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Innovative valorisation of dyed waste fibres through production of siro-mélange yarn: Towards circular economy and sustainability

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Abstract

This study was initiated to address two critical needs in the textile industry: the sustainable utilization of waste from sueding machines and the reduction of production costs by reusing dyed waste fibres, thereby eliminating the need for additional dyeing processes. The primary objective was to create siro-mélange yarn from such dyed waste fibres using the ring spinning process, which was then analysed for its feasibility and industrial applicability. To achieve this, three different counts of siro-mélange yarn were produced and evaluated based on yarn quality parameters. This research found that ring-spun siro-mélange yarn produced from dyed waste fibre showed a 41.8% increase in unevenness, an 8.7% rise in hairiness, and a 7.3% reduction in strength compared to ring-spun regular mélange yarn made from viscose fibre. The findings revealed that although the yarn quality was slightly compromised due to the shorter length of the raising waste fibres, significant benefits were observed. These benefits include efficient utilization of waste material, cost savings in dyeing processes, reduced water and energy consumption, and a lower carbon footprint. The economic analysis indicated that the cost of producing siro-mélange yarn was competitive, with potential savings being substantial for a factory of a certain capacity. This is primarily due to the reduction in raw material and dyeing costs. Additionally, this process significantly reduces pollution and resource consumption, aligning with sustainable and circular economy principles. In conclusion, the production of siro-mélange yarn from dyed waste fibre waste is not only feasible but also presents a sustainable alternative to traditional yarns, offering both economic and environmental advantages.

Keywords: Sustainable Process, Dyed Waste Fibers, Siro-Mélange Yarn, Cost Reduction

1 Introduction

The overexploitation of virgin materials in the textile industry has resulted in increased levels of landfill waste, which has further exacerbated environmental impacts. This has led to the depletion of natural resources and a significant increase in the production of greenhouse gases, mainly carbon dioxide, contributing to climate change. To mitigate these harmful effects, textile waste must be recycled and reused (Arafat and Uddin, 2022). This shift towards recycling will not only reduce the consumption of virgin materials but also lower the industry's ecological footprint, conserve energy, and reduce carbon emissions. Beyond waste reduction, recycling fibres and textile waste within sustainable production cycles presents a significant opportunity for creating a more environmentally friendly and resource-efficient industry.

Recent advances in recycling technologies have also sparked interest in utilizing pre- and post-consumer textile waste for producing new yarns and fabrics. Researchers have explored the potential of making sustainable textiles from recycled fibres (Zaman et al., 2023). For instance, post-consumer waste has been successfully used in yarn production, including recycled polyester, cotton, and even textile remnants that would otherwise end up in landfills. These efforts align with the concept of a circular economy, which emphasizes minimizing waste and reusing raw materials in a closed-loop production cycle (Singh et al., 2019). Despite these advancements, a substantial amount of textile waste remains unutilized, particularly the fibres generated during mechanical finishing processes.

A promising source of recyclable textile waste is the raising waste fibres produced by sueding machines during the fabric finishing process. Sueding machines, used to impart texture to fabrics, generate large amounts of fibre waste, commonly known as brushing waste. This waste is typically discarded in landfills. However, utilizing this fibre waste for value addition presents an opportunity not only for waste reduction but also for resource optimization in textile production (Purushothama, 2018).

In this research, we propose incorporating dyed waste fibres aka raising waste fibres from sueding machines into the production of siro-mélange spun yarn. Siro-mélange is a pseudo-two-fold yarn made by twisting two untwisted roving strands. Compared to standard worsted yarn, siro-mélange yarn exhibits improved properties, including higher tenacity, lower hairiness, and enhanced abrasion resistance (Cheng and Yuen, 1997). By reusing raising fibres, we aim to retain the desirable properties of siro-mélange yarn while promoting environmentally friendly practices. This approach contributes to a reduction in the use of viscose, a material with a high environmental impact, and supports the principles of the circular economy, emphasizing zero waste and responsible resource consumption (Sehnem et al., 2019). Furthermore, incorporating recycled materials into the manufacturing process has the potential to lower raw material costs and further the industry's transition to a greener and more resource-efficient future.

This study not only addresses the environmental impact of virgin material overuse but also provides a solution for the effective management of fibre waste in textile production. By utilizing raising waste fibre in siro-mélange yarn, we contribute to reducing the ecological footprint of textile production while ensuring the development of high-quality, sustainable yarns. This research aligns with global efforts to minimize the environmental impact of textile manufacturing while offering an economically viable approach to waste management.

This research is targeted to work for the development of an eco-friendly yarn, siro-mélange, using wastes generated within the fleece fabric production process. This yarn is supposedly used instead of conventional mélange yarn, which is produced with black viscose, involving some environmental and economic disadvantages. Incorporation of the recycled fibres within yarn manufacturing also contributes to the development of sustainable practice within the textile industry and helps to save natural resources. Besides, this will reduce at least some of the harmful materials, decrease production costs, and in general, the ecological footprint from textile production will be lower.

Besides that, the current project will also evaluate the industrial production by using siro-mélange yarn from the point of view of its commercial feasibility with low water and energy consumption, considering environmental safety. This research therefore contributes to the development of sustainable practices within the textile industry and to the approach of the circular economy by valorising wastes and efficiently using resources.

Not many significant research or projects have been exclusively devoted to yarn production; the only exception being a project by Bangladesh University of Engineering and Technology where even the prime focus was on making paper sheets (Hasan et al., 2018), not yarn.

2 Material and methods

Cotton was collected from Multazim Spinning Mills Ltd. Raising waste fibre was used in this work for blending with cotton which was collected from Reedisha Knitex Ltd. The ratio of Polyester and Cotton in raising waste fibre is 85:15.

For the production of siro-mélange yarn, two rovings were prepared: one made of 100% cotton fibre and the other one was a 50:50 blend of cotton and raising waste fibre. The cotton fibre was tested by High Volume Instrument (HVI) for fibre length, fibre strength, micronaire, colour, moisture content **(Table 1)** and raising waste fibre was tested by Advance Fibre Information System (AFIS) **(Table 2, Table 3)**. Waste fibre is tested by AFIS because the amount of short fibre remains in raising waste fibre is so significant that it can’t be tested by HVI machine.

Table 1: Properties of cotton fibre from HVI machine

Country of Origin	SCI	Mic	Mat	Moist	UHML (mm)	UQL (mm)	UI (%)	SFI (%)	Elg (%)	Str (gm/Tex)	Rd	+b
Benin	133	4.17	0.86	6.4	28.97	29.25	82.05	10.6	2.8	31.3	72.2	9.9
Burkina Faso	133	3.99	0.86	5.8	29.17	29.5	81.49	9.4	5.7	30.8	75.7	9.5
Mali	123	4.07	0.86	6.1	28.38	28.85	81.85	9.5	5.7	27.8	75.6	9.7

Abbreviation: SCI = Spinning Consistency Index; Mic = Micronaire; Mat = Maturity Index; Moist = Moisture; UHML = Upper Half Mean Length; UQL = Upper Quartile Length; UI = Uniformity Index; SFI = Short Fiber Index; Elg = Elongation; Str = Strength; Rd = Reflectance; +b = Yellowness.

Here is percentage of cotton (from different country of origin) used in Blowroom line: Benin: 40.53% + Burkina: 26.55% + Mali: 32.92%.

Figure 1 Raw cotton (Left) and raising waste fibre (Right)

Table 1: AFIS report (NEP Module) for raising waste fibre

	Total Nep Count	Total Nep Mean Size	Fiber Nep Count	Fiber Nep Mean Size	SC Nep Count	SC Nep Mean Size
Mean	49	613	49	613	0	0
Std. Dev	11	28	11	28	0	0
CV%	22.5	4.6	22.5	4.6	0.0	0.0

Table 2: AFIS report (LEN Module) for raising waste fibre

	L(w) [mm]	L(w) CV %	SFC(w) % < 12.7mm	UQL (w) [mm]	L(n) [mm]	L(n) CV %	SFC(n) % < 12.7mm	5% L(n) [mm]	Fineness [mtex]	Maturity ratio [mat]	IFC [%]
Mean	8.5	74.1	80.0	10.3	5.1	74.7	93.8	13.1	166	0.76	11.9
Std. Dev	1.1	1.8	5.4	1.9	0.5	4.5	2.0	2.0	1	0.02	0.5
CV%	13.3	2.4	6.8	18.3	9.1	6.0	2.2	15.0	0.7	3.0	4.2

Abbreviation: L(w) = Length (weighted); SFC = Short Fiber Content; UQL = Upper Quartile Length; L(n) = Length (number weighted).

Siro-mélange yarn from raising waste fibre and cotton fibre whereas regular mélange yarn, GM 90:10 (cotton : black viscose), were manufactured for comparison.

One of the rovings of siro-mélange yarn was prepared by using cotton as raw material along with the raising waste fibre. The processes in the blow room utilized Trützschler machines that open the material into tufts as fine as possible and clean the fibres for the subsequent processes. Generally, the chute mat is supposed to go into the carding machine through the duct pipe in the Blow room section. However, here the material has been pulled out from the duct line for hand mixing before going to the carding machine.

A total of 20 kg was prepared through hand mixing, in which 10 kg was cotton and the other 10 kg was raising waste fibre. In this case, hand mixing involved laying down five layers of cotton and five layers of raising waste fibre to make a homogenous mixture **(Figure 2)**. In each layer of the mixture, there was 2 kg of cotton while every layer of the raising waste fibre similarly weighed 2 kg as well. The blend, after hand mixing, was manually fed through a duct pipe into the carding machine to produce card sliver. Further, the card sliver was processed through subsequent stages to produce one roving of siro-mélange yarn. The other roving was produced using 100% cotton fibre as usual. The complete machine sequence for siro-mélange yarn production is illustrated in **Figure 3**.

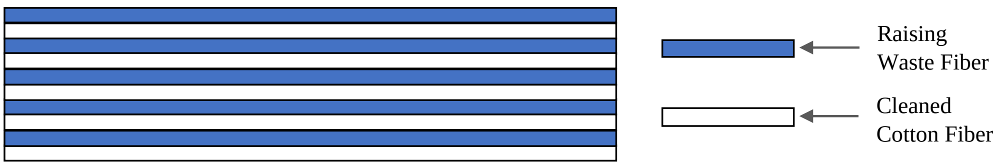

Figure 2: Hand-mixing of cotton and raising waste fibre

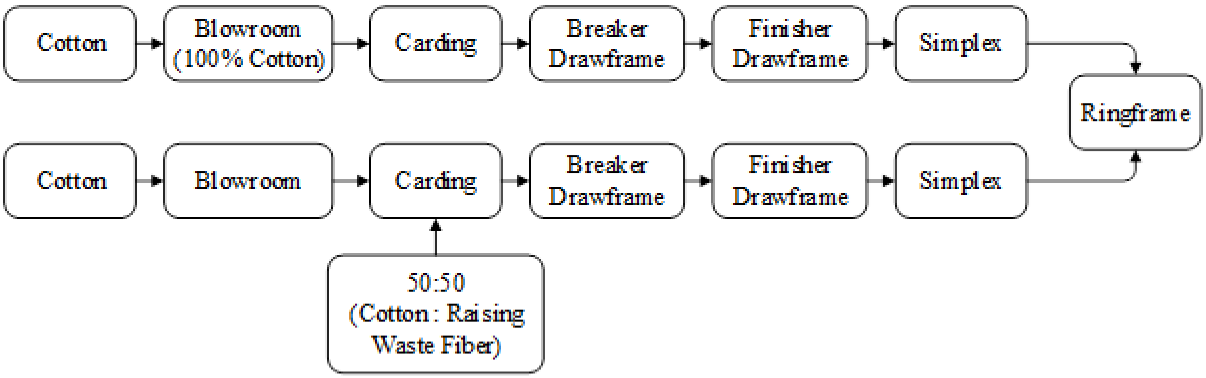

Figure 3: Process flowchart of siro-mélange yarn

Testing samples were conditioned in standard atmospheric condition (RH=65%, Temp=25º). Many tests were carried out during the manufacturing of siro-mélange yarn. Test name, testing equipment and testing principle are detailed in **Table 4** below.

Table 4: Testing parameters and standards

Name of Test	Testing instrument	Testing principle	Testing length	Testing speed
Count (Linear Density)	Wrap reel and Electronic Balance	ASTM-D1059-17	120Yds	-
Mass Variation	Uster Tester 6	ASTM D1425M-14	400m	400m/min
Bundle Strength	Ele Stretch XT	ASTM D1578-93	120Yds	300mm/min

3 Results and discussion

3.1 Yarn properties

The achieved siro-mélange yarn after the production process is shown below in **Figure 4**. The yarn properties of regular mélange yarn and siro-mélange yarn from raising waste fibre and cotton fibre depict below in **Table 5**.

Figure 4: Siro-mélange yarn consisting of cotton and raising waste fibre

Table 5: Yarn properties of siro-mélange yarn & regular mélange yarn

	10 Ne		14 Ne		16 Ne	
	Siro-Mélange	Regular Mélange	Siro-Mélange	Regular Mélange	Siro-Mélange	Regular Mélange
CV%	13.33	9.27	16.17	10.55	16	11.3
Thin Place -50%/km	0	0	6	0	10	0
Thick Place +50%/km	100	2	390	8	357	16
Neps +200%/km	45	1	253	5	218	8
CSP	2288	2470	2205	2394	2247	2368
Hairiness	8.54	9.32	6.99	7.85	6.99	7.32
Total IP Stand. /Km	145	3	649	13	585	23
Total IP Sens./km	1040	28	2993	145	2876	264

Quality of siro-mélange and regular mélange yarn in three different counts 10 Ne, 14 Ne and 16 Ne were compared and reported in **Figure 5**. The study is based on mass variation (CV%), count strength product (CSP), imperfection index (IPI), and yarn hairiness.

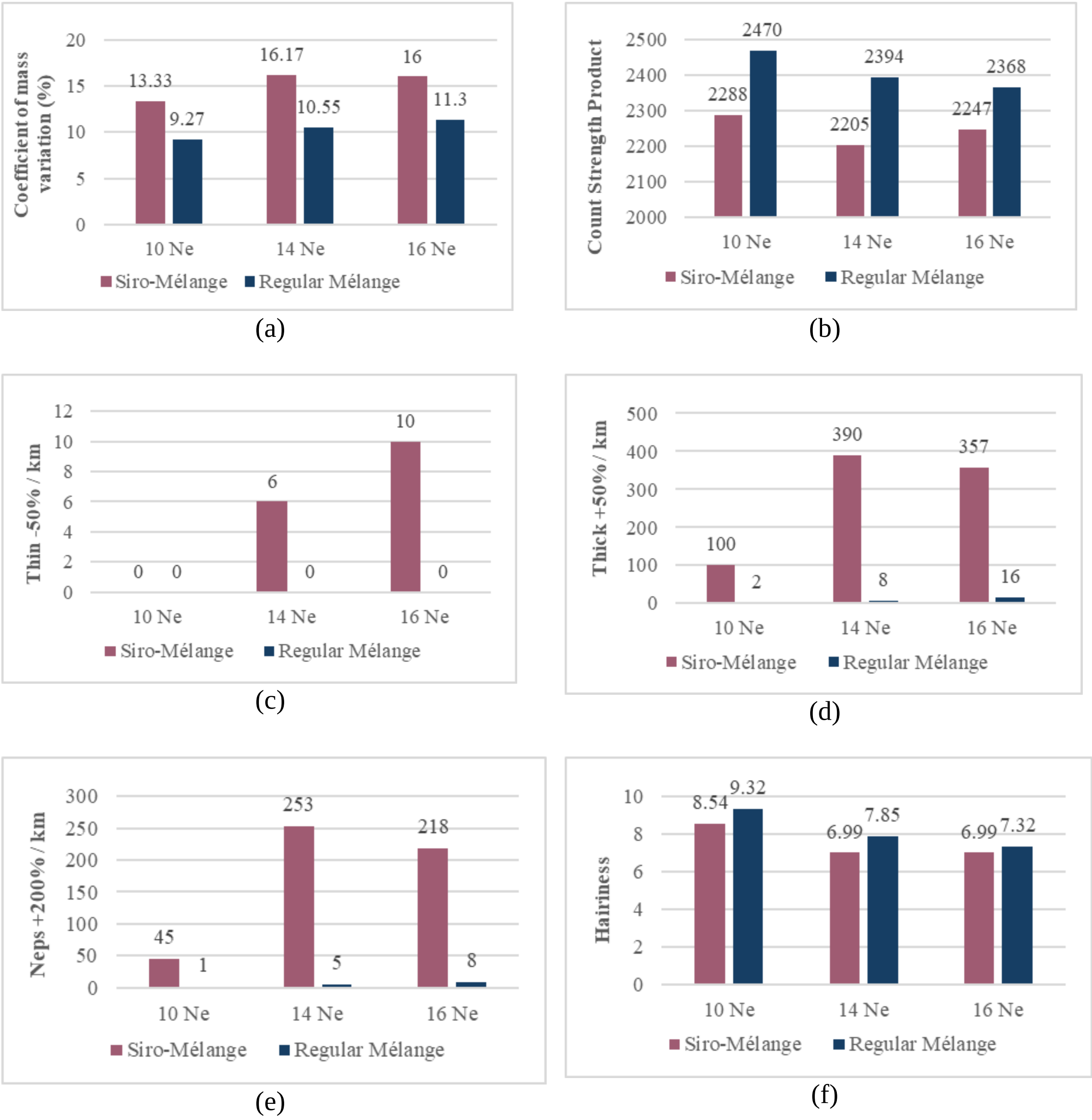

Figure 5 Evenness report of siro-mélange and regular mélange yarn. (a) coefficient of variation of mass (b) count strength product (c) thin places (-50%) (d) thick places (+50%) (e) neps (+200%) (f) hairiness

Coefficient of mass variation (CV%) was measured as a parameter for the irregularity of yarns. Coefficient of mass variation shows great sensitivity to fibre properties and process variables (Zeidman & Sawhney, 2002). During the whole experiment, the processing parameters are kept the same; however, the most important alterations have been done according to fibre parameters. Accordingly, it was observed that, for all three counts, siro-mélange yarn had more mass variation compared to regular mélange yarn. More precisely, the CV% related to siro-mélange yarn regarding 10 Ne, 14 Ne, and 16 Ne counts was higher by 4.06%, 5.62%, and 4.70%, respectively (shown in Figure 5(a)). The reason for this may be explained by the better length and uniformity of viscose fibres that suffered less during processing compared to raising waste fibres (Ray et al., 2018). The latter, because of the higher percentage of short fibres, increased the irregularity, that is, in finer yarns where a smaller number of fibres per unit area result in high mass variation. In fact, this result agrees with the previous work of the authors who found that the shorter length of raising waste fibres and its high percentage of short fibres result in greater irregularity, a finding in agreement with that made by (Kanon et al., 2023).

Count strength product (CSP) is the indication of strength and fineness of yarn calculated by multiplying yarn count with yarn tenacity. According to Figure 5(b), at counts 10 Ne, 14 Ne, and 16 Ne, regular mélange yarn had higher CSP of 182, 189, and 121 points respectively, against the siro-mélange yarn. Usually, siro yarns must have higher CSP because these are made as two-fold yarns. However, occurrence of short raising waste fibres in siro-mélange yarn decidedly discounted the strength of it, which was represented by the lower CSP as compared with that of regular mélange yarn (Zeidman & Sawhney, 2002). Another interesting point is the inverse relation between yarn counts and CSP; the finer the yarn, the less the number of fibres in cross-section area, the lower the strength. These findings agree with the previous study, as it was pointed out that the presence of short fibres leads to the loss in yarn strength (Khan et al., 2023).

IPI is the imperfection index of yarn, which comprises the thin places of -50%, thick places of +50%, and neps of +200%. Siro-mélange yarn showed values for imperfection of 145 and 649 for counts 10 Ne and 14 Ne, respectively, higher than that obtained for regular mélange yarn (Ochola et al., 2012). Whereas, the 16 Ne count, the values of imperfection of regular mélange yarn were higher by 585. All these IPI values was calculated from the Figures 5(c), 5(d) and 5(e). Probably, the increased imperfections of siro-mélange yarn are because of a shorter length and higher percentage of short fibres in raising waste fibres, fibre control in the process of drafting is a bit poor and thus sliver unevenness causes defects in yarn. The results also highlight that stiff, short, or dead fibres and those of highly variable length significantly enhance the imperfection index. The findings corroborate the work carried out by (Chaudhari et al., 2017), where it was observed that yarn quality is highly dependent on the quality of card slivers and that the variable slivers give rise to a number of yarns faults (Rashid et al., 2021).

Yarn hairiness can be described as the total protruding fibre length ratio per unit length of yarn and depends upon some important parameters like fibre length, proportion of short fibres, and rigidity (Cheng & Li, 2002). Data obtained shows that for every count, siro-mélange yarn was less hairy as compared to regular mélange yarn and at the count of 16 Ne, regular mélange yarn showed less hairiness. However, the actual values of hairiness for regular mélange yarn were respectively 0.78, 0.86 and 0.33 points higher for counts 10 Ne, 14 Ne and 16 Ne (see Figure 5(f)) even though the siro yarns normally have less hairiness due to two-fold structure. A relatively higher percentage of short fibres in the raising waste fibre contributed to more protruding fibre ends in siro-mélange yarn. This is a situation of less hairiness with increased fineness of yarns, which is probably because of decreased number of fibres per unit cross-sectional area. The above observations agree with the findings of (Yuksekkaya, 2008), who reports that the presence of short fibres increases yarn hairiness because of reduced cohesion between fibres and increased loose ends (Zhigang Xia et al., 2011).

3.2 Cost Analysis

The production costs of siro-mélange yarn and regular mélange yarn were investigated and compared. A comparison is given in Table 7. Raw materials accounts for 65-70% of all manufacturing cost. For the production of 10% regular mélange yarn, estimation shows that raw cotton fibre composed of 90-92% cost and 8% cost due to colour part. If 1% cost of the colour part is saved, a factory with 30ton capacity can save up to $405 USD per day.

Table 6 Costing of siro-mélange yarn and regular mélange yarn

Type of Yarn	Raw Material	Price of Raw Mat. (USD/kg)	Act. Mat. Ratio	Source Material Amount (Kg)	Input Mat. Price (USD)	Production Overhead Cost (USD/Kg)	Total Input Mat. Cost (USD/Kg)	CNF Cost (USD/Kg) (6%)	Approx. Final Yarn Cost (USD/Kg)
Siro-Mélange Yarn	Cotton	2.31	75.0	0.75	1.73	0.21	2.16	0.13	2.29
	Raising Waste Fiber	0.88	25.0	0.25	0.22				
	Total		100.0	1.0	1.95				
Regular Mélange Yarn	Cotton	2.31	90.0	0.90	2.08	0.21	2.59	0.16	2.75
	Black Viscose	2.96	10.0	0.10	0.30				
	Total		100.0	1.0	2.38				

Here, regular mélange yarn production cost is 2.75 USD/kg whereas siro-mélange yarn cost is 2.29 USD/kg. So, by using dyed waste fibre we can reduce the mixing cost up to 16% for 1 kg yarn production. If a spinning mill has the capacity of producing 10 Ton Yarn per day, they can save up to 4600 USD per day.

3.3 Sustainability benefits and integration into the circular economy

Nowadays, one of the most significant transformations for the textile industry, however, is the adoption of environmentally friendly ways of production. A very common example of substitution of regular mélange yarn with regular mélange yarn made from waste after fleece fabric brushing can be considered. The regular way of producing classical regular mélange yarn is conventionally judged as being incompatible with environmental requirements because of its high consumption of water and energy and reliance on synthetic fibres. In contrast, the production of siro-mélange yarn offers a closed-loop system, effectively reducing the industry's carbon footprint, conserving natural resources, and advancing the goals of a circular economy. By repurposing and reutilizing waste materials, this process contributes to the development of a more sustainable textile manufacturing industry (Singh et al., 2019).

Regular mélange yarn, because of aesthetic flexibility, poses a different set of environmental challenges to sustainability. This yarn often results from the blending of synthetic fibres, which, besides being highly energy-intensive, further sustains very high-water usage, especially for dyeing purposes. Further, the use of harmful chemicals for dyeing fabrics considerably aggravates environmental degradation in the form of pollution and resource depletion (Sehnem et al., 2019).

On the other hand, siro-mélange yarn is more ecological since it is prepared from raising waste fibre, usually at the time of fleece fabric making. This kind of waste, which would normally find its way into landfills, is collected and reprocessed for raw material into siro-mélange yarn. This reduces waste and lessens the environmental impact when compared to conventional yarn manufacturing processes. The siro-mélange yarn production closed-loop system feeds the waste back into the production cycle. This decreases significantly the consumption of virgin raw materials and decreases water and energy consumption by a lot (Niinimäki et al., 2020). It closes the material loops within the textile industry by creating a circular resource flow, thus responding to the general sustainability challenges of the industry (Geissdoerfer et al., 2017).

Having raising waste fibre included in siro-mélange yarn is representative of the philosophy of waste reduction and optimization of resources that forms the core of the circular economy. In such a value chain, waste gets valorised; therefore, there would be less landfilling, conservation of valuable resources, potentially decreasing demand on virgin material, hence helping industries to become less environmentally harmful. It further encourages sustainability for the textile industry in the development of a resource-efficient system that has no need for continuous extraction from natural resources (Wang, 2006).

Among many others, it disrupts the dependence on new raw materials, tantamount to environmental degradation, being at the top. It reduces the overall environmental impact of the textile industry in part by lessening demand for virgin raw materials-such as cotton and synthetic fibres-that in turn reduce carbon footprint and water usage. It enhances resource efficiency by diverting the waste materials away from landfills and incineration into production, consequently reducing the draw on non-renewable resources, such as the oil used to produce synthetic fibres (Purushothama, 2018). Besides the environmental advantages, huge economic and social advantages are accrued from switching into siro-mélange yarn production: the creation of jobs associated with recycling and reprocessing is thus made possible; and local and regional economies can take up the benefit. Besides, a reduction in synthetic fibres and chemicals intake cuts down on health risks for both workers and communities that are living nearby. This environmentally friendly approach thus creates a safe and sustainable workplace that promotes well-being among people engaged directly or indirectly in the textile business (Cheng & Yuen, 1997).

3.4 Limitations

There were various limitations realized in undertaking the project; thus, it may affect the general assessment or scalability of such results. One of the key limitations in these regards was the lack of concrete data about the actual percentage of the recycled fibre in the final yarn. This in turn made further analysis of the product's sustainability even more difficult to fully undertake as would have been needed to meet the strategic objectives of waste reduction and greater use of recycled materials in producing textiles. Furthermore, the production process for the yarn made up of the recovered fibres has not been fully scaled. Full scaling is one of the key factors that must be considered when the commercial viability of a product is to be considered at an industrial level. Without this valuation, it cannot be gauged if large-scale production or opening up to wider markets is possible. Besides, there is always a question over the availability of raw materials in sufficient and continuous quantity-the yet another big drawback. Also, uncertainty in the steady availability of raw materials undermines the scaling up of production in quantity, possibly at higher costs, thereby impacting economic feasibility. Overcoming these limitations in future studies will be an important step in realizing the full environmental and commercial potential of this novelty recycled fibre yarn.

Conclusion

Since the beginning of this work, the idea of recycling the specific waste material produced in one fleece fabric production process has motivated us. In the following thesis, we would like to research possibilities of its usage for making siro-mélange yarn. Nowadays, in the actual textile chain, waste derived from fleece fabrics goes to the landfills or incinerators and burdens the environment. In this direction, we're trying to introduce more sustainable diversified applications with the help of siro-mélange yarn for such leftovers, keeping our commitment to environmental responsibility in view.

From the regular mélange yarn to the latest siro-mélange yarn made from the raising waste of fleece fabric production was promising for both commercial and sustainable use, though with limitations. Therefore, siro-mélange yarn showed higher mass variation for all yarn counts: 4.06%, 5.62%, and 4.70% for 10 Ne, 14 Ne, and 16 Ne, respectively, compared to the latter due to the higher percentage of short fibres in raising waste. Although siro yarn has an intrinsic two-fold twist structure, because of the shorter fibres, siro yarn showed lower CSP values and its counterpart regular mélange yarn was performing better at 10 Ne, 14 Ne, and 16 Ne counts. However, IPI was higher for the siro-mélange yarn at 10 Ne and 14 Ne, though the number of imperfections was lesser at 16 Ne. Moreover, siro-mélange yarn showed less hairiness at 10 Ne and 14 Ne, which means that the finer the count, the more hairiness increases. Finally, even though siro-mélange yarn has some drawbacks concerning strength and regularity, it presents a promising sustainable product in terms of reducing the dependency on virgin material, reducing production cost, and reaching some of the industrial environmental goals.

In the spinning industry, cost efficiency is always the prime factor, and our project has huge significance in regard to this. The cost of raw material constitutes around 60% of all the production costs. We will add a generous amount of raising waste fibre to the raw cotton or other natural and synthetic fibres in the yarn making process, and it is definite that this will have quite an impact on the production cost. It, therefore, stands out as one of the most vital innovations in the industry, since it tackled the cost component of production.

The waste material generated from fleece fabric manufacturing basically consists of dyed fibre, which can replace 10% of the coloured viscose. Such is the context wherein by consuming this dyed fibre in our siro-mélange yarn, we aim at reducing the demand for the coloured fibre and, subsequently, the demand for the power-intensive dyeing process. This approach of environmentalists saves not only prime resources such as water and electricity but also keeps the environment safe due to low levels of pollution.

Other value addition applications of these types of recycled fibres in the Bangladesh textile industry are still at their infancy. However, this study can hopefully serve as a catalyst for transformation through the introduction of siro-mélange yarn produced from that particular class of recycled fibres. This can unlock newer opportunities and open new vistas regarding value addition in textile products within our country while upholding the pledge for sustainability and innovation.

Roles of author

Study Conception and Design (M.B.U); Experimentation – Collection of data (F.M., A.H.R., M.K.H, M.A.H); Analysis and Interpretation of Results (F.M., A.H.R., M.K.H, M.A.H); Writing the Original Draft (F.M., A.H.R., M.K.H, M.A.H); Writing-review and Editing (F.M., A.H.R., M.K.H, M.A.H); Overall supervision (M.B.U).

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Conflict of interest

The author declares that there is/are no conflicts of interest.

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