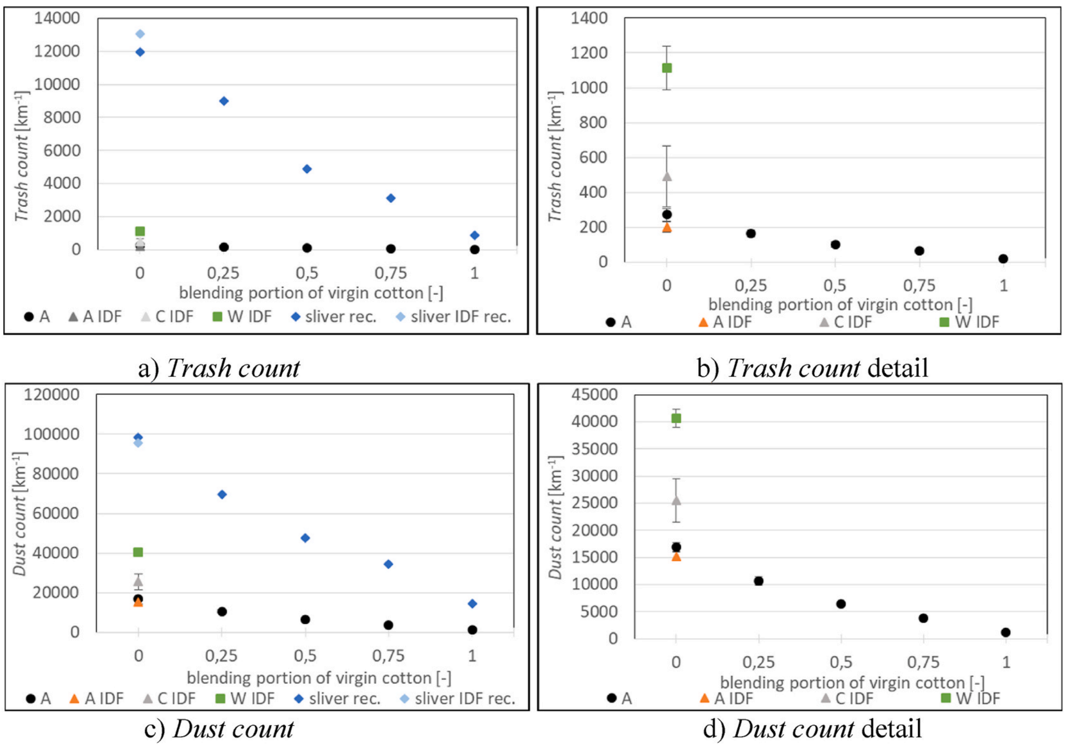


Fig. 2. Contamination of yarns and slivers by trash and dust particles.

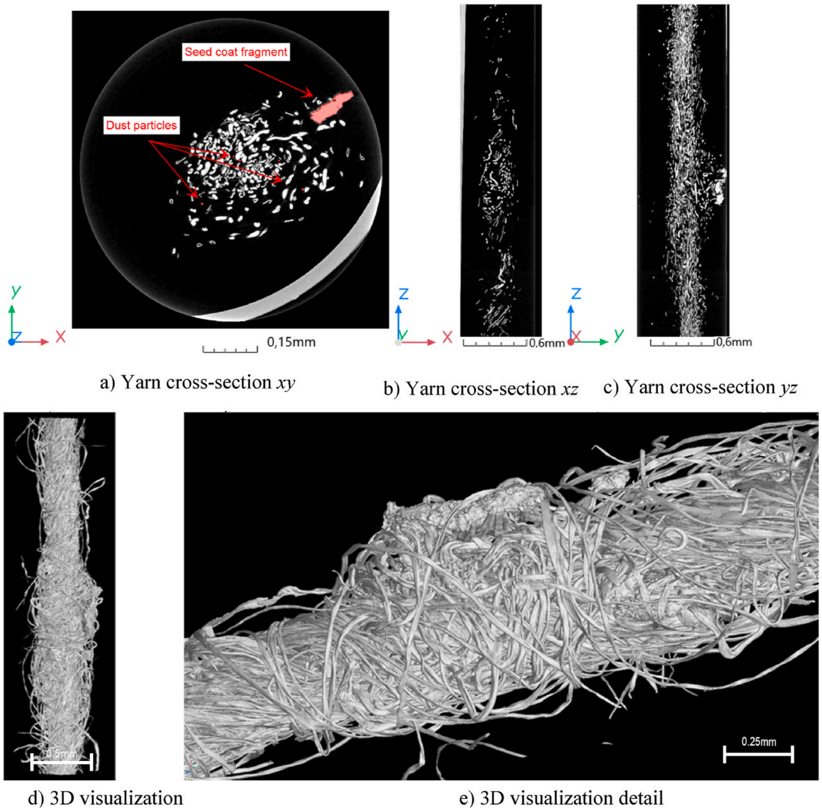


Fig. 3. Examples of impurities fixed in yarn structures scanned using computed tomography—presentation of cross-sections in the *xyz* coordinate space and 3D visualization.

spun with cleaning channel A was slightly better than those of the other channels, but the difference was hidden in overlapping confidence intervals. The amount of excluded trash during spinning agreed well with these results (Fig. 4, Appendix). The amount of *Trash exclusion* during rotor spinning by cleaning channel A decreases as the portion of virgin cotton increases when comparing the processing of slivers prepared in the classical way. Furthermore, the comparison of *Trash exclusion* during rotor spinning by cleaning channel A (*Trash exclusion* 4 %) and W (*Trash exclusion* 0,5 %) from slivers prepared by IDF technology showed the potential of fibrous material savings in the amount of 3,5 %. In spite of the less quality of fibrous material, both fibers and plant contamination are incorporated into the yarn structure. The amount of waste of spinning is reduced but yarn quality can be deteriorated. The using of cleaning channel C leads to *Thrash exclusion* in amount of 2 % so it reduced the saving of material to the level of 1.5 % in comparison with cleaning channel W but potentially allow to get better yarn quality.

A comparison of yarn quality in terms of the fiber arrangement level is presented in Fig. 5 and in form of table in the Appendix. The experimental results show that the unevenness in the sliver prepared classically tended to improve as the blending portion of virgin

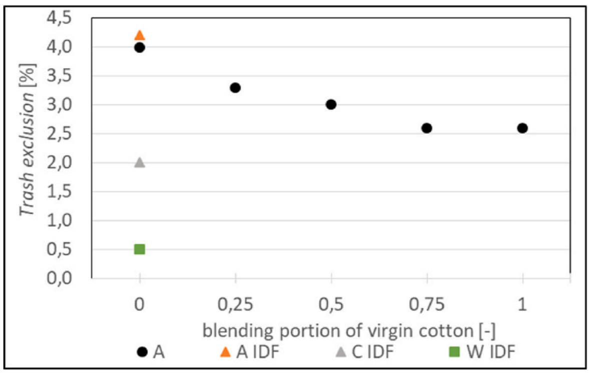


Fig. 4. Trash exclusion during rotor spinning.

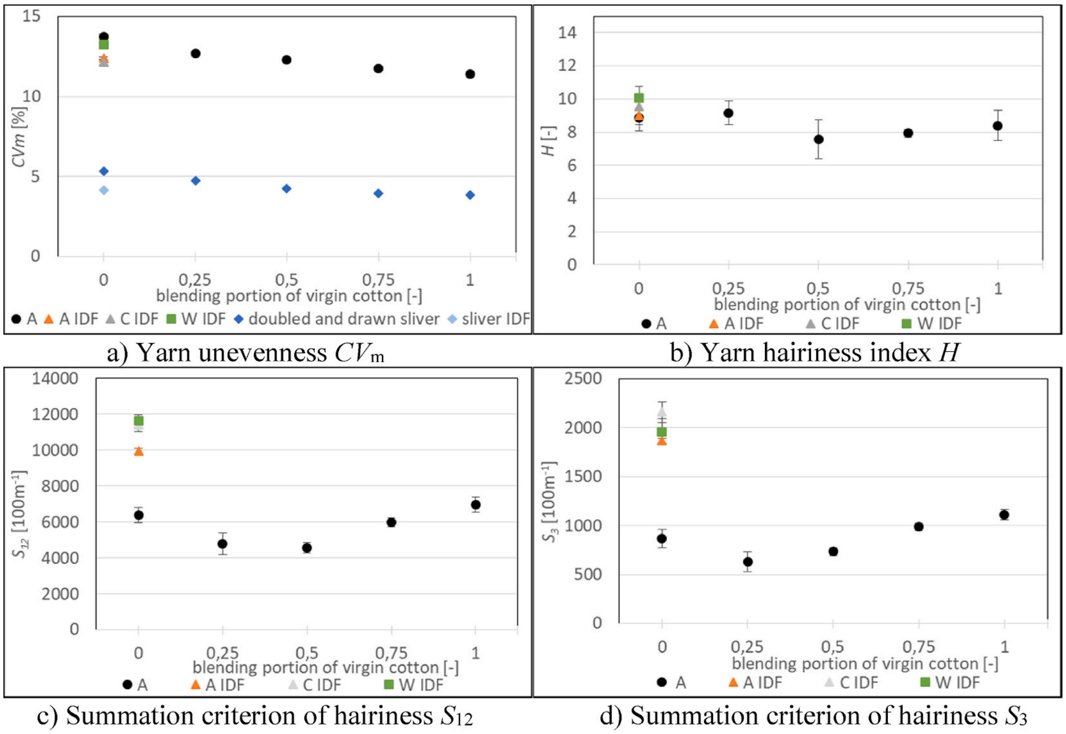


Fig. 5. Comparison of yarn quality in terms of the level of fiber arrangement.

cotton increased. The yarn unevenness spun from this sliver with cleaning channel A followed the same trend. Meanwhile, the sliver prepared by IDF showed a better unevenness than that of the sliver prepared classically from 100 % cotton waste, which might have been due to the reduced influence of floating fibers. Yarns produced using the rotor spinning technology with the implemented cleaning channels A and C from the sliver prepared by IDF from 100 % cotton waste showed good yarn unevenness. Moreover, very similar results were obtained when the yarns were spun using cleaning channel W from the sliver prepared by IDF compared with yarns produced with cleaning channel A from the sliver prepared classically from 100 % cotton waste.

The trends of the hairiness index and summation criteria in relation to the increasing proportion of virgin cotton were not evident. Yarns spun from 100 % cotton waste from the sliver prepared by IDF with cleaning channels A, C, and W showed higher hairiness (H, S_{12}, S_3) than the yarns produced from 100 % cotton waste from the sliver prepared classically. The reason might be hidden in the lower parallelization of fibers in the sliver given by higher amounts of short fibers, trash, and dust due to the shortening of sliver preparation and skipping of sliver doubling (using IDF technology).

Table 3
Number of yarn faults.

Experiment	Step 1					Step 2		
Amount of virgin cotton [−]	0	0.25	0.5	0.75	1	0	0	0
Sliver preparation	**Classical doubling and drawing**					**IDF**		
Cleaning channel	**A**					**A**	**C**	**W**
***T* [tex]**	**98,3**							
***Z* [m^{-1}]**	**425**							
$T_{exp.}$ [tex]	97.40 (94.66; 100.14)	98.80 (97.16; 100.4)	97.85 (96.62; 99.08)	97.95 (97.27; 98.64)	98.15 (97.19; 99.11)	92.05 (91.37; 92.74)	92.60 (92.05; 93.15)	96.35 (94.30; 98.41)
Thin − 40 % [km^{-1}]	73.6	36.4	25.8	14.2	8.8	32	28	82.8
Thin − 50 % [km^{-1}]	0.4	0.2	0	0	0	0	0	0.4
Thick + 35 % [km^{-1}]	510	293	240.8	178.6	133.8	342.4	271.8	489.4
Thick + 50 % [km^{-1}]	54.8	23.6	14	8.8	4.8	36.6	40.2	36.2
Neps + 200 % [km^{-1}]	163.6	124.4	54.2	36.4	22.2	126.6	128.4	294.6
Neps + 280 % [km^{-1}]	14.4	12.2	3.4	1.2	0.40	14.2	22.4	18.6

The impact of shorter fiber lengths and their variability, the higher content of short fibers in the fiber blend, and the higher level of contamination leading to worse sliver quality are also visible in cases where the number of yarn faults was evaluated with respect to the amount of virgin cotton fiber (Table 3). In addition, yarns from 100 % cotton waste spun from the sliver prepared by IDF using cleaning channel A or channel C had a lower number of faults than that of the yarns spun from 100 % cotton waste from the sliver prepared classically using cleaning channel W.

The mechanical parameters of the yarns are graphically compared in Fig. 6 and in table form in The Appendix. The increasing trend of relative yarn strength with the increasing portion of virgin cotton was apparent. Meanwhile, the influence of the blending portions of virgin cotton in the slivers on yarn elongation was not significant. Interestingly, the yarn spun from 100 % cotton waste from the sliver prepared by IDF with cleaning channel A had relative yarn strength comparable to that of the yarn produced from 100 % cotton waste from the sliver prepared classically with cleaning channels A and C. The only mechanical parameters in terms of relative yarn strength and elongation of yarns made from 100 % cotton waste spun from the sliver processed by IDF with cleaning channel W were a bit lower than the level of mechanical parameters of yarn spun from the sliver prepared classically with cleaning channel A.

The increase in the blending portion of virgin cotton led to a progressive increase in yarn abrasion resistance and a decrease in lint generation amount during the yarn abrasion test (Fig. 7, Appendix). The lower number of cycles to yarn destruction during cyclic loading by friction and higher fiber segments release was obtained when the yarn spun from 100 % cotton waste from the sliver processed by IDF with cleaning channels A, C, and W was compared with the yarn spun from 100 % cotton waste from the sliver processed classically with cleaning channel A (Fig. 7, Appendix). It is in a good accordance with the fact that the fibers with lower length as well as more plant impurities is incorporated to yarn structure due to lower level of trash exclusion by cleaning channels C and W. In other words, yarns marked as A IDF, C IDF, W IDF (Fig. 7) have the higher level of trash count, dust count and worse unevenness and it is caused by lower level of fiber arrangement in yarn structure what allowed fibers to be released from the surface more easily.

3.3. Impact assessment of fiber quality using analysis of variance

Potential effects on selected important qualitative yarn properties are statistically evaluated. A generalized analysis of variance (later "GANOVA") was used because the influencing factors are combinations of qualitative parameters and quantitative numerical values. The linear regression model (1), which allows to evaluate the influence of fixed factors and continuous variables on the response, was used. The overall test of whether the predictors have any influence on the response as well as the source of variability is evaluated. The sum of squares, F-statistics, and p-values for all individual predictors were evaluated as well as the overall results in terms variability measured by sum of squares. The total TSS, explained ESS and residual RSS sum of squares were calculated in respects to (2). GANOVA was applied (1), (2) to prove whether the selected numerical response variable of the yarn characteristics (yarn unevenness CV_m, yarn hairiness expressed as hairiness index H as well as summation criteria S_{12}, S_3 together with mechanical parameter F, ε, abrasion resistance and lint generation) was influenced by qualitative factors (e.g., the way of sliver preparation and the used cleaning channel during rotor spinning) and/or quantitative numeric variables (e.g., waste portion resulting in various fiber qualities defined by the fiber length $L_{(w)}$ and short fiber content $SFC_{(w)}$). The linear regression model with unknown parameters could be used to describe observations Z_i at n_j different levels of the predictor factor X_j and various values of the predictor variable Y_k, where α_0 is the absolute term (overall mean value), α_j is an $(n_j \times 1)$ vector of latent parameters for the jth factor, and β_k is the regression coefficient for the kth variable. A normal distribution with zero mean $\varepsilon \sim N(0,\sigma^2)$ was assumed for the random error ε_{ij} [30].

$$Z = \alpha_0 + \sum_j \alpha_j X_j + \sum_k \beta_k Y_k + \varepsilon, \tag{1}$$

$$TSS = \sum_{i=1}^{n} (Z_i - \overline{Z})^2, ESS = TSS - RSS, RSS = \sum_{i=1}^{n} \left[Z_i - \left(a_0 + \sum_j a_j X_{ij} + \sum_k b_k Y_{ik} \right) \right]. \tag{2}$$

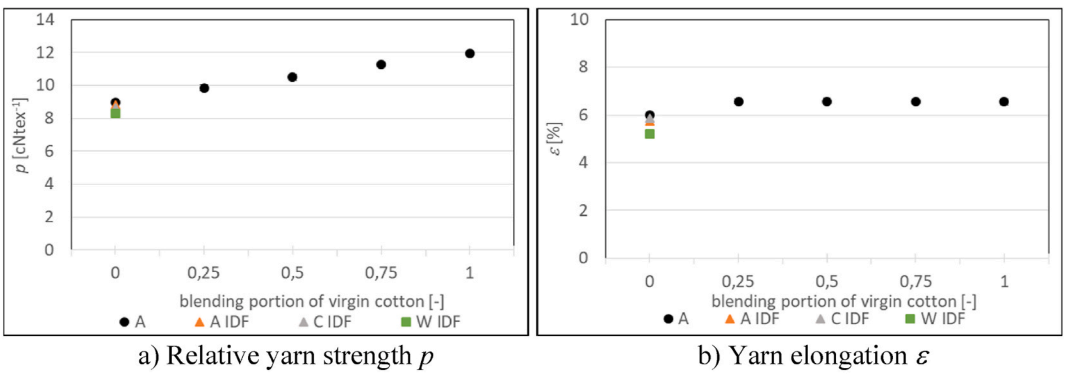
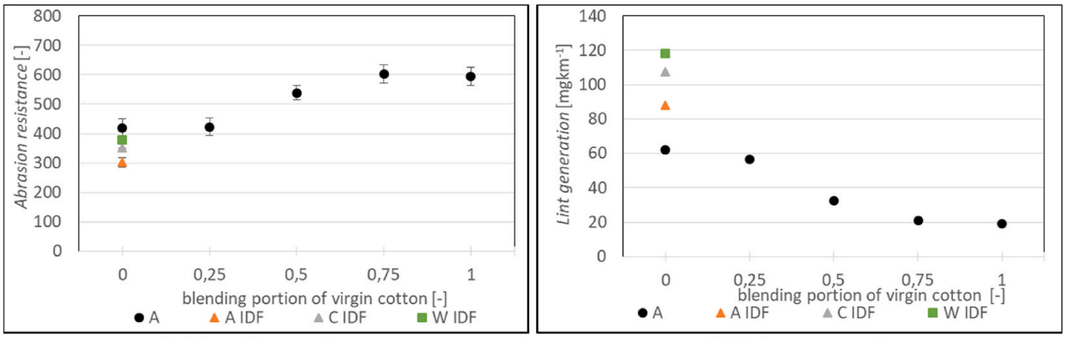


Fig. 6. Mechanical parameters of the yarns.



a) Abrasion resistance b) Lint generation

Fig. 7. Evaluation of yarns in terms of their resistance to frictional stress.

The influence of the selected predictors (type of fiber material blend—five levels; the combination of sliver preparation and used cleaning channel during spinning—four levels) on yarn quality (in terms of CV_m, H, S_{12}, S_3, F, ε, yarn abrasion resistance, and *Lint generation*) was verified by GANOVA at a significance level of $\alpha = 5$ %. Table 4a, b summarizes the results of analysis for individual predictors as well as overall results.

All results of GANOVA have been evaluated and if the *p*-value for an individual predictors is less than the selected significance level of $\alpha = 5$ %, then the factor is statistically significant. Similarly, the model is significant if it explains a satisfactory proportion of the response variability. Statistically significant results are marked in bold in Table 4a, b.

GANOVA confirmed that the short fiber content of $SFC_{(w)}$ in combination with sliver preparation and the used cleaning channel had statistically significant effects on CV_m, H, F, ε, and the abrasion resistance of yarn, fiber length $L_{(w)}$ had a statistically significant effect on the hairiness indices S_{12} and S_3, and the interaction of all factors was significant in the case of *Lint generation*. These results might have been affected by the limited number of yarn samples considered in the experiment. However, the findings suggest that a shortened sliver preparation by IDF can improve the quality of yarns produced from 100 % cotton waste and that the yarn quality can be influenced in a controlled way by the selection of cleaning channels during production on the rotor spinning machine Rieter R 37. All regression models can be considered statistically significant based on the results in Table 4b because they explain a satisfactory proportion of the response variability.

3.4. Yarn quality comparisons with USTER ®STATISTICS

Some diversities among the yarn qualitative indicators were hidden in overlapping confidence intervals. Therefore, the classification of the overall quality of the yarns is provided using USTER ®STATISTICS (2018) [31]. The selected qualitative indicators were evaluated with respect to the following specifications: cotton fibers, carded sliver technology, and rotor-spun yarn for weaving. The conclusion of this evaluation considered that the data in this database were for yarn spun from virgin cotton fibers only and yarns were mostly produced following first strategy, where the excellent quality of all semiproducts and the final quality of yarns for a wide range of applications were preferred. Yarn characteristics were classified using a partial qualitative indicator—the relative cumulative frequency—termed USTER®STATISTICS percentile (later "USP^{TM}"). Generally, the lower the USP^{TM} level, the better the yarn quality. Yarn qualities were graded into six qualitative groups: ≤5, 6–25, 26–50, 51–75, 76–94, and ≥95. The category with the most frequent

Table 4a
GANOVA results for individual predictors.

Predictor	Sum of squares	*F*-statistic	*p*-value	Sum of squares	*F*-statistic	*p*-value
		CV_m [%]			F [cNtex^{-1}]	
$L_{(w)}$ [mm]	0.77	0.31	0.816	7.19	1.79	0.2367771
$SFC_{(w)}$ [%]	**2.11**	**7.58**	**0.028**	**12.28**	**317.39**	**0.0000004**
Sliver preparation and used cleaning channel	**2.71**	**13.90**	**0.007**	**11.47**	**74.87**	**0.0000551**
		H [−]			**ε [%]**	
$L_{(w)}$ [mm]	3.04	2.30	0.165	**1.61**	**8.60**	**0.010**
$SFC_{(w)}$ [%]	**2.95**	**11.17**	**0.012**	**1.20**	**12.86**	**0.009**
Sliver preparation and used cleaning channel	**2.52**	**7.75**	**0.027**	**0.94**	**7.21**	**0.031**
		S_{12} [100 m^{-1}]			***Abrasion resistance* [−]**	
$L_{(w)}$ [mm]	**53809001**	**16.92**	**0.001**	4.91	1.95	0.21068
$SFC_{(w)}$ [%]	23800058	4.86	0.063	**7.64**	**84.21**	**0.00004**
Sliver preparation and used cleaning channel	13980180	2.22	0.180	**6.99**	**38.10**	**0.00046**
		S_3 [100 m^{-1}]			***Lint generation* [mgkm^{-1}]**	
$L_{(w)}$ [mm]	**2425504**	**21.81**	**0.001**	**8701**	**7.26**	**0.015**
$SFC_{(w)}$ [%]	905944	3.80	0.092	**8604**	**35.56**	**0.001**
Sliver preparation and used cleaning channel	474251	1.58	0.249	**6999**	**14.85**	**0.006**

Table 4b
The overall GANOVA results (degree of freedom 7).

Source	Sum of squares	Variance	*F*-statistic	*p*-value	Sum of squares	Variance	*F*-statistic	*p*-value
		CV_m [%]				**F [cNtex^{-1}]**		
TSS	**4.07**	**0.581**			**12.55**	**1.792**		
ESS	**3.95**		**34.61**	**0.00007**	**12.42**		**98.81**	**0.000002**
RSS	**0.12**	**0.017**			**0.13**	**0.018**		
		H [−]				**ε [%]**		
TSS	**4.80**	**0.686**			**1.86**	**0.265**		
ESS	**3.77**		**4.64**	**0.0303**	**1.82**		**45.39**	**0.00003**
RSS	**1.04**	**0.148**			**0.041**	**0.006**		
		S_{12} [100 m^{-1}]				***Abrasion resistance* [−]**		
TSS	**58049191.88**	**8292742**			**8.27**	**1.182**		
ESS	**56634841.74**		**41.04**	**0.00004**	**8.13**		**59.90**	**0.00001**
RSS	**1414350.13**	**202050**			**0.14**	**0.020**		
		S_3 [100 m^{-1}]				***Lint generation* [mgkm^{-1}]**		
TSS	**2573818**	**367688.3**			**10298.07**	**1471.153**		
ESS	**2554839.54**		**135.62**	**0.0000006**	**10269.05**		**354.80**	**0.00000002**
RSS	**18978.46**	**2711.209**			**29.03**	**4.146**		

level of individual USP^{TM} was used to obtain the overall classification $USP^{TM}{}_{\text{overall}}$. If more categories had the same frequency of partial USP^{TM}, the relevant interval for $USP^{TM}{}_{\text{overall}}$ was selected. Table 5 summarizes all information on the individual USP^{TM} and $USP^{TM}{}_{\text{overall}}$ for the analyzed rotor yarns of 98 tex.

From previous experience and information from USTER®STATISTICS, the summation criteria of the hairiness indices S_{12} and S_3 were classified as worse as the older ZWEIGLE instrument gave a higher level of these parameters because of the lower testing speed and various optical sensors incorporated in it in comparison with ZWEIGLE®USTER used for obtaining data for S_{12} and S_3 implemented in USTER®STATISTICS. The classification of yarn mechanical parameters was not realized because of different measurement conditions in terms of the testing speed (a lower testing speed was used in the experiment using an INSTRON tester than that of the data of USTER®STATISTICS with measurements using Uster®Tensorapid or Uster®Tensojet tester), which led to the underestimation of USP^{TM} for yarn tenacity and elongation. An increase in the amount of virgin cotton improved the yarn quality in most of the evaluated qualitative yarn indicators, as reflected in the improvement of the individual USP^{TM} values and the overall yarn assessment by $USP^{TM}{}_{\text{overall}}$. Apparently, the higher portion of repeatedly used fibers with worse quality in terms of fiber length parameters and higher contamination caused more disordered yarn structures in terms of the number of faults, *Trash Count*, and *Dust count*. A comparison of the yarn qualities of yarns spun from standardly prepared slivers and the slivers prepared by IDF technology confirmed that the yarn quality could be significantly influenced by choosing different cleaning channels (A, C, and W). The qualitative parameters were similar in terms of statistics, and most of them differed insignificantly because the differences were hidden in overlapping confidence bounds, as proven above. Meanwhile, they were classified into different qualitative categories of worldwide production. The diversity of the resulting qualitative category could be expected as related to the diversity of the final price of the yarn.

3.5. Comparing of earlier experiments and expectations

The comparison of the results with the previous experiments is limited. The main reasons are the different conditions of the

Table 5
USTER®STATISTICS 2018 USP^{TM} [%] levels for the set of open-end rotor yarns (98 tex).

Experiment	Step 1					Step 2		
Amount of virgin cotton [−]	**0**	**0.25**	**0.5**	**0.75**	**1**	**0**	**0**	**0**
Sliver preparation	**Classical doubling and drawing**					**IDF**		
Cleaning channel	**A**					**A**	**C**	**W**
CV_m [%]	90	60	46	28	15	78	42	78
Thin − 40 % [km^{-1}]	≥95	70	54	31	13	25	59	≥95
Thin − 50 % [km^{-1}]	≤5	≤5	≤5	≤5	≤5	12	≤5	35
Thick + 35 % [km^{-1}]	94	67	55	46	23	76	62	92
Thick + 50 % [km^{-1}]	≥95	74	54	33	8	88	91	88
Neps + 200 % [km^{-1}]	≥95	≥95	80	67	51	≥95	≥95	≥95
Neps + 280 % [km^{-1}]	≥95	≥95	56	19	≤5	≥95	≥95	≥95
H [−]	77	83	39	51	66	79	92	≥95
sh [−]	84	78	47	56	78	63	71	84
S_{12} [1/100 m]	≤5	≤5	≤5	13	24	72	86	77
S_3 [1/100 m]	56	24	19	48	67	≥95	≥95	≥95
Trash count [km^{-1}]	≥95	≥95	≥95	69	≤5	≥95	≥95	≥95
Dust count [km^{-1}]	≥95	≥95	≥95	90	54	≥95	≥95	≥95
$USP^{TM}{}_{\text{overall}}$	**≥95**	**51–95**	**51–75**	**26–50**	**6–25**	**≥95**	**≥95**	**≥95**

experiments in terms of the technology used and its settings, the chosen yarn construction parameters and the purpose of its final use, the different character of the fiber material defined by the quality of individual components before mixing, which changes during the sliver formation process. **The summary of findings can be as follows:**

The decrease of the virgin cotton content in the fiber blends led to the decrease of the fiber quality (worse length parameters, higher amount of short fiber content and higher amount of dust and trash particles or fiber neps). The deterioration of quality of fibrous material led to deterioration of rotor yarn quality, mainly in number of neps, thin and thick places, hairiness as well as mechanical parameters. These experimental results are in a good agreement with previous studies oriented to rotor yarn similar count [20–22,10,9,27] as well as for finer ring yarns [13–17]. Furthermore, as in the case of medium-fine ring yarns, it has been confirmed that the fiber quality and the level of impurities interact and have a significant influence on the quality of the 98 tex rotor yarn [15,13,14] and it has been consistently confirmed in the experiment that a higher level of fibrous neps in the sliver leads to a deterioration in the number of yarn faults, especially in terms of neps +200 % [15]. Unfortunately, it is not possible to make a detailed comparison in terms of contamination in the line of fiber-sliver-yarn, since the articles oriented on rotor yarns do not mention these fiber quality parameters.

In addition, compared to the experiments conducted:

- ✓ The consistency of slivers made solely from cotton waste can be optimized by using IDF technology, which eliminates the doubling process and reduces the potential influence of float fibers. Despite the high contamination of the fibrous raw material in the slivers (blends with only 0 % or 25 % virgin cotton), the IDF technology has succeeded in preparing optimal consistent slivers that can be processed into yarn by rotor spinning. In addition, shortening the sliver preparation process can save production time.
- ✓ The amount of waste in the slivers has a significant effect on the contamination of the yarn by *Dust count* and *Trash count.* The amount of *Trash extraction* during spinning can be affected by using of cleaning channels A, C and W for yarn with excellent quality for wide final application or only optimal quality for narrow end use. Replacing a small segment in the spinning unit can have a significant impact on the entire technology. Competitive solutions require changing many settings or replacing blocks of different parts in the spinning unit to achieve similar abilities. The solution of exchangeable cleaning channels also enables energy savings thanks to the innovation in the mechanical segments and air consumption savings thanks to the specific design of the cleaning channels in terms of their geometry and surface treatment.
- ✓ The implementation of both strategies in spinning mills allows yarn manufacturers to balance the sustainability and the economy of yarn production for different application segments by controlling the level of fiber yield and waste generation on the rotor spinning machine. Although, yarns made from lower quality of fibrous materials, e.g. using exchangeable trash channel W, are marketed for a narrower portfolio of end applications and offered at a lower price.

4. Conclusion

In this study, experiments were conducted to examine the use of new innovative methods of cleaning on the rotor spinning machine Rieter R37 and verify the possibility of spinning strategy selection based on the implementation of various cleaning channels. Moreover, the effects of repeatedly used fibers obtained from preconsumer cotton waste and the way of sliver preparation on the quality of rotor yarns were evaluated. Five various fiber blends with 0%–100 % virgin cotton were processed under the same conditions, and yarns were thereafter produced. The yarn quality was analyzed in the line fiber–sliver–yarn, and the results were statically processed using GANOVA and compared with worldwide production by using of USTER®STATISTICS 2018.

The fibers repeatedly obtained from blowroom cotton waste had a quality that allowed the preparation of slivers with suitable consistency by classical means (including doubling and drafting processes of slivers) and the IDF technology (shortening of the technology where only drafting processes of sliver are adopted) give the opportunity to improve the sliver consistency to be processed by rotor spinning technology. Moreover, rotor-spun yarns were successfully realized on the Rieter R 37 machine with the implementation of cleaning channels A, C, and W. Statistical processing and GANOVA proved that the quality of fibers in terms of the blending portion of virgin cotton fibers in the yarn and the way of sliver preparation together with the implemented cleaning channel on the Rieter R 37 spinning machine significantly influenced the quality of yarn. Qualitative assessments confirmed that all yarns were suitable for final use in weaving for final applications, such as home textile or denim fabrics, including those yarns spun only from 100 % cotton waste. Only yarns with a higher cotton waste content tend to release fibers from the surface more easily under mechanical stress (they have lower abrasion resistance and higher lint generation), due to the fact that shorter fibers are less arranged in the yarn structure. The use of higher twist in the production of these yarns can reduce this negative phenomenon.

In addition, the experiment verified the used spinning strategy with the selection of various cleaning channels. Yarn manufacturers can decide to produce excellent yarns for a wide range of final applications (first spinning strategy) by using cleaning channels A or C with respect to fiber contamination level. In contrast, the implementation of cleaning channel W in the spinning unit of the rotor spinning machine Rieter R 37 should allow better fiber yield during spinning, resulting in yarns with optimal quality for preselected final use (second strategy). In other words, cleaning channel A, based on the obtained results, may be recommended for fibrous materials with average levels of impurities, typically virgin cotton and its blends with cotton waste, whereas cleaning channel C may be suitable for processing fibrous materials with very low levels of impurities. Meanwhile, cleaning channel W may be advantageously used to process fibrous materials with high amounts of impurities (typically blowroom wastes), minimize the loss of good fibers during spinning, and reduce the production of waste. Further, the integration of fibers with low quality and the potential incorporation of trash and dust into the yarn structure caused the deterioration of yarn quality and required an adequate choice of the final yarn application and adequate adjustment of technological processes of finishing the fabrics made from it. This allows yarn manufacturers to respond to customer demands, ensure the required yarn quality at optimal levels, gain benefits associated with the higher fiber yield in the yarn and support sustainability efforts. The experiment confirmed that for a 98 tex cotton yarn formed from a 5850 tex sliver, the amount of *Trash extraction* can be deliberately adjusted with respect to the chosen strategy, varying between 0.5 % and 4.5 %, resulting in material savings of up to 3.5 %.

The innovation in the spinning unit allows to influence the trash removal rate and to extend the limited possibility given by the appropriate choice of the opening roller speed, which has to be balanced with the rotor and the delivery speed together with underpressure on standard rotor spinning machines. The specific geometry and surface treatment of the cleaning channels also lead to potential savings in air and energy consumption associated with the replacement of a small segment in the spinning unit that has a significant impact on the entire technology.

The results of this study can only give an insight into the reuse of cotton fibers and its effect on yarn quality when processed on the R37 rotor spinning machine with exchangeable cleaning channels. The validity of the results for a wider range of yarn product portfolios for different types of fiber blends (e.g. mixtures of pre and postconsumer cotton waste or blends of cotton waste with polyester fibers), along with case studies introducing the cost analysis, should follow. The impact on the quality of the fabric made from these yarns is also part of the future work.

Declaration of generative AI in scientific writing

The author confirmed that they did not use any AI technology during the preparation of the article.

CRediT authorship contribution statement

Gabriela Krupincová: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table
Selected qualitative characteristics of rotor yarns and technological data

Amount of virgin cotton [−]	0	0.25	0.5	0.75	1	0	0	0
Sliver preparation	**Classical doubling and drawing**					**IDF**		
Cleaning channel	**A**					**A**	**C**	**W**
***T* [tex]**	**98.3**							
***Z* [m^{-1}]**	**425**							
T [tex]	97.40 (94.66; 100.14)	98.80 (97.16; 100.4)	97.85 (96.62; 99.08)	97.95 (97.27; 98.64)	98.15 (97.19; 99.11)	92.05 (91.37; 92.74)	92.60 (92.05; 93.15)	96.35 (94.30; 98.41)
CVm [−]	13.73 (13.55; 19.91)	12.67 (12.52; 12.82)	12.27 (12.19; 12.35)	11.75 (11.64; 11.86)	11.39 (11.19; 11.59)	12.38 (12.29; 12.47)	12.15 (11.99; 12.31)	13.25 (13.12; 13.38)
H [−]	8.89 (8.46; 9.32)	9.18 (8.47; 9.89)	7.56 (6.38; 8.74)	7.94 (7.7; 8.18)	8.4 (7.48; 9.32)	8.99 (8.09; 9.89)	9.52 (8.80; 10.24)	10.09 (9.41; 10.77)
S_{12} [100m^{-1}]	6372 (5791; 6953)	4790 (3958; 5621)	4565 (4190; 4940)	5989 (5642; 6335)	6963 (6396; 7530)	9962 (9757; 10168)	11434 (10892; 11975)	11632 (11139; 12125)
S_3 [100m^{-1}]	868 (743; 992)	633 (497; 768)	736 (679; 792)	987 (936; 1037)	1116 (1043; 1188)	1865 (1835; 1895)	2160 (2013; 2306)	1959 (1775; 2143)
F [cNtex^{-1}]	8.98 (8.81; 9.15)	9.85 (9.66; 10.04)	10.48 (10.29; 10.67)	11.28 (11.13; 11.43)	11.92 (11.76; 12.08)	8.71 (8.56; 8.86)	8.65 (8.53; 8.78)	8.31 (8.17; 8.45)
ε [%]	6.01 (5.89; 6.13)	6.58 (6.47; 6.69)	6.58 (6.45; 6.70)	6.56 (6.45; 6.67)	6.55 (6.42; 6.68)	5.74 (5.6; 5.89)	5.85 (5.76; 5.95)	5.21 (5.07; 5.34)
Lint genration [mgkm^{-1}]	62.16	56.42	32.38	21.01	19.17	88.03	107.37	118.11
Abrasion restistance [−]	419	422	539	601	594	302	353	379

(*continued on next page*)

Table (*continued*)

Amount of virgin cotton [−]	0	0.25	0.5	0.75	1	0	0	0
Sliver preparation	**Classical doubling and drawing**					**IDF**		
Cleaning channel	**A**					**A**	**C**	**W**
***T* [tex]**	**98.3**							
***Z* [m^{-1}]**	**425**							
	(387; 451)	(393; 451)	(514; 564)	(570; 632)	(562; 625)	(287; 318)	(337; 369)	(351; 407)
Trash count [km^{-1}]	272.7 (236; 305.5)	165.2 (144.7; 185.7)	103.2 (88.6; 117.8)	66.3 (59.2; 73.4)	19.9 (12.9; 26.9)	202.4 (171.1; 233.7)	492.5 (318; 667)	1112 (987; 1237)
Dust count [km^{-1}]	16940 (16169; 17711)	10660 (9841; 11479)	6419 (6120; 6718)	3834 (3687; 3981)	1201 (1084; 1318)	15200 (14375; 16026)	25480 (21502; 29458)	40610 (38933; 42287)
Trash exclusion [%]	4.0	3.3	3.0	2.6	2.6	4.2	2.0	0.5

References

[1] D. Damayanti, L.A. Wulandari, A. Bagaskoro, A. Rianjanu, H.-S. Wu, Possibility routes for textile recycling technology, Polymers 13 (2021) 3834, https://doi.org/10.3390/polym13213834.

[2] D.G.K. Dissanayake, D.U. Weerasinghe, Fabric waste recycling: a systematic review of methods, applications, and challenges, Mater. Circ. Econ. 3 (2021) 24, https://doi.org/10.1007/s42824-021-00042-2.

[3] F.A. Esteve-Turrillas, M. de la Guardia, Environmental impact of recover cotton in textile industry, Resour. Conserv. Recycl. 116 (2017) 107–115, https://doi.org/10.1016/j.resconrec.2016.09.034.

[4] S. Johnson, D. Echeverria, R. Venditti, H. Jameel, Y. Yao, Supply chain of waste cotton recycling and reuse: a review, AATCC J. Res. 7 (3) (2020) 19–31, https://doi.org/10.14504/ajr.7.S1.

[5] G. Sandin, G.M. Peters, Environmental impact of textile reuse and recycling–a review, J. Clean. Prod. 184 (2018) 353–365, https://doi.org/10.1016/j.jclepro.2018.02.266.

[6] T. Duhoux, E. Maes, M. Hirschnitz-Garbers, K. Peeters, L. Asscherickx, M. Christis, B. Stubbe, P. Colignon, M. Hinzmann, A. Sachdeva, Study on the Technical, Regulatory, Economic and Environmental Effectiveness of Textile Fibres Recycling, 2021 [Final report].

[7] M. Ichim, C. Sava, Study on Recycling Cotton Fabric Scraps into Yarn, 3/2016, Buletinul AGIR, 2016, pp. 65–68.

[8] W. Klein, The Rieter Manual of Spinning - Volume 2: Blowroom & Carding, Rieter Holding, 2018.

[9] H. Mohamed Taher, A. Bechir, B.H. Mohamed, S. Faouzi, Influence of spinning parameters and recovered fibers from cotton waste on the uniformity and hairiness of rotor spun yarn, J. Eng. Fibers Fabr. 4 (2009) 155892500900400, https://doi.org/10.1177/155892500900400304.

[10] B. Ütebay, P. Çelik, A. Çay, Effects of cotton textile waste properties on recycled fibre quality, J. Clean. Prod. 222 (2019) 29–35, https://doi.org/10.1016/j.jclepro.2019.03.033.

[11] B. Wanassi, B. Azzouz, M.B. Hassen, Value-added waste cotton yarn: optimization of recycling process and spinning of reclaimed fibers, Ind. Crops Prod. 87 (2016) 27–32, https://doi.org/10.5604/01.3001.0010.2340. D., Yelkovan, S., Tirak, Y., 2017. Comparison of the effects of different cotton fibre wastes on different yarns types. Fibres Text. East. Eur. 25.

[12] B. Wanassi, B. Azzouz, M.B. Hassen, Recycling of post-industrial cotton wastes: quality and rotor spinning of reclaimed fibers, J. Adv. Res. 3 (6) (2015) 94–103.

[13] M. Krifa, J.-P. Gourlot, J.-Y. Dréan, Effect of seed coat fragments on cotton yarn strength: dependence on fiber quality, Textil. Res. J. 71 (2001) 981–986, https://doi.org/10.1177/004051750107101108.

[14] M. Krifa, J.-P. Gourlot, R. Frydrych, J.-Y. Drean, Effect of seed coat fragments on cotton yarn structure: impact of fragment size, attached fibres and position within yarn core, J. Text. Inst. 99 (2008) 551–560, https://doi.org/10.1080/00405000701692452.

[15] P.C. Jones, J.C. Baldwin, The influence of seed coat neps in yarn manufacturing, in: Presented at the Beltwide Cotton Conference Volume 2, National Cotton Council, Memphis TN, 1996, pp. 1454–1460.

[16] X. Kuang, Y. Hu, C. Yu, The theoretical yarn unevenness of cotton considering the joint influence of fiber length distribution and fiber fineness, Textil. Res. J. 86 (2016) 138–144, https://doi.org/10.1177/0040517515586161.

[17] H.H. Ramey, R. Lawson, S. Worley, Relationship of cotton fiber properties to yarn tenacity, Textil. Res. J. 47 (1977) 685–691, https://doi.org/10.1177/004051757704701008.

[18] D. Yilmaz, S. Yelkovan, Y. Tirak, Comparison of the effects of different cotton fibre wastes on different yarns types. Fibres Text. East, Eur 25 (2017), https://doi.org/10.5604/01.3001.0010.2340.

[19] W. Klein, Practical Guide to Opening and Carding, Textile Institute, Manchester, 1987.

[20] M. Taher Halimi, M. Ben Hassen, B. Azzouz, F. Sakli, Effect of cotton waste and spinning parameters on rotor yarn quality, J. Text. Inst. 98 (2007) 437–442, https://doi.org/10.1080/00405000701547649.

[21] H. Hasani, S.A. Tabatabaei, Optimizing spinning variables to reduce the hairiness of rotor yarns produced from waste fibres collected from the ginning process. Fibres Text. East, Eur 3 (2011) 21–25.

[22] H. Hasani, D. Semnani, S. Tabatabaei, Determining the optimum spinning conditions to produce the rotor yarns from cotton wastes, Ind. Textil. 61 (2010) 259–309.

[23] S. Kaplan, Ö. Göktepe, Investigation into navel selection for rotor spinning machine using cotton waste. Fibres Text. East, Eur. 14 (2006) 58–62.

[24] P.N. Duru, O. Babaarslan, Determining an optimum opening roller speed for spinning polyester/waste blend rotor yarns, Textil. Res. J. 73 (2003) 907–911, https://doi.org/10.1177/004051750307301010.

[25] MdR. Repon, R.A. Mamun, S. Reza, M. Kumer Das, T. Islam, Effect of spinning parameters on thick, thin places and neps of rotor spun yarn, J. Text. Sci. Technol. 2 (2016) 47–55, https://doi.org/10.4236/jtst.2016.23007.

[26] B.T. Ute, P. Celik, M. Bunyamin Uzumcu, Utilization of cotton spinning mill wastes in yarn production, IntchOpen. https://doi.org/10.5772/intechopen.85127, 2019.

[27] M. Zeidman, P.S. Sawhney, Influence of fiber length distribution on strength efficiency of fibers in yarn, Textil. Res. J. 72 (2002) 216–220, https://doi.org/10.1177/004051750207200306.

[28] G. Krupincová, The influence of various portion of cotton waste and way of cleaning on quality of open-end rotor yarns. 22th International Conference Structure and Structural Mechanics STRUTEX 2022, FT TUL Liberec Czech Republic, December 2022.

[29] G. Krupincová, M. Pechová, The quality comparison of open end rotor spun yarns produced from cotton waste in gray state and after dyeing, Textil. Res. J. 93 (9–10) (2023).
[30] M. Meloun, J. Militký, M. Forina, Chemometrics for Analytical Chemistry: Volume I PC-Aided Statistical Data Analysis, second ed., Ellis Horwood Ltd, 1992.
[31] USTER ® AFIS, PRO–What Does the Data Mean?, 2004.