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Research article

Sustainable yarn production using leftover fabric from apparel industries

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ABSTRACT

A huge amount of waste was generated from the apparel industries. This study aims to develop the process of producing recycled yarn from apparel waste. The apparel leftover fabric was converted to fiber, and the fiber was mixed with virgin cotton in different ratios to produce sustainable 6/1 Ne rotor yarn. The produced yarn qualities viz. count strength product (CSP), elongation percentage, total quality index (TQI) and tenacity were decreased linearly, and opposite scenario observed for thick and thin places, neps, imperfection index (IPI) and hairiness (H) attributes with increasing the amount of waste addition with virgin cotton. The leftover fabric (LOF) can be utilized to develop a sustainable yarn and to zero waste management.

1. Introduction

The ready-made garments (RMG) sector generates a tremendous amount of waste continuously. The garment industry's waste, or leftover fabric seems too many to be nothing more than junk. Still, for those engaged in the 'leftover fabric' business, it demonstrates its immense potentiality both within and beyond the nation. In Bangladesh, leftover fabric or fiber cutting from garment manufacturing businesses is known as 'Jhuta'. Every day, the Chittagong port exports about 550 tonnes of textile waste to other countries. Cotton yarn, and even clothing are now being made from these scraps. Many people make a living by processing 'leftover fabric' or running a leftover fabric company [1, 2, 3]. Figure 1 indicates the waste generation locations in the apparel manufacturing industry. According to the World Economic Forum, 85 percent of worn clothing is disposed in landfills each year, where it either burns or adds to landfills. Another 12% of worn clothing is recycled into cleaning cloths for cleaning kitchenware, furniture, glass, and floors. Only 1% of it is up-cycled, and processed into new clothing [4].

Sustainability focuses on addressing current demands without jeopardizing the ability of future generations to meet their own. The three pillars of sustainability are economic, ecological and social, known informally as profit, planet, and people. Companies are increasingly making public pledges to sustainability through initiatives such as waste reduction, renewable energy investment, and support for groups working toward a more sustainable society. Sustainability encourages a green environment in the modern property market [5, 6, 7, 8].

Currently, leftover garment fabrics were sold to local shopkeepers to produce children's clothing. Furthermore, the bedding business in Dhaka is reliant on leftover fabric. In addition, recycled fabric and processed cotton are used in many items, such as mattresses, pillows, cushions, seat filling, and cushioning, in vehicles, public buses, and rickshaws. Furthermore, between 15% and 20% of the leftover fabrics are used as fake materials, fabric samples, and other items. These artificial textiles are also used in the Ella Pad. During menstruation, textile workers used their hand-made underwear and pads. Furthermore, pre-consumer synthetic textile waste may be utilized to create a soundproofing application. Clothing may also be used to wipe off surfaces such as furniture, glassware, and floors. In Bangladesh, Kantha-making is a prevalent method for producing garments from leftover fabric. Raw fibers are used to produce ring-spun yarn. Approximately 20% of the waste is generated during the production process of ring-spun yarn [9]. These wastes (card waste,

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Figure 1. Manufacturing process in apparel industry along with waste generation locations.

blow-room waste, sliver waste, etc.) are used as raw material with raw fiber in rotor spinning to produce yarn [10].

Many researchers have already studied the effect of waste on yarn quality from different perspectives. The results of several investigations have revealed that the waste of different sections of the apparel industry significantly affects the physical and mechanical properties of the yarn [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]. Jamshaid et al. [11] took spinning scraps and turned them into open-end yarn. It has been determined that hard waste can be used to make yarn. The fiber length, homogeneity, and floating fiber contents of the yarn waste were higher than those of the rag waste. Awgichew et al. [12] investigated the impact of the use of recycled fibers on OE-rotor yarns manufactured of 100% virgin cotton and virgin cotton/recycled fiber blends in various proportions (25%, 50% and 75%). The tensile strength of recycled blended yarns is higher than that of virgin yarns. Taher et al. [17] used recovered cotton waste fibers in a spinning mill to make rotor yarn. The yarn hairiness reduces as the yarn count increases. On the other hand, as the latter increases, the number of faults rises too. From the leftover fibers recovered during the ginning process, Hossein and Akhavan [19] produced rotor yarns. Three different waste proportions were used to make yarns (65%, 50% and 35%). The results demonstrate that the diameter of the rotor and the type of navel are the most critical elements in the influence of ginning waste on the hairiness of open-end yarn for all yarns produced with varying waste proportions. Halimi et al. [23] investigated the efficiency of various spinning methods and revealed that the generated waste included 50% excellent fiber and could be combined with virgin cotton to make rotor yarn. Yilmaz et al. [24] investigated the development of ring and OE yarn properties for waste-to-virgin fiber mixing at various ratios. However, there is a lack of investigations in the field of the rotor yarns used for sustainable economy published in the literature.

Therefore, the purpose of this exploration was to construct a rotor yarn from apparel waste. The physical properties such as CVm %, thick and thin places, neps, hairiness and imperfections, tensile properties such as tenacity, elongation percentage, total quality index, and count strength product (CSP) of yarn were also examined to measure the feasibility. The impacts of virgin cotton-leftover waste composite yarn in different ratios on a yarn performance were likewise evaluated. The overall goal of this design is to recycle and reuse of textile waste in order to reduce the negative environmental impact. In context of the present energy crisis, the environmental responsibility associated with textile waste disposal, and the economy of production, such an approach would be both sustainable and environmentally begin.

2. Materials and methods

The apparel leftover fabric was collected from Mirpur Jhutpolli, Dhaka, Bangladesh. The leftover fabric was processed and mixed with raw cotton to produce sustainable yarn. The spinning process was used to make the yarn, as shown in Figure 2.

Then, the leftover fabric was categorized according to color. The pale color fabrics were converted into dark black color by the dyeing process. These black fabrics were cut into small pieces. These small pieces of fabric were fed into the willowing machine to convert the fiber called Jhut waste fibers (JWF). This JWF was used as the raw material of the spinning process. This JWF was fed to the 1st blow room and the 1^{st} carding section to properly open, clean, mix, remove impurities and parallelize the fibers. Virgin cotton was chosen as fresh raw material. Table 1 presents the summary of the properties of the raw materials.

The virgin cotton and the JWF were mixed and processed through the 2nd blow room machine. The 2nd blow room is followed by the carding

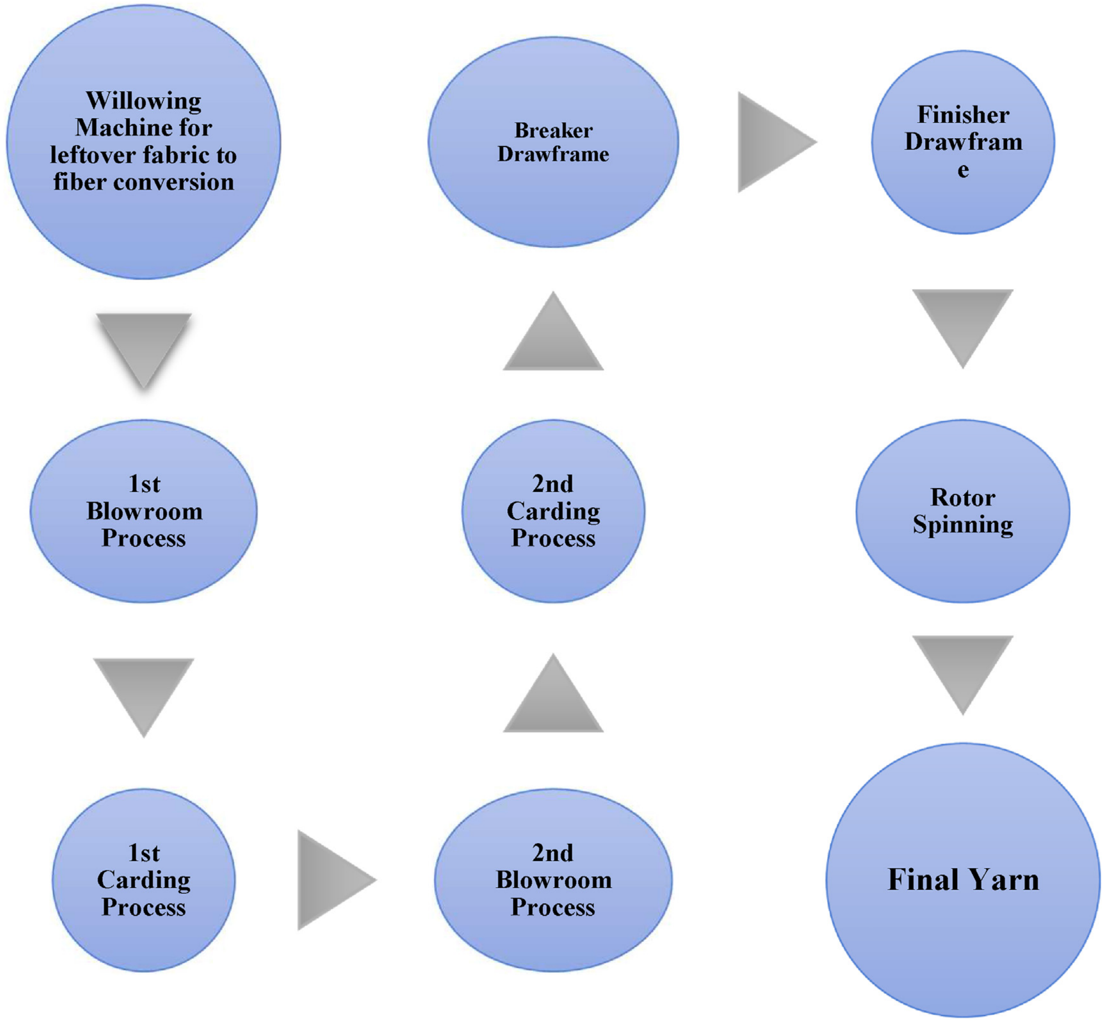

Figure 2. Processing steps for producing sustainable yarn.

machine by means of the carding action to obtain a uniform card sliver. The sliver was subsequently processed in two-stage roller drawing machines for parallelization and leveling of the fiber. Then the output drawn sliver was fed into the rotor spinning machine to produce 6/1 tex yarn.

The quality of the yarn is determined by the JWF/virgin cotton ratio. The mixing ratios of the different samples are presented in Table 2.

The eight variants of composite yarns were prepared depending on the mixing ratio of virgin cotton and the leftover fiber. Then, comparative analysis was done between the control sample and the other samples considering yarn tenacity, hairiness, mass coefficient of variance (CV_m), imperfection index (IPI), count strength product (CSP) and total quality index (TQI). Equations i, ii) and (iii) were used to calculate the yarn imperfection index (IPI), count strength product (CSP) and total quality index (TQI), respectively, of the designed composite yarn. Unevenness/imperfections and irregularity of yarn was checked for characteristics of yarn quality, such as classifying and counting faults in yarn, on a Uster Tester-5 using the standard test method ASTM D6197. Imperfections include thick, thin places (±50% with respect to the mean value of the cross-sectional size), and the number of neps (may exceed the 200% limit). A yarn with more imperfections will give poor performance in weaving due to low strength, which leads to poor quality of fabric. Yarn irregularities, i.e. CVm% (Coefficient of variation of the yarn mass) also affect subsequent process efficiency and quality.

Table 1. Properties of raw material.

Fiber Properties	Fresh Greek Cotton	Leftover Fiber
Maturity (%)	89	86
Fiber tenacity (cN/tex)	29.8	25.9
Fiber elongation (%)	8.5	7.2
Mean length by weight (mm)	23.7	21.9
CV length by weight (%)	34.1	32.4
Short fiber content by weight (%)	9.4	7.8
UQL (upper Quartile length by weight) (mm)	28.1	26.7
Mean length by number (mm)	19.8	18.9
Short fiber content by number (%)	24.1	29.1

Table 2. Fiber mixing ratio and sample identification.

Sample Identification	Fiber mixing ratio	
	Greek cotton, %	Leftover fiber %
Control Sample (S0)	100	0
S1	87.5	12.5
S2	75	25
S3	62.5	37.5
S4	50	50
S5	37.5	62.5
S6	25	75
S7	12.5	87.5
S8	0	100

Table 3. Yarn evenness properties of specimens.

Sample type	CVm%		Thin (−50%)/km		Thick (+50%)/km		Neps (+280)/km		Hairiness, H		IPI	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
S0	13.91	0.08	3.00	0.00	36.00	1.00	6.33	0.58	7.8	0.12	45.33	1.53
S1	14.02	0.16	4.00	0.00	37.33	0.58	7.00	1.00	7.9	0.14	48.33	0.58
S2	14.27	0.18	4.00	0.00	37.33	0.58	8.00	1.00	8.1	0.15	48.67	0.58
S3	14.62	0.18	5.33	0.58	38.67	0.58	9.33	0.58	8.3	0.09	53.00	1.00
S4	14.68	0.18	5.33	0.58	40.33	0.58	11.33	0.58	8.4	0.15	56.00	2.00
S5	14.54	0.25	5.00	1.00	41.00	2.00	12.00	2.00	8.4	0.21	58.00	1.00
S6	15.34	0.37	6.33	0.58	46.00	1.00	14.00	1.00	8.9	0.09	66.00	2.00
S7	16.01	0.40	8.33	0.58	51.00	3.00	17.00	2.00	9.5	0.15	76.00	3.00
S8	16.82	0.80	12.00	1.00	57.00	3.00	21.00	3.00	10.2	0.51	90.00	3.00

The tensile properties of the yarn were evaluated using Uster® Tensorapd according to ASTM D 2256. It measures tensile forces and elongation. Then the other values such as tenacity are determined from them. Tenacity and elongation are two important properties of yarn quality, as both effect the efficiency of subsequent processes such as yarn breakage during weaving.

$$\text{IPI} = \text{Thin places/km } (-50\%) + \text{thick places/km } (+50\%) + \text{Neps/km } (+280\%) \quad \text{(i)}$$

$$\text{CSP} = \text{Strength of one lea yarn in pound} \times \text{Count in English system} \quad \text{(ii)}$$

$$\text{Total Quality Index (TQI)} = \frac{\text{Tenacity (cN/tex)} \times \text{Elongation (\%)}}{\text{CV\%}} \quad \text{(iii)}$$

All data were expressed as the means of the triplicate measurements. All investigations were conducted in a controlled environment following LST EN ISO 139:2005.

3. Results and discussions

Rotor spinning is a rising spinning process used to make coarse and medium-count yarns. This is so because of its higher productivity, better product quality and profitability. Considering such sustainability and the circular economy, the present research work was initiated to study the effect of the addition of leftover wastage on the yarn quality. Yarn faults in the shape of neps, thin and thick places, hairiness, and imperfection on the external appearance of yarns and the obtained products are decisive to minimize. The yarn quality on the basis of tenacity, count strength product (CSP), and elongation (%) were also investigated and discussed analytically.

3.1. Physical properties of yarn

The sustainable rotor yarn was produced using the apparel leftover waste fiber. The results of the physical properties of all samples are shown in Table 3. As expected, yarns made from waste (sample S1–S8) was under one subset of more irregularities than the control sample (S0) which is due to more uniform fibers.

Yarn hairiness and imperfections are the most important parameters that influence yarn quality in terms of appearance of the final product. The fiber ends protrude from the yarn body, the looped fibers extend from the yarn core, and the wild fibers in the yarn generate hairiness [17]. Table 3 represents the CVm %, thick and thin places, neps, hairiness and imperfections of the developed samples. The CVm %, thick and thin places, neps, hairiness and imperfections of the specimens increase progressively with the increase of amount of the leftover waste fibers in the specimen (see Table 3). This is most likely due to the preferential relocation of the coarser and shorter component, which has longer protruding ends from the yarn body. The addition of wastes to the mixing increases the irregularity of the yarn. The dependence of the generated irregularity on the addition of leftover fiber has a linear character. As expected, the raw material (fibers) has a significant impact on yarn unevenness. The unevenness of the yarn can be correlated with the characteristics of the fiber, according to empirical studies. It has long been known that longer fibers reduce yarn unevenness; as a result, spun yarns produced with a lower waste proportion have less unevenness, as can be seen in Table 3. The samples made from pure virgin cotton exhibit the lowest unevenness. The standard thick and thin places, neps, hairiness, and imperfections are determined by the requirement of the customer as well as the end-use of garments. Thus, the sustainable yarn can be produced using any mixing ratio of JWF to meet the customer's yarn hairiness requirements. Figure 3 displays the correlation coefficients of hairiness and yarn imperfection index depending on the leftover fiber percentage.

3.2. Tensile properties of yarn

The results of tensile properties such as tenacity, elongation (%) and count strength product of all samples are shown in Table 4.

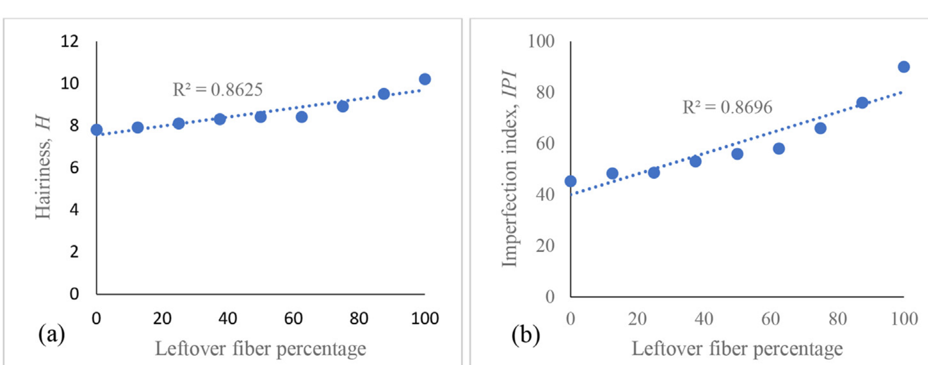

Figure 3. (a) Hairiness and (b) yarn imperfection index correlation coefficients depending on the leftover fiber percentage.

Table 4. Yarn tensile properties of specimens.

Sample type	Tenacity (cN/tex)		Breaking Elongation (%)		CSP		TQI	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
S0	11.16	0.40	7.09	0.10	1886	8.19	5.69	0.09
S1	10.96	0.17	7.00	0.16	1852	6.24	5.47	0.21
S2	10.87	0.11	6.88	0.14	1848	7.55	5.24	0.13
S3	10.64	0.17	6.71	0.19	1826	8.54	4.88	0.12
S4	10.35	0.15	6.45	0.15	1811	4.58	4.55	0.23
S5	10.18	0.19	6.43	0.20	1790	9.17	4.50	0.29
S6	9.32	0.27	6.01	0.17	1620	6.56	3.65	0.33
S7	8.52	0.17	5.34	0.08	1498	5.57	2.84	0.17
S8	6.71	0.70	4.84	0.50	1310	9.54	1.93	0.24

Yarn tenacity, elongation percentage and count strength product are the influencing parameter of the yarn's quality, and these parameters are significantly influenced by leftover waste fibers. Table 4 represents the tensile properties of developed composite yarn. In Table 4, it is clearly seen that the tensile properties such as tenacity, elongation (%) and the count strength product linearly decreased by increasing the additional percentage of JWF with virgin cotton fiber. When a yarn is subjected to tensile testing, the short fibers present in the yarn are more prone to slip, resulting in lower values of tenacity, elongation (%) and count strength product [11]. The yarn made with virgin cotton showed higher tenacity, elongation (%) and count strength product. The short fibers were increased with the increase of waste and decreased tensile strength accordingly. Figure 4 indicates the correlation coefficients of tenacity, breaking elongation, CSP and yarn TQI depending on the leftover fiber percentage.

4. Conclusions

Sustainability is the most crucial factor in this modern world. The wastes of different industries are the main factor in environmental pollution. A considerable amount of waste was generated from the apparel industries that pollute the environment. Therefore, the recycling of this waste is an attractive solution for a sustainable green world. This study would be open a new door to use the apparel leftover waste to produce sustainable yarn. Several samples with different blending ratios

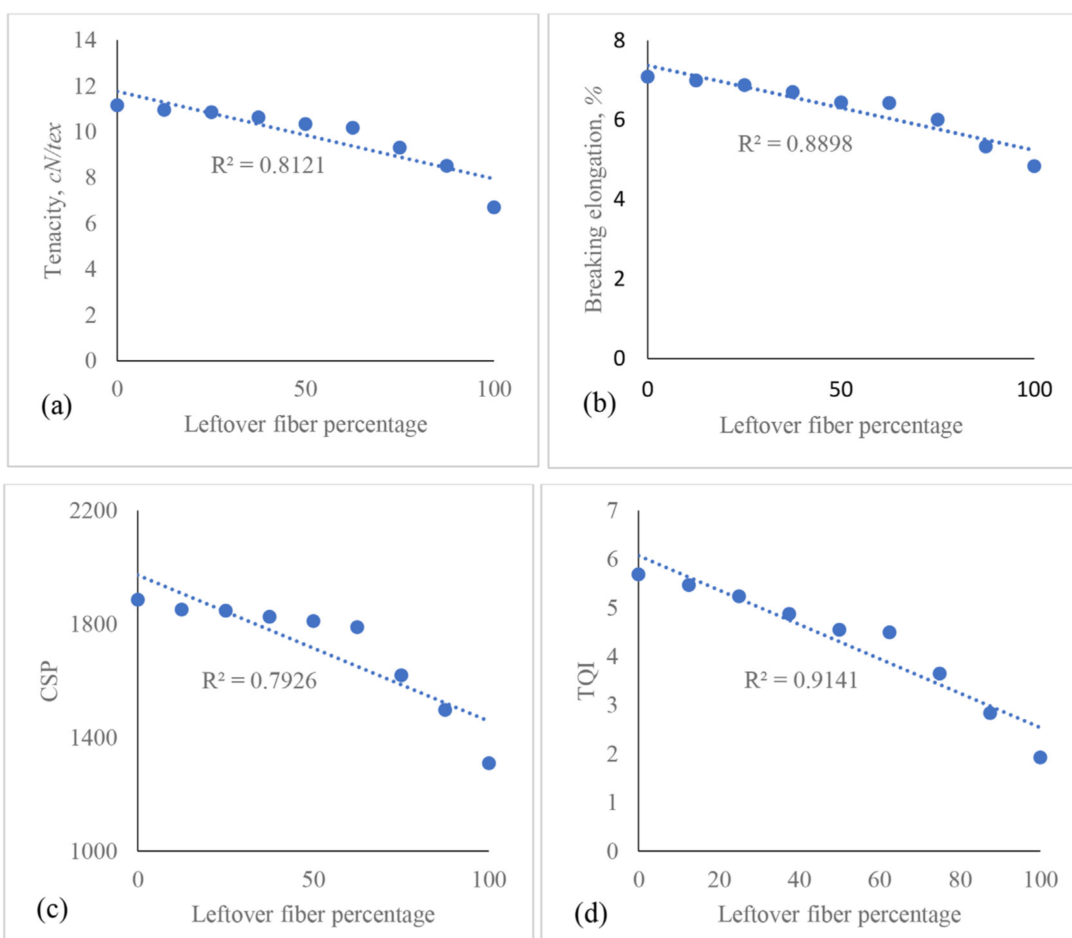

Figure 4. (a) Tenacity, (b) breaking elongation, (c) CSP and (d) yarn TQI correlation coefficients depending on the leftover fiber percentage.

were produced and their properties were evaluated. From the findings, it can be concluded that the leftover fabric can be utilized to develop sustainable yarn. Therefore, the wastage of the apparel industries is effectively converted into money.

Declarations

Author contribution statement

G. M. Faysal, Md. Tanjim Hossain: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

T. N. Sonia Azad: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Md. Reazuddin Repon: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohammad Abdul Jalil: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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