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Metrological Analysis of Cotton Yarns Processed by Different Spinning Technologies: A Comparative Study between Ring Spinning, Solar Electric Spindle with Pedal and Open-end Spinning

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Abstract

The aim of this work is to establish spinning equipment and conduct a metrological comparative analysis with traditional spindle methods and open-end industrial spinning. To achieve this, five selected artisans were tasked with producing yarn using both sets of equipment, using conventional cotton fibers in roving form, followed by a comparative study with conventionally industrially produced yarn, using open-end industrial spinning.. Physical parameters such as twist, count, elongation, tensile strength, and tenacity were analyzed using USTER AUTOSORTER 5, USTER EVENNESS TESTER 6, and AUTODYN II MESDAN instruments. We have obtained the following results for the designed equipments: twist 424 tr/min, count 15.24 tex, elongation 7.81%, tensile strength 3.77 N, and tenacity 25.92 cN/tex, compared to 437 tr/min, 14.33 tex, 8.38%, 3.13 N, and 22.02 cN/tex for artisanal equipment. Morphological analysis revealed irregularity rate, size, fineness, imperfection count, and hairiness of 15.95%, 36.66, 19.33, 23, and 1262%, respectively, for the designed equipment, as opposed to 17.13%, 81.33, 29.4, 54.2, and 1919% for artisanal equipment. Based on these results compared to yarn produced industrially, we can conclude that this equipment allows for the production of industrially acceptable quality yarn, with a daily production capacity 13 times higher than that of traditional equipment.

Keywords: Cotton fiber • Yarn • Spindle • Spinning • Spinning wheel • Open-end • Metrological

Introduction

Textiles represent the fourth largest manufacturing industry globally in terms of revenue and production. The apparel sector comprises the most significant portion of this industry. Textile industries are responsible for producing yarns, fabrics, and finished products from natural or synthetic fibers [1]. Yarn-making is one of the earliest endeavors undertaken by humans. Neanderthals noticed that nature provided various materials such as fibers and wool, with certain plants resembling cotton. They also observed that by twisting these fibers together, they could create cohesive strands, from which items could be fashioned. Subsequently, they began weaving them together to form surfaces used in clothing and tent-making for protection against natural elements like sunlight, rain, snow, and others. These yarns have various classifications based on their properties. Despite advancements in manual work methods and tools used for manual spinning, the yarn industry remained artisanal from ancient times until the early stages of the industrial revolution in Europe in the last century [2]. Spinners must ensure minimal irregularities in yarn thickness to produce the desired quality [3]. Weaving involves intertwining two sets of threads or yarns at right angles to each other to produce fabric. Africa, particularly Cameroon, is rich in traditional and cultural identity. Traditional fabrics in Cameroon are predominantly made from cotton fibers, often through labor-intensive manual spinning and weaving processes with low yields. These activities are prevalent in the northern and western regions, with distinct patterns reflecting local customs and traditions. Cotton, grown primarily in the northern part of the country, serves as the main raw material for traditional fabric production [4,5]. Raw cotton is hand-picked from fields or purchased at markets, then hand-spun into yarn using a spindle known as an "Enzirt." Factory-spun cotton thread is often used as the warp thread, while hand-spun thread serves as the weft. In traditional weaving, the weft thread is wound onto the shuttle before being inserted into the wooden loom. As the shuttle carrying the weft moves back and forth across the warp, the weft thread interlaces with the warp thread. The inserted weft thread is then pressed onto the fabric using a comb, and the process is repeated until the desired length of fabric is achieved. Hand weaving and crafts are significant sources of non-agricultural income in Ethiopia, Burkina Faso, Mali, and the northern regions of Cameroon. In rural and semi-urban areas like Maroua (Cameroon), hand spinning and weaving remain common techniques for producing both special fabrics and garments of high artistic and traditional value. Cameroonian cotton is of premium quality in the international market. Given the low rate of local cotton transformation, continuous research is being conducted to increase processing in line with Camerounian gouverment strategies up to the year 2030. Weaving is the process of fabric production where two sets of threads, the warp and the weft, interlace to form a fabric. The warp is arranged lengthwise, and the weft is woven perpendicularly through

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the warp to create the fabric. This can be done by hand or with machines in textile factories using a loom. For those made by hand, good quality warp and weft threads are required for the traditional weaving process [5]. Variations in thread properties may result from differences in their composition, stemming from various production processes. In the spinning of short textile fibers, four types of yarn production processes—compact spinning, rotor spinning, and vortex spinning are commonly accepted today [6]. Yarn production technology, structure, properties, and performance are directly related. Yarn production technology defines the terms of the yarn formation process in this sequence of relationships, where ring spinning, rotor spinning, vortex spinning, and friction spinning have different effects on the produced yarns. The open-end rotor spinning system is the second most favoured spinning system for short fiber spinning after ring spinning. The open-end rotor spinning system is gaining popularity due to its significant reduction in space and personnel requirements. Production volume in rotor spinning has also increased in recent years, which is understandable given the current trend in textile production and consumption. Rotor spinning ushers in a new era for producing more uniform, fuller, airy, and consistently strong cotton yarns. Rotor spinning is a recognized spinning system primarily for medium and coarse counts. The characteristics of rotor-spun yarn are influenced by numerous factors primarily related to raw material, machine, and processing parameters. Repon MdR, et al. [7] revealed that rotor spinning is considered the most suitable and successful spinning process among many open-end spinning processes. This spinning system is significantly acceptable for high-volume yarn production using lower to medium quality cotton, or even waste, at a relatively lower cost than any other existing spinning technology. It is common in rotor spinning for yarns to be spun from raw materials. Rotor spinning opens a new era for producing more uniform, fuller, airy, and consistently strong cotton yarns. Rotor spinning is a recognized spinning system primarily for medium and coarse counts [8]. This spinning system offers economic advantages due to its lower process requirements and higher production rate compared to ring spinning [9]. Cameroon ranks among the leading cotton-producing countries in sub-Saharan Africa with a production of 350 thousand tons in 2021. 98% of its production is intended for export, with only 2% processed locally (ECBT, 2019). Regarding the Camerounian gouverment strategies up to the year 2030, cotton plays a significant role in achieving the objectives, envisioning the transformation of over 50% of local production by 2035. Given the aging and low productivity of production equipment, the high cost of industrial equipment, and the laborious nature of the work contribute to the decline of the activity. To revitalize the sector and boost local consumption, it is urgent to optimize our production system. In response to this challenge, we have designed and implemented a spinning device that not only increases production but also reduces labor intensity, thus revitalizing this sector. The objective of this study is to conduct a comparative analysis between the yarn produced by local artisanal equipment, the yarn produced by a reference industrial equipment such as that of conventional, and our designed and implemented equipment. To the best of our knowledge, no previous research has addressed this aspect. The novelty of this work lies in evaluating our manually operated, solar-powered electric spinning device in comparison to the quality of the yarn produced. The work is organized as follows: In section 2, we present materials and method implemented in our study. Section 3 is devoted to present our results and discussion.

Materials and Methods

Materials

The cotton samples were supplied by Industrial Cotton Farm from Cameroon (CICAM) in March 2023. The properties of the virgin cotton fibers (100%) used in yarn production were sourced from Cotton Development Company (SODECOTON) of Cameroon. Cotton parameters were determined using a high-volume instrument for cotton testing, namely the USTER HVI SPECTRUM, in the spinning mill where the yarns for this study were manufactured. The average physical properties of cotton fibers are summarized in (Table 1).

100% cotton fibers sourced from CICAM, with characteristics provided in Table 1, were spun to produce yarns using three different types of equipment: spinning by artisans (traditional method), spinning by our designed and produced equipment, and spinning by CICAM equipment. The same raw material was utilized for spinning. A series of 10 tests was conducted using traditional equipment, followed by tests using the equipment designed by us. The characteristics of the spun products were compared to the yarns obtained by CICAM, which served as the reference. The spinning technique involved four craftsmen working together for artisanal spinning and using the designed and produced equipment. The repetitions were carried out to evaluate the standard deviation and repeatability of the yarn obtained. The subsequent section describes the images and operation mode of the spinning equipment.

Table 1. Properties of virgin cotton.

Qualitys Parameters	Symbol	Cotton
Miconaire (µg/in)	Mic	4.34 ± 0,36
Tenacity (gr/in)	Str	30.3 ± 1,57
Elongation %	EL	7,9 ± 1,23
Uniformity index %	SFI	7,6 ± 0,96
Brithtness %	Rd	73,6 ± 4,28

To carry out this task, we selected 5 artisans, comprising 3 women and 2 men, from the Diamaré department, specifically from the municipalities of Bogo, Meri, and Maroua 1st. Each artisan was assigned to both types of equipment (ET and EA). Every artisan produced 5 threads from the yarn provided by CICAM for 5 days on each equipment. The choice of the number of threads took into account the standard deviation, reproducibility, and repeatability. The equipment and their descriptions used in the study are depicted in Figures 1 to 3. To assess the quality of the obtained threads, tests were developed and compared to standards, which correspond to those produced by CICAM (metric thread number N°16, with ribbon characteristic (Nr) and yarn number (Nm)). For a 16 tex cotton thread, the yarn number is 36.88 and the ribbon number is 18.44.

Testing of yarn

Microscopically morphologic measurements: For optical microscopic images, cotton fibers were meticulously arranged on a sample slide. The slide underwent polarization under a digital microscope (KH-8700, Hirox, Hackensack, NJ, USA), and images were captured.

The yarn cones were conditioned under standard atmospheric conditions in accordance with ISO 139:2005 [10]. Subsequently, conditioned yarns were assessed for unevenness, imperfections, and hairiness using the USTER TESTER 5. Additionally, breaking strength, elongation at break, and tenacity were measured using the USTER TENSORAPID, following standard methods ISO 16549:2004 and ISO 2062:1993 [11].

All tests were conducted in accordance with ASTM and standard ISO methods. The testing environment maintained a standard atmosphere of 65 ± 2% relative humidity and 20 ± 2 °C temperature.

Determination of yarn twist: The twist tester Zweigle D312 was employed to measure the twist in the yarn. Twist was measured using the direct counting method, following the procedure outlined in ASTM D 1423-02. To detect twist variation, a special gauge length of 5 cm was utilized. The counter reading was recorded, representing the ply twist in turns per 5 cm. fifteen readings were taken for each package.

Determination of yarn tensile strength and elongation: The USTER TENSOJET 3 was utilized to measure the tensile strength and elongation of the yarn. This test was conducted in accordance with ASTM D2256-02.

Determination of yarn evenness:

- The USTER EVENNESS TESTER 3 was utilized to measure the tensile strength and elongation of the yarn. This test was conducted in accordance with ASTM D1425-96. However, the evenness tester did not accept counts less than Ne 10, so it was not possible to test the evenness of the Ne 16/2 plied yarn.
- The H.V.I Instrument System was employed according to ASTM

standards (D-4603-86-1776-98) to determine the upper half mean length (in mm), uniformity index, micronaire value (microgram/inch), and fiber strength (cN/Tex). Fiber elongation (FE %) was determined using ASTM standard D-1440-65.

- The Stelometer Instrument, following the standard method of ASTM D-1445-75 (1984), was used to measure the flat bundle tensile strength (tenacity) of the yarn. Yarn mechanical properties, including yarn strength (Lea product), were determined by testing the skein strength on the Good Brand lea tester to estimate the lea strength in pounds (ASTM 1967-D 1578). The broken leas were weighed using a Souter Alfered Balance (ASTM 1967 D-1907) to estimate their actual count. The lea breaking strength was corrected according to the actual count. The lea product was estimated using the nominal count from the following formula: Lea product=Corrected breaking load in pounds x nominal count. The coefficient of variation of the yarn evenness (C.V.%), number of neps/400 m, number of thin places/400 m, and number of thick places/400 m of the yarn were measured using the Uster Evenness Tester III, as described by the designation of ASTM 1984 D-2256

Results and Discussion

Optical microscopic images

The optical micro morphologic images are presented in Figure 1. The polarized optical microscopic analysis could be used to qualitatively evaluate the convolutions and birefringence intensity of the cotton fibers.

Physical and mechanical properties of obtained threads

Based on the yarn and ribbon from CICAM, the properties of the obtained threads are illustrated in Table 2, which presents the descriptive physical parameters of the metric number, twist, count, elongation at break, applied force, and obtained toughness of the threads produced during the spinning operation by the 5 artisans on both equipment (EC and EA) (Table 2).

The reference thread used is the 16 Nm one because it closely resembles the artisanal aspect in terms of title and quantity of fibers. For our various analyses, we produced 25 meters of thread per artisan with each having 5 repetitions for standard deviation. The analysis of the properties of the threads obtained during spinning is presented in Table 2. We notice that the first two values differ from the last three values. This difference could probably be attributed to the artisans adapting to the new equipment during the first two trials, followed by a gradual mastery of the equipment during the last three trials. When spinning on the artisanal equipment, we obtain values ranging from 435 to 440 Nm, suggesting that the threshold twist has been reached. This threshold value could be justified by the artisans' mastery of the artisanal tool, which becomes routine for them, and the low twist would be attributed to the architecture of the equipment.

Toughness and elongation: The number or title is the ratio between the fixed weight (kilogram) and the variable length of the thread. The breaking force is generally the tensile or compressive load required to fracture or cause a rupture in the sample. Once these two terms are obtained, we calculate toughness. Toughness is the ability of a material to resist the propagation of a crack [12]. The average toughness varies between 25.9 cN/tex for the designed equipment and 22.02 cN/tex for the traditional equipment. Compared to the reference value (CICAM), which is 29.49 cN/tex, we can say that the improved equipment produces threads close to the reference value. The difference is likely due to the twist and the title. Observation of Table 2 shows that toughness varies depending on the title and its twist. As for elongation, it ranges from 7.81% for Designed Equipment (DE) to a value of 8.38% for (EA). It is noticeable that elongation is high for traditional equipment. Comparing this value to that of toughness, we can say that the thread from traditional equipment has low toughness and a high elongation value, which would suggest that the thread obtained from traditional equipment has low tensile strength compared to the thread from designed equipment. We can thus conclude that at low elongation values, we obtain good tensile strengths. In light of the work of Togola, et al., who worked on three cotton varieties to produce threads, we can conclude that the Table 3 provides the average values of the parameters studied per equipment. We observe that the obtained toughness is slightly lower than the reference value, suggesting the need for some improvements to achieve a value closer to the reference. There is also a difference of almost 4 units between the reference value and the value of the traditional equipment (Table 3).

Studying the responses of threads to mechanical stresses and deducing mechanical properties is undoubtedly a fundamental factor in thread characterization. Indeed, the mechanical properties of textile structures and the limits of their performance will be defined based on those of the threads that constitute them. In most applications, threads are primarily subjected to tension. Therefore, tension is the type of stress we have chosen to prioritize in this paragraph, and the parameters we have focused on are tensile strength, deformation, and toughness. Compared to the work of Dallet (2012) and ASTM standard D2256/D2256M [13], we have a very high toughness value, which allows us to have threads with good tensile properties suitable for various textile applications and high torsion values.

Morphological properties of obtained threads

Before addressing the morphological parameters, it will be useful to recall some concepts for better understanding:

The CV% value: Coefficient of Variation: corresponds to the standard deviation of the distribution expressed as a percentage of the mean of the distribution.

Statistically: $$CV\% = \frac{100}{\overline{X}} * \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{\ })^2}$$ (Equation 1)

Including: Xi: the instantaneous value of mass; x: the average value of mass per unit length, and N: Total number of measurements.

The U% value: Coefficient of Linear Mean Irregularity (or Uster value): corresponds to the percentage of area exceeding the mass mean of the yarn.

Table 2. A descriptive analysis of the threads spun by the 5 artisans on both types of equipment.

	Tests	Torsion (rpm)		Title (tex)		Elongation (%)		Force (N)		Toughness (cN/tex)	
CI	/	497		15,87		7,84		4,68		29,49	
EC	A	398	424,6 ± 73,28	15,00	15,24 ± 0,32	8,39	7,81 ± 0,52	3,76	3,77 ± 0,41	25,06	25,9 ± 2,15
	B	307		14,80		8,35		3,36		22,70	
	C	470		15,40		7,30		4 ,155		26,98	
	D	473		15,51		7,43		4,19		27,01	
	E	475		15,50		7,60		4 ,36		28,16	
EA.	A	436	437,6 ± 2,07	13,50	14,33 ± 0,62	8,41	8,38 ± 0,02	2,98	3,132 ± 0,12	22 ,07	22,02 ± 0,12
	B	439		14,90		8,40		3,26		21,90	
	C	435		14,98		8,35		3 ,315		22,13	
	D	438		14,02		8,37		3,10		22 ,09	
	E	440		14,27		8 ,41		3,14		22,00	

CI: Industrial Equipment (Open-end Spinning), EA: Artisanal Equipment (Spindle), EC: Designed Equipment (Solar Electric Spindle with Pedal)

Statistically:

$$U\% = \frac{100}{\overline{X}} * \frac{1}{N}\sum_{i=1}^{N} | X_i - ^{-} |$$ (Equation 2)

The number of thicknesses (Thick) is the number of times the yarn exhibits a mass increase exceeding a preselected threshold (here +50%). It is calculated for an average of 100 meters. The number of thin spots (Thin) is the number of times the yarn exhibits a mass decrease exceeding a preselected threshold (here -50%). It is calculated for an average of 100 meters. The number of neps is the number of times the yarn exhibits a mass increase exceeding a preselected threshold. Typically, this threshold is +200%. It represents the number of buttons. It is calculated for an average of 100 meters.

The textural and morphological properties of the yarns obtained from the sliver provided by CICAM are grouped in Table 4. These include fineness, thickness, irregularities, coefficients of variation of mean metric numbers, and imperfections. Table 4 provides a summary of the measured properties (Table 4 and Table 5).

The evaluation of yarn samples produced from different spinning equipment provides important insights into their quality and uniformity. Based on the data collected in Table 5, several conclusions can be drawn regarding the fiber size, fineness, and neps of the yarns.

Fiber size (in microns):

- Sample CI exhibits an average fiber size of 28 microns with a variation of 14.58% and a uniformity/coefficient of variation (U/CV) ratio of 0.89. These results indicate a finer fiber size and good uniformity. This suggests a relatively uniform fiber size and less bulkiness compared to the other samples, indicating consistent production, explaining the industrial control process.
- Sample EA exhibits an average fiber size of 17.38 microns with a variation of 1.77% and a U/CV ratio of 0.98. This suggests a relatively uniform fiber size but larger compared to the other samples, indicating less consistent production. This uniformity is attributed to more traditional spinning processes.
- Sample EC exhibits an average fiber size of 15.09 microns with a variation of 0.65% and a U/CV ratio of 1.056. It appears to produce finer and more uniform fibers than sample EA but slightly less uniform compared to sample CI, indicating an improvement in uniformity while aiming for increased fineness.

Finesse: Regarding fineness, sample 1 (CI) exhibits a relatively homogeneous fiber quality, with an average fineness of 81.4 and a low coefficient of variation (CV%=9.63%). This consistency could result from careful fiber selection. In contrast, sample 2 (EA) shows a higher average fineness but with considerably greater variation (CV%=36), which could reflect quality defects in the industrial production process. Sample 3 (EC) presents an intermediate fineness, with an average of 36.66 and moderate variation (CV%=19.33%), indicating a more uniform fiber quality but less fine compared to the other samples.

Neps: Finally, concerning the neps, sample 1 (CI) shows an average number of neps of 54.2 ± 7.25 with relatively low variation (CV%=3.84%), suggesting a homogeneous fiber quality with few defects. In contrast, sample 2 (EA) displays a higher average number of neps of 67 with significant variation (CV%=50%), indicating less consistent fiber quality and more susceptibility to defects. Sample 3 (EC) presents an average number of neps of 36.66 with moderate variation (CV%=28%), signaling an improvement compared to sample 2 (EA) but still some presence of defects in the fibers. These results highlight the advantages and limitations of different spinning equipment. While the industrial equipment (CI) offers better uniformity, artisanal equipment (EA) exhibits variable performance, while the designed spinning equipment (EC) shows signs of improvement in fineness and uniformity while possibly still requiring adjustments to reduce defects. These findings are consistent with previous research on textile fiber quality and spinning practices [14,15]. The irregularity or regularity of yarn mass is expressed as the coefficient of variation of yarn mass (CVm%). For a comprehensive quality analysis, statistics offer the method of calculating the coefficient of variation of yarn mass or yarn mass irregularity, which numerically represents the amplitude of mass variations. If a yarn has a high CVm%, it can be assumed that this yarn will cause problems in subsequent or downstream processes. The analysis of Table 4 shows that irregularity is more pronounced in samples produced with the designed

Table 3. Valeurs moyennes des paramètres de filature des deux équipements.

	Torsion (rpm)	Title (tex)	Elongation (%)	Force (N).	Toughness (cN/tex)
CI	497	15,87	7,84	4,68	29,49
EC	424,6 ± 73,28	15,24 ± 0,32	7,81 ± 0,52	3,77 ± 0,41	25,92 ± 2,15
EA	437,6 ± 2,07	14,33 ± 0,62	8,38 ± 0,02	3,132 ± 0,12	22,02 ± 0,12

Table 4. Descriptive analysis of morphological and textural parameters.

	U %		CV%		U/CV	Grosseur		Finesse		Neps	
CI	13, 03		14 ,58			28		08		16	
	17,28		28 ,42			98		36		67	
	19,74	17,13 ± 1,77	17,43	17,38 ± 0,21		76	81,4 ± 9,63	28	29,4 ± 3,84	50	54,2 ± 7,25
	16,58		16 ,98			74		26		53	
	16,43		17,58			78		29		51	
EA	15,78		17,15			81		28		50	
	27,02		33,56			59		28		43	
	21,43		29,58			44		27		36	
	15,78	15,95 ± 0,65	13,56	15,09 ± 1,39		39	36,66 ± 2,61	19	19,33 ± 3,95	23	23 ± 2
EC	16,02		16,28			34		22		21	
	14,79		15,43			37		17		25	

Table 5. Summary of descriptive and morphological analyses of the yarns.

	U %	CV%	U/CV	Size	Fineness	Neps
CI	13, 03	14 ,58	0,89	28	08	16
EA	17,13 ± 1,77	17,38 ± 0,21	0,98	81,4 ± 9,63	29,4 ± 3,84	54,2 ± 7,25
EC	15,95 ± 0,65	15,09 ± 1,39	1,056	36,66 ± 2,61	19,33 ± 3,95	23 ± 2

equipment. The values of 15.95% for (EC) compared to 17.13% (EA) contrast with the reference value of 13.03%. There is a difference of 2% between the standard and the traditional equipment, indicating that the designed equipment performs close to the CICAM standard. This can also be explained by the coefficient of variation of the mean metric numbers, which varies very little. The U/CV ratio close to 1 for EC indicates a normal distribution. However, for all other yarns, this ratio is below this threshold value, indicating that the yarns concerned have a symmetrical distribution with the presence of periodic defects. Given the relatively short length of the tested yarn (25 m), it corresponds to a wavelength of about one meter. With such a low wavelength, these defects likely originate from the drafting process or the average fiber length. Yarn imperfections include thin places, thick places, and neps; these are common yarn defects. Due to their more or less frequent occurrence, these defects can influence the quality of the end product (the external appearance of the yarns and the finished products made from them). They can also have a harmful influence on subsequent manufacturing processes depending on their dimensions and frequency. Thin places and thick places, counted among imperfections, fall within the range of ± 100% relative to the effective average of the yarn's section. Neps, also counted among imperfections, can exceed the + 100% limit and are defined below based on their dimensions within sensitivity thresholds. The observation from Table 4 shows that imperfections are around 54% for EA and 23% for EC, compared to the 16% reference value for CICAM. We observe that the designed equipment produces fewer imperfections. Since the imperfection rate correlates with yarn hairiness, Table 6 provides the yarn hairiness obtained from both equipment.

The yarn hairiness refers to the quantity of fibers (or hairs) belonging to the surface of the yarn and emerging from the fibrous mass. Some fibers tend to protrude from the core of the yarn due to twisting. The consequences of yarn hairiness on the characteristics of the fabric after weaving or knitting operations, especially in terms of touch or the presence of defects, have introduced the necessity of quantifying yarn hairiness. This parameter becomes even more important with the progress and technological advances that have enabled very high speeds on knitting machines and looms. The method used is the Zweigle Hairiness Index, where we isolated 25 meters of yarn from each sample for analysis (Tables 6 and 7) (Figures 1-3).

According to the obtained values of hairiness (in addition to the visual appearance of the produced yarns), the thicker the yarn, the hairier and fluffier it is. This can be explained by a lesser degree of twist (Dalleld). Hairiness increases with the yarn count, which is logical since the probability of having surface fibers responsible for this hairiness is higher in thicker yarns [16]. In our case, it gives the impression of having more fibers in cross-section, which is confirmed by the morphological analysis of the yarns visualized under the microscope (Figure 1-3). Considering the yarn count and its twist coefficient of the reference, the twist value decreases for each sample produced by different artisans on both machines. Thus, for the reference yarn CICAM with the following characteristics: 497 twists/m at 15.87 Tex, then for the machine-made yarns, we have 424.6 (± 73.28) twists/m at 15.24 (± 0.32) Tex, and subsequently for the artisanal yarns, we have 437.6 (± 2.07) twists/m at 14.33 (± 0.62) tex. Observation of the data shows that hairiness increases with the yarn count, based on twist parameters. Dalleld's work (2012) demonstrates

Table 6. Obtained yarn hairiness.

	Hairiness	
CICAM	832,50	
EA	2143,25	1919,33 ±32,71
	1989 ,56	
	1957.23	
	1898,10	
	1903,82	
EC	1413,65	1262 ± 66,48
	1357,09	
	1257,46	
	1226,33	
	1208	

Table 7. Summary values of the yarn hairiness obtained.

	Hairiness
CICAM	832,50
EA	1919,33 ± 32,71
EC	1262 ± 66,48

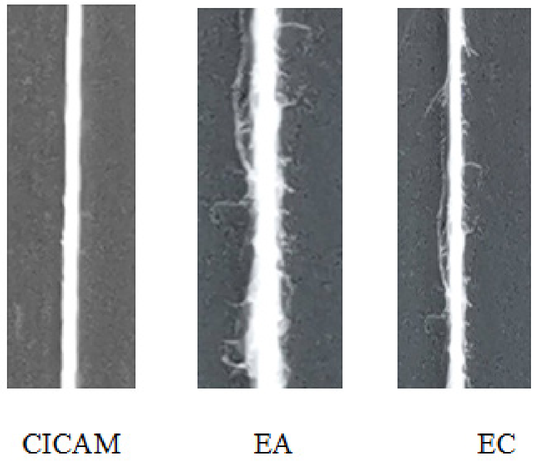

Figure 1. Micrograph at 13X magnification.

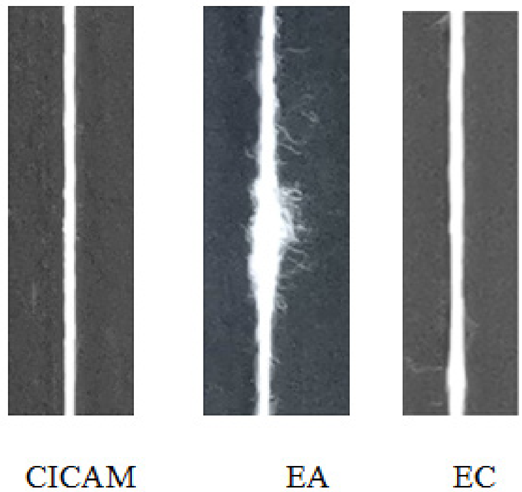

Figure 2. Micrograph at 11.50X magnification.

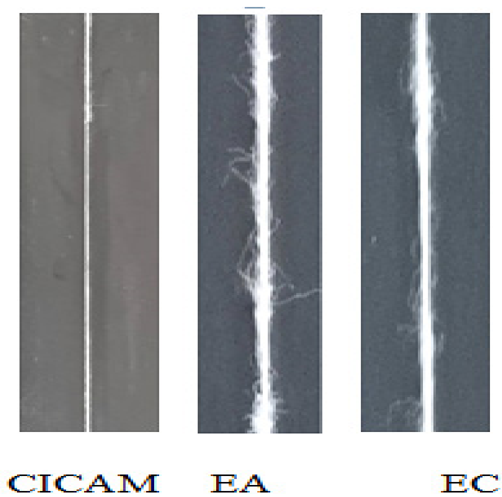

Figure 3. Micrograph at 10X magnification.

Figure 4. Crafters in traditional spinning.

Figure 5. Spinning on equipment designed by artisans.

that the lower the twist, the greater the hairiness, as marginal fibers are less restrained towards the core of the yarn. Figures 4 and 5 depict images of the artisans during the spinning operation (Figures 4 and 5).

Conclusion

The textile industry plays a crucial role in the global economy, with the clothing sector leading the way. Practices as ancient as hand spinning have evolved into modern technologies such as open rotor spinning, offering new possibilities for producing higher-quality yarns more efficiently. However, it is important to recognize and preserve the artisanal traditions that have shaped the history of textile manufacturing, such as hand weaving practiced in many regions worldwide, including Cameroon. Preserving these practices not only maintains a connection with cultural heritage but also provides economic opportunities for local communities. Yet, to ensure competitiveness and meet international quality standards, it is essential to invest in modernizing production equipment while preserving traditional craftsmanship. In this regard, research and development of new spinning systems, such as the one we have designed, can contribute to improving the quality and efficiency of production while preserving artisanal traditions. The northern part of Cameroon, with its sociological and cultural habits, relies on clothing from neighboring countries, contributing to currency outflow. This external dependence is partly due to the unavailability of yarns for fabric production. This lack of yarns has prompted us to conduct research to address this issue. As a result of all these investigations, we have designed an improved spinning equipment and conducted a comparative study between the yarn produced by the existing traditional equipment on the market, which is laborious with a low production rate. The metrological analyses conducted on the physical, mechanical, and morphological aspects have yielded good results compared to the CICAM standard yarn. The characteristics of the yarns obtained through the following instruments, USTER AUTOSORTER 5, USTER EVENNESS TESTER 6, AUTODYN II MESDAN, have provided the following properties: physical parameters such as twist, count, elongation, breaking force, and toughness are in the order of 424rpm, 15.24 tex, 7.81%, 3.77N, and 25.92cN/tex for the designed equipment compared to 437rpm, 14.33tex, 8.38%, 3.13N, and 22.02cN/tex for artisanal equipment. The morphological analysis gives us a rate of irregularity, size, fineness, the number of imperfections, and hairiness of the order of 15.95%, 36.66, 19.33, 23, and 1262% for the designed equipment compared to 17.13%, 81.33, 29.4, 54.2, and 1919% for artisanal equipment. Considering all these results compared to the reference value, which is the yarn industrially produced by CICAM, we can affirm that this device enables the placement of yarns of industrially acceptable quality on the market, and the daily production capacity is 13 times higher than traditional equipment. However, efforts still need to be made, particularly in improving the count, meaning having finer yarns for more advanced applications. To enhance this work, we suggest conducting further studies on the automation of our equipment to avoid variations in the metrological parameters of the produced yarns and optimizing production yield to boost this struggling sector in the northern regions.

Data Availability

Data used for the findings of the study are available on request from the corresponding author.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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