ENVIRONMENTAL SUSTAINABILITY: A CHALLENGE FOR LEATHER INDUSTRY

Kanij FATEMA[1], Md. Rayhan SARKER[1*], Kawsar AKHTAR[1], Aklima BEGUM[2], Shafiqul ISLAM[1,3]

[1]Institute of Leather Engineering and Technology, University of Dhaka, Dhaka-1209, Bangladesh,

kanijfatema19d@gmail.com, sarker.rayhan@du.ac.bd, kawsarakhtar32@du.ac.bd

[2]Electronics Division, Atomic Energy Centre, Dhaka-1000, Bangladesh, akhi.eeebd97@gmail.com

[3]Limex Technologies Ltd., Dhaka-1209, Bangladesh, shafiqle12@gmail.com

Received: 03.05.2023 Accepted: 06.09.2023 https://doi.org/10.24264/lfj.23.3.6

ENVIRONMENTAL SUSTAINABILITY: A CHALLENGE FOR LEATHER INDUSTRY

ABSTRACT. Adopting pollution prevention strategies (PPS) can ensure environmental sustainability (ES) in the leather industry and can help the industry achieve several sustainable development goals (SDGs). In order to ensure the ES of the leather industry, there is a need for research to identify a comprehensive list of PPS. This research aims at identifying the most effective PPS for the leather industry, which are categorized into 4R (reduce, reuse, recycle, and recover) dimensions. This is a case study where four leather processing companies from Bangladesh were purposively selected. Through an extensive literature review and experts' opinions, 21 PPS are identified for the leather industry's ES. Also, this study shows several benefits of PPS through which various SDGs can be achieved in the leather industry. This study will certainly guide the leather industry managers to ensure the ES of the leather industry and, consequently, assist in achieving several SDGs.
KEY WORDS: 4R strategies, environment sustainability, leather industry, pollution prevention, sustainable development goals

SUSTENABILITATEA MEDIULUI: O PROVOCARE PENTRU INDUSTRIA DE PIELĂRIE

REZUMAT. Adoptarea strategiilor de prevenire a poluării poate asigura sustenabilitatea mediului în industria de pielărie și poate ajuta industria să atingă mai multe obiective de dezvoltare durabilă (ODD). Pentru a asigura sustenabilitatea mediului în industria de pielărie, este nevoie de cercetare pentru a identifica o listă cuprinzătoare de strategii de prevenire a poluării. Această cercetare își propune să identifice cele mai eficiente strategii de prevenire a poluării pentru industria de pielărie, pe principiul 4R (reducere, reutilizare, reciclare și recuperare). În acest studiu de caz s-au selectat intenționat patru companii de prelucrare a pielii din Bangladesh. Printr-o analiză extinsă a literaturii de specialitate și a opiniilor experților, s-au identificat 21 de strategii de prevenire a poluării pentru sustenabilitatea mediului în industria de pielărie. De asemenea, acest studiu arată câteva beneficii ale strategiilor de prevenire a poluării prin care pot fi atinse diverse ODD-uri în industria de pielărie. Acest studiu va ghida cu siguranță managerii din industria de pielărie pentru a asigura sustenabilitatea mediului în industria de pielărie și, în consecință, pentru a ajuta la atingerea mai multor ODD.
CUVINTE CHEIE: strategii 4R, sustenabilitatea mediului, industria de pielărie, prevenirea poluării, obiective de dezvoltare durabilă

LA DURABILITÉ ENVIRONNEMENTALE : UN DÉFI POUR L'INDUSTRIE DU CUIR

RÉSUMÉ. L'adoption de stratégies de prévention de la pollution peut garantir la durabilité environnementale dans l'industrie du cuir et aider l'industrie à atteindre plusieurs objectifs de développement durable (ODD). Pour garantir la durabilité environnementale dans l'industrie du cuir, des recherches sont nécessaires pour identifier une liste complète de stratégies de prévention de la pollution. Cette recherche vise à identifier les stratégies de prévention de la pollution les plus efficaces pour l'industrie du cuir, basées sur le principe des 4R (réduire, réutiliser, recycler et valoriser). Quatre entreprises de transformation du cuir au Bangladesh ont été délibérément sélectionnées dans cette étude de cas. Grâce à une analyse approfondie de la littérature et des avis d'experts, 21 stratégies de prévention de la pollution pour la durabilité environnementale dans l'industrie du cuir ont été identifiées. En outre, cette étude montre certains avantages des stratégies de prévention de la pollution grâce auxquelles divers ODD peuvent être atteints dans l'industrie du cuir. Cette étude guidera sûrement les responsables de l'industrie du cuir pour assurer la durabilité environnementale dans l'industrie du cuir et contribuera par conséquent à atteindre plusieurs ODD.
MOTS CLÉS : stratégies 4R, durabilité environnementale, industrie du cuir, prévention de la pollution, objectifs de développement durable

INTRODUCTION

The leather processing companies known as tanneries produce huge amounts of pollutants during preservation to finished leather production. During 1,000 kg of hides or skins processing into leather, 30-40 m^3 of wastewater and 800-850 kg of solid wastes are generated, which contain 300 kg of hazardous chemicals [1]. Bangladesh has huge potential for developing this sector as it has an abundant supply of quality raw materials and cheap production costs. However, the country is lagging behind in the competition due to the lack of environmental sustainability (ES) of its tanneries [2]. Nowadays, ES has become a burning issue for the leather industry due to global warming and the worsening of the environmental ecosystem [3-4]. Moreover, most consumers and reputed buyers are giving

* *Correspondence to: Md. Rayhan SARKER, Institute of Leather Engineering and Technology, University of Dhaka, Dhaka-1209, Bangladesh, sarker.rayhan@du.ac.bd*

priority to outsourcing leather and leather products from sustainable tanneries. Therefore, the need for adopting sustainable practices has become a major priority for the leather processing industry in every country. However, most of the tannery owners in Bangladesh consider adopting sustainable practices an expensive and complex process, which will increase the cost of manufacturing. As a result, ES has become a massive challenge for the leather industry in Bangladesh. In the previous literature, researchers have tried to find a better way to shape the leather industry as more sustainable. In this vein, Marrucci *et al*. (2022) argued that life cycle assessment is a necessary approach to ensure a circular business model in the leather industry for ensuring a zero-carbon future [5]. Huang *et al*. (2022) developed chrome-free eco-friendly leather to mitigate the environmental pollution from chrome-tanned leather processing [6]. Karuppiah *et al*. (2021) conducted a review article to find out the inhibitors of circular economy practices in the context of the leather industry [7]. China *et al*. (2020) performed a review study on possible alternative technologies rather than the widely used chrome tanning process to prevent environmental pollution [8]. Islam *et al*. (2020) identified the challenges of sustainable supply chain management for the Bangladeshi leather industry [9]. Moktadir *et al*. (2020) identified the challenges to implementing circular economy practices in the Bangladeshi leather industry for achieving ES [10]. Kanagaraj *et al*. (2015) and Dixit *et al*. (2015) have explored various cleaner technologies for mitigating the environmental footprint of the leather industry [11-12]. Gupta *et al*. (2018) conducted a case study on a leather processing company in India to explore the firm performance between pollution prevention and control strategies and its benefits over the triple bottom line (TBL) approach [13].

From an extant literature review, it is evident that there were various studies that focused on the implementation of cleaner technologies in leather processing and the identification of the challenges of circular economy practices and sustainable supply chain management in the leather industry. However, there was a scarcity of literature on a summarized comprehensive list of pollution prevention strategies (PPS) for the leather industry. To the best of our knowledge, no prior research was carried out on the existing state of adoption of various PPS for achieving ES of tanneries and their prospective benefits on achieving several sustainable development goals (SDGs). Therefore, this research is intended to fulfill the following objectives:

1. To identify the pollution prevention and control strategies for the leather industry under the 4R (Reduce, Reuse, Recycle, and Recover) dimensions and explore the environmental benefits of those strategies.
2. To find out the current status of practicing the identified 4R practices for the selected four case leather companies in Bangladesh.
3. To suggest practical implications for achieving SDGs and environmental compliance certification (e.g., Leather Working Group) for the leather industry in the way of ensuring environmental sustainability.

Literature Review

An Overview of the Leather Industry in Bangladesh

Bangladesh has a good reputation for manufacturing excellent quality leather around the world at competitive prices due to low labor costs, availability of raw hides/skins, and government incentives for export [14]. The country has 200 tanneries and 165 leather goods and footwear companies, which are contributing to the country's export market. According to the Export Promotion Bureau of Bangladesh, in the last fiscal year 2021-2022, Bangladesh exported $ 1.245 billion in leather, leather goods, and leather footwear with a positive growth of 32.31% against that of the previous year, achieving the 2nd export earning sector in the country [15]. Currently, Bangladesh is contributing less than 0.5% of the total world demand for leather, leather goods, and leather footwear. The major barrier to escalating the export volume of the leather

industry is a lack of ES. The absence of proper waste management, inferior technologies, traditional methods of leather processing, lack of facilities for improvement, and unwillingness for adopting eco-friendly practices have created a negative environmental impression for the leather industry in the international business environment [12]. This industry creates a huge amount of hazardous and toxic pollutants degrading the surrounding environments, creating serious health problems among the employees working in the leather processing companies, and thus lowering the living standards of the community people. Due to severe environmental pollution, degraded human life in the Hazaribagh area (a residential zone in Dhaka city), and simultaneous pressurization from the environmental protection agencies, pollution control bodies, buyers, well-known brands, etc., the Bangladesh government took an initiative of relocating all the leather processing units from Hazaribagh to the Tannery Industrial Estate, Hemayetpur, Savar. This specialized estate has a Central Effluent Treatment Plant (CETP) system that can treat 30,000 m^3 effluents in a single day with extra facilities for chrome recovery, water treatment, and sludge treatment [16]. Though solid wastes are the major wastes of this industry, there is no solid waste management plant in the Tannery Industrial Estate so far. Also, at the Tannery Industrial Estate, the central effluent treatment plant (CETP) system is not functional at the required scale [17-18]. Due to the improper installation of some pre-planned facilities, and improper regulations from the authority, the Dhaleaswari river near the CETP plant, has been polluted and thereby, the surrounding environment is destroying a great deal [19-21]. If this situation continues to degrade the ecosystems at this devastating rate, this will turn into a death trap for the leather industry. Therefore, more research is needed to make a guideline on how to implement sustainable leather processing for ensuring ES in the Bangladeshi leather industry.

Environmental Sustainability (ES)

Elkington first used the phrase 'triple bottom line', a way of measuring a company's sustainability, in his book named *Cannibals with the Fork: The Triple Bottom Line of 21st-Century Business* [22]. The author explained in that book that a sustainable company will not only preserve and use natural and energy resources but also give importance to human rights with keeping the best interest of the company's economic condition. In other words, the sustainability of an organization is branched into three dimensions, i.e., environmental, social, and economic sustainability. Sutton *et al*. (2014) defined environmental sustainability as the capability to maintain things or qualities that are valued in natural and biological environments [23]. It is a way of conserving natural resources and protecting the ecosystem for current and future generations [24]. Broadly, it is a state of balancing resiliency and interconnectedness that allows human society to satisfy its needs neither by exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity [25-26]. As leather processing operations are extremely polluting, sustainable practices can lead this industry to achieve ES [11,13]. The International Council of Tanners (ICT), an organization of the world's leather trade association has described ES for the leather industry in the following contexts: whole compliance with environmental regulations that include water and air emissions, and solid wastes; obedience to energy efficiency; processing life cycle assessment and identification of the environmental footprint of leather processing; commitment to doing the operations towards best practices in processing to predict ever-increasing environmental controls and carbon reduction targets and to practice due diligence.

ES can be achieved by practices such as adopting clean production practices in leather processing, efficient usage of energy, effective waste minimization techniques, proper waste management practices, reduction of natural resources consumption, better usage of raw materials and processing chemicals, reduction

of the quantity of the pollutants emitted, and reduction of the environmental cycle of products [27-29]. In addition, adopting environmentally sustainable practices influence organizational performance creating economic, environmental, and social benefits and improving the company's image among the supply chain members [27, 30-32]. An environmentally sustainable leather processing company can lead to several environmental benefits represented in Table 1, which will not only improve any company's business but also ensure the overall protection of the environment.

Table 1: Potential Environmental Benefits from 4R Practices [33]

Environmental benefits
1. Reduction of water, chemical, raw materials, and energy consumption.
2. Less generation of the air pollutants emissions such as carbon products, nitrogenous products, VOC (volatile organic chemicals), particulate matter, smoke, dust, heat, etc.
3. Almost no or less generation of hazardous pollutants such as heavy metals, chemical oxygen demand (COD), biological oxygen demand (BOD), pH values, nitrogenous and phosphorous compounds, suspended solids, etc., in the wastewater and releasing clean water into the environment.
4. Less generation of solid wastes and usage of the solid wastes into value-added products.

4R Strategies for Pollution Prevention and Pollution Control

Pollution prevention is the process of reducing the amount of generation of wastes including source reduction, and efficient use of raw materials and energy resources, whereas pollution control, is the process of managing the pollutants after it is emitted by recycling and recovering them in order to reduce the impact of pollutants on the environment [34-35]. Pollution prevention, i.e., source reduction, cleaner technology, etc., may seem a costly process at the initial stage of adaptation in the leather industry but in the long run, it will benefit this industry by reducing the risk of liability, saving the operating cost, lowering the housekeeping cost, increasing the productivity and process efficiency, reducing the environmental impacts of the wastes, protecting the eco-system and resources [32, 36]. Both pollution prevention and pollution control strategies can improve the industry's current deteriorating situation, which can effectively aid the leather industry of Bangladesh in thriving. 4R, i.e., Reduce, Reuse, Recycle, and Recover strategies are widely used in waste management, which is a great tool for minimizing, managing, and recovering reusable materials from both solid and liquid wastes. A brief description of the 4R strategies is given below:

- ***Reduce***

Reducing means minimizing the consumption of any resources (e.g., chemicals, energy) and lowering the generation of waste during any stage of leather processing [37].

- ***Reuse***

Reuse means the usage of tannery wastes as raw materials or products either in the same function or in other functions [37].

- ***Recycle***

Recycling means the conversion of tannery wastes into useable products or the usage of these wastes as raw materials in another process after simply treating them by collection, separation, and suitable modification while all the physical and chemical characteristics remain similar to the wastes [37].

- ***Recover***

Recover means the usage of tannery wastes as raw materials or products after technical treatment while the main physical and chemical properties of these wastes change to their prior conditions [37].

There were very few studies based on 4R practices of waste management for pollution prevention and control in the leather processing industry in the previous literature. Leather processing involves many unit operations using a lot of chemicals that emit many hazardous and carcinogenic pollutants posing a serious threat to the ES of this industry [38]. The negative impact on the environment

and high dissipation of energy of this industry can be mitigated by adopting a closed-loop economy or zero-waste technologies rather than depending on the linear economy of waste management where wastes will be recovered and recycled and reused in the same industry or other similar industries [39]. Cleaner production can be introduced in the leather processing industry by changing raw materials and production processes in beam house operations, using alternatives to chrome tanning, increasing the uptake of chrome in the tanning process, recovering and reusing chromium, and direct chromium recycling [40]. Waste utilization might also be beneficial for this industry as many solid wastes can be altered into biodiesel/biomass [41], composite sheets [42], electromagnetic interference shielding [43] mixing with other materials; buffing dust can be used as a filler in the production of rigid polyurethane foams [44] and for the fabrication of composite sheet [45], leather solid wastes can be also turned into new leather by solid-state shear milling technology by incorporating thermoplastic polyurethane [46]. Additionally, recovered protein hydrolysate from chrome shaving dust can be utilized as a filler/fat-liquoring agent, free from any toxic chemicals in the re-chroming/ fat-liquoring operation that will produce high-quality leather [47]. Also, these protein hydrolysates are applicable in agriculture, feed, adhesives, bio-plastic, construction, cosmetics, pharmaceutical industries, and bone and tissue engineering combined with several polymer composites or matrixes [48].

However, all these studies indicate the pilot application and theoretical exploration of the waste minimization, waste management, and waste utilization techniques that can be applied to the leather industry aiming at achieving ES. The real-life observations of these techniques and methods have not been explored in the context of the leather industry of Bangladesh. Against this backdrop, this study first focuses on the identification of a comprehensive list of pollution prevention strategies (PPS) for the leather industry's sustainability. Second, this study finds the current practices of adopting PPS in the leather industry. Finally, this study also highlights the gaps in why the practitioners of this industry are not adopting PPS for ensuring ES. This study contributes to the existing literature in the following ways. This study will identify the PPS under the 4R dimensions of waste management, which will be feasible to implement in leather processing operations. The findings of this study will particularly help industry practitioners achieve ES and thereby ensure several sustainable development goals (SDGs).

Table 2: Potential 4R Practices in leather processing from literature review and experts' opinions

4R dimensions	Pollution prevention strategies (PPS)	References
Reduce	1. Usages of green or raw hides/skins	49
	2. Usage of silica gel/boric acids/SMB (sodium chloride and sodium meta bi-sulfite method)/phytochemical preservation/bacteriocin solution in preservation stages of leather processing	11
	3. Usage of green fleshing	49
	4. Practicing short float operations	37
	5. Ammonium-free deliming	50
	6. Usage of sulfur stripping in dehairing and liming	49
	7. Enzymatic dehairing operations using proteolytic and lipolytic enzyme or using enzyme hydrogen peroxide	51
	8. Hair-saving methods in dehairing operations	52
	9. Usage of water-based liquor in finishing operations	49

4R dimensions	Pollution prevention strategies (PPS)	References
	10. Alternatives of chromium salts in tanning systems such as fleshing-acrylate composite, nanoparticle dispersion (NPD), phosphonium-based tanning agents, Nanoparticle polymer (NPP), and combination tanning using vegetable tannins and aluminium sulphate	11, 13, 53
	11. Mass balance in the process and Zero Liquid Discharge (ZLD) in the tannery	Proposed in this article
Reuse	1. Usage of the same float in soaking and liming operations	37
	2. Usage of pre-deliming float in the liming and reliming operations	54, 55
	3. Usage of bating float in the pre-diming, liming, and bating operations	
	4. Usage of the tanning liquors after screening and biological/chemical treatment in the pickling and tanning operations	
	5. Usage of the recovered chrome from the tanning effluents in percentage with fresh chrome salts in tanning operation	
Recycle	1. Conversion of solid wastes (raw trimmings, fleshings, chrome shaving) into by-products (composite leather sheet, glue, gelatin, biodiesel, etc.)	56
	2. Recycling of waste liquor such as liming, pickling, and tanning liquors and reusing it in a loop system	Proposed in this article
Recover	1. Energy recovery from different solid wastes (raw trimmings, pre-fleshings, limed fleshings, buffing dust, chrome shavings, etc.)	57-59
	2. Chrome recovery by various economic methods and usage of the recovered chrome in the tanning operation	58, 60, 61
	3. Recovering protein hydrolysate from raw trimmings, buffing dust, and chrome shaving dust and usage of it in the re-chroming/fat-liquoring process as a filler/fat-liquoring agent, surface up-gradation of the leather, brick, and concrete manufacturing process, composite materials formation	45, 57, 62

Methodology

This study used a qualitative case study. The case study was chosen because it is a proper method for investigating a specific problem in any industry [32]. Case study often leads to new, creative, and in-depth insights about any problem, develop a new, novel, testable, and analytically valid theory, and present real-life situations about the subjects of interest [49]. In order to get in-depth and real-life data, the case study was selected for this particular study. In this study, a non-probability sampling technique was used to choose an expert panel of 17 members. In the expert panel, the faculty members of the Institute of Leather Engineering and Technology, University of Dhaka, Bangladesh, Khulna University of Engineering and Technology, Bangladesh, and tannery experts of Bangladesh who have at least 5 years of working experience were targeted as the samples for finalizing the potential 4R practices at the first step. A total of 21 potential PPS were identified from a literature review. Then, the PPS were validated by the expert panel. The validated PPS are presented in Table 2, in which there are 11 practices under the reduce section, 4 for reuse, 2 for recycling, and 3 for the recover sections. Later, a survey questionnaire and an interview protocol were developed to capture the data from the expert panel about 4R practices regarding PPS in the context of the leather industry's ES. For the case study, four tanneries were purposively selected to explore the current status of adopting the identified 21 PPS. Figure 1 represents the research framework that was followed for this study.

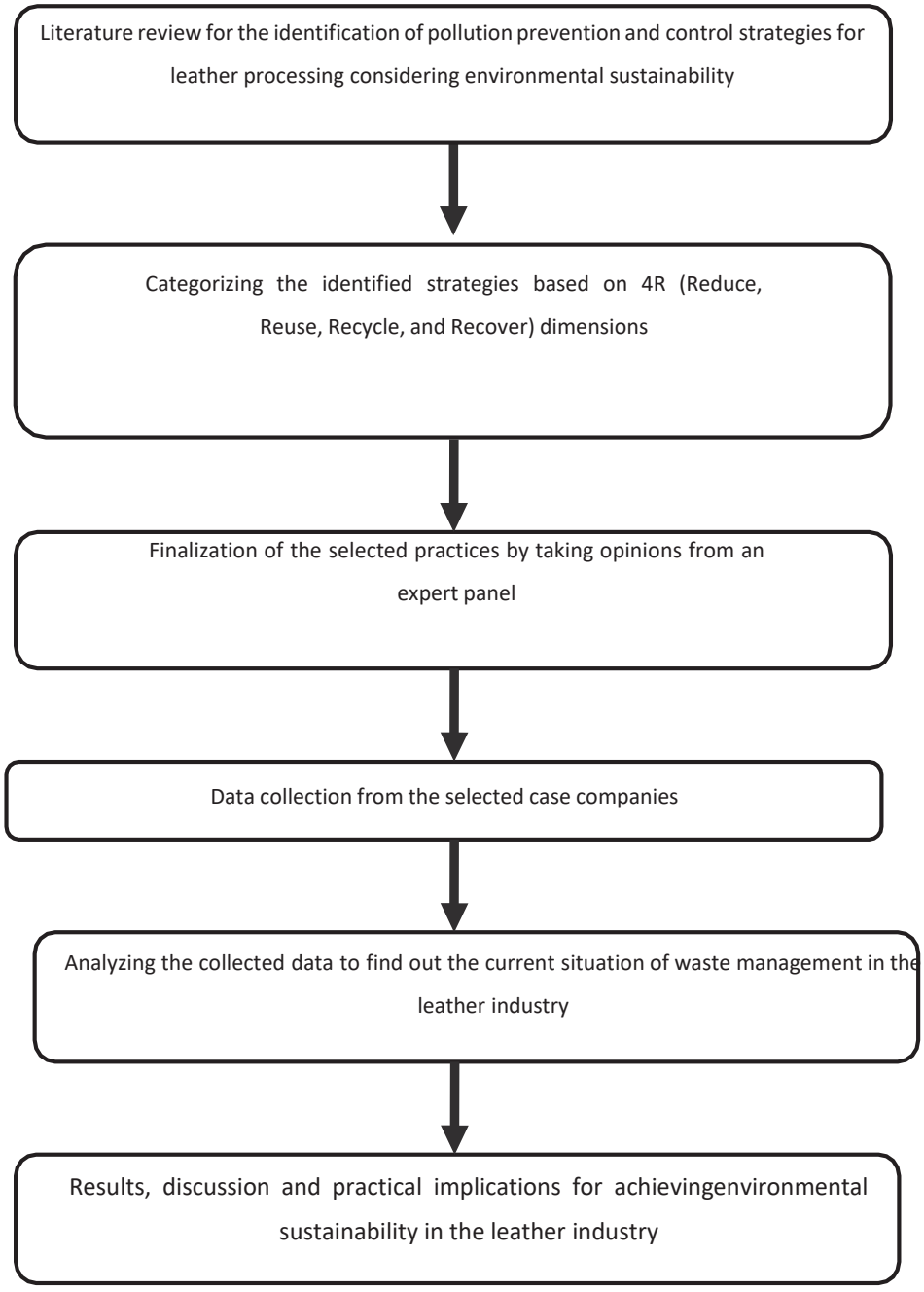

Figure 1. Research framework of this study

Case Study and Data Collection

The previous literature showed that purposive sampling has gained popularity among researchers in the case study [4]. Therefore, in this study, purposive sampling was used to select the four case tanneries in Bangladesh. The selected four leather processing companies (LPC) are referred to as LPC 1, LPC 2, LPC 3, and LPC 4 in this article. The general manager of each tannery was interviewed about their 4R practices based on the questionnaire focusing on 21 PPS as shown in Table 2, the benefits of 4R practices to the environment, and what approaches they are willing to take in the future were asked. The recorded data are presented in Table 3 and Table 4.

Table 3: The practical scenario of case companies against 4R practices for pollution prevention and control

4 R dimension	Potential practices	LPC 1	LPC 2	LPC 3	LPC 4
Reduce	1. Raw materials	Salted hides/skins	Salted hides/skins	Salted hides/skins	Salted hides/skins
	2. Preservation techniques	Salt curing	Salt curing	Salt curing	Salt curing
	3. Green fleshing utilization	No	No	No	No
	4. Practicing of short float in beam house operations	Moderate float	Moderate float	Moderate float	Yes
	5. Deliming procedure	Conventional	Conventional	Conventional	Conventiona
	6. Dehairing procedure	Conventional	Conventional	Conventional	Modern
	7. Usage of water-based liquor in the finishing process	Depending on the final finished leather requirements	Depending on the final finished leather requirements	Depending on the final finished leather requirements	Depending on the final finished leather requirement
	8. Tanning salts used in tanning operation	Basic chrome salts	Basic chrome salts	Basic chrome salts	Basic chrom salts
	9. Utilization of mass balance and zero-liquid discharge (ZLD)	No	No	No	No
	10. Any special method/techniques that reduce the generation of the wastes	No	No	No	Yes, hair separation from liming operation.
Reuse	1. Usage of the same float in soaking and liming operation	No	No	No	No
	2. Usage of pre-deliming float in the liming and reliming operations	No	No	No	No
	3. Usage of bating float in the pre-deliming, liming, and bating operations	No	No	No	No
	4. Usage of the tanning liquors after screening and biological/chemical treatment in the pickling and tanning operations	No	No	No	No
	5. Usage of the recovered chrome from the tanning effluents in percentage with fresh chrome salts in the tanning operation	No	No	No	No
	6. Any special techniques/methods that include reusing the solid/liquid wastes	No	No	No	No

4 R dimension	Potential practices	LPC 1	LPC 2	LPC 3	LPC 4
Recycle	1. Conversion of solid wastes (raw trimmings, fleshings, chrome shaving) into by- products (composite leather sheet, glue, gelatin, biodiesel, etc.)	No	No	No	No
	2. Recycling of waste liquor such as liming, pickling, tanning liquors and reusing it in a loop system	No	No	No	No
	3. Any method/technique the company has implemented that recycle the wastes	No	No	No	Trying to implement
Recover	1. Energy recovery from different solid wastes (raw trimmings, pre fleshings, limed fleshings, buffing dust, chrome shavings, etc.)	No	No	No	No
	2. Chrome recovery from tanning effluents	No	No	No	Yes
	3. Recovering the protein hydrolysate from raw trimmings, buffing dust, chrome saving/tanned saving	No	No	No	No
	4. Any special method/techniques that recover value-added products from wastes	No	No	No	Yes, hair separation from liming operation

Table 4: Environmental benefits from sustainable leather processing practices

Environmental benefits from PPS	LPC 1	LPC 2	LPC 3	LPC 4
1. Reduction of the water, chemical, raw materials, and energy consumption	Agree	Agree	Agree	Agree
2. Less generation of the air pollutants emissions such as carbon products, nitrogenous products, VOC (volatile organic chemicals), particulate matters, smoke, dust, heat, etc.	Agree	Agree	Agree	Agree
3. Almost no or less generation of the hazardous pollutants such as heavy metals, COD, BOD, pH values, nitrogenous and phosphorous compounds, suspended solids, etc. in the wastewater and releasing clean water into the environment	Agree	Agree	Agree	Agree
4. Less generation of the solid wastes and usage of the solid wastes into value-added products	Agree	Agree	Agree	Agree

RESULTS AND DISCUSSION

Analysis of the Data

From the collected data, it is found that the case companies did not follow much of the 4R practices even though they agreed on the fact that adopting 4R practices result in benefitting the environment and human life. In the reduce section, 10 questions were asked to get the practical approaches for reducing the generation of waste. For raw materials, all of the selected case companies used salted hides/skins. Salt curing was used as preserving the raw hides/skins. The green fleshing from the salted hides/skins was dumped in the open areas. During beam-house operations, moderate floats were generally used. For deliming operations, ammonium sulfate and ammonium chloride were used. Mixtures of lime and sodium sulfides were used in the unhairing/dehairing operation. Depending on the customer's or buyer's requirements, water-based liquors were used in the finishing operation whereas generally solvent-based liquors were preferred. Basic chrome salts were utilized in the tanning process. In any of the processes, mass balancing and zero-liquid discharge methods were also not employed. Three of the companies do not have any special techniques for reducing the generation of waste while LPC 4 was using hair separation techniques from the liming operation. 6 questions were interrogated in the reuse section. Usage of the same float in the soaking and liming was not utilized in the case companies. Utilization of the pre-deliming float in the liming and re-liming operations, bating float in the pre-deliming, liming, and bating operations were not followed. Finally, usage of the tanning liquors after treatment in the next tanning/pickling operation and usage of the recovered chrome from tanning effluents in certain percentage with fresh chrome salts were not utilized. Currently, the selected companies are not performing any special methods/techniques for reusing waste. In the recycling criteria, 3 questions were posed. Conversion of solid wastes (raw trimming, fleshing, chrome shaving) into by-products (composite leather sheet, glue, gelatin, biodiesel, etc.) were not performed in those companies. Recycling the waste liquors i.e., liming, pickling, tanning, and reusing in the loop system was not utilized. Furthermore, case companies do not have any method involved in recycling the waste. 5 questions were asked in the recovery criteria. All four of them did not recover energy from different solid wastes (raw trimmings, pre-fleshing, limed fleshing, buffing dust, chrome shavings, etc.). Chrome from the tanning effluents and protein hydrolysate from raw trimmings, buffing dust, and chrome saving/tanned saving were not recovered as well for the 2 case companies whilst among them, LPC 4 were using chrome recovery techniques. LPC 4 company was just separating chrome from waste liquors, it was not processing this recovered chrome waste for further use in any other operations. Moreover, the three case companies did not have any special chrome recovery techniques. The general manager from LPC 1, LPC 2, LPC 3, and LPC 4 were requested to share their opinions about the benefits the leather processing company may provide to the environment through adopting those potential 4R practices. All of them agreed on the point that adopting the 4R practices in leather processing will result in less generation of air pollutants emissions such as carbon products, nitrogenous products, VOC (volatile organic compounds), particulate matter, smoke, dust, heat, etc. They also agreed that 4R practices will generate almost no or less amount of hazardous pollutants such as heavy metals, decreased chemical oxygen demand (COD), decreased biological oxygen demand (BOD), standard discharged pH values, reduced nitrogenous and phosphorous compounds, reduced suspended solids in the wastewater, and releasing nearly pure water into the environment. In addition, less generation of solid wastes and usage of the solid wastes into value-added products will be induced by 4R practices. Moreover, they agreed that 4R practices can reduce the amounts of chemicals, raw materials, energy consumption, and different wastes during leather processing.

From this case study of the leather processing companies, it is clear that the Bangladeshi leather industry is still far behind in achieving ES. Due to the inefficient CETP in

the Hemayetpur area, the collected effluents from the local leather processing companies are not treated properly. Hence, the effluents that are discharged into the Dhaleshwari river from the CETP, are polluting the river with highly contaminated with chromium and other heavy metals [50] and surrounding because of the dumping of the solid wastes in the open yards. From Table 3, it is visible that the case leather processing companies are not concerned about adopting the PPS in their companies. This study finds that three of the four tanneries did not have any effluent treatment system, which is a prerequisite condition for sustainable leather processing. The main reason for that is the lack of investment in cleaner processing technologies, advanced machinery, and equipment. Though practitioners of the leather industry believe in several environmental benefits from the enlisted PPS, they are not interested in investment for change management in their organizations. They believe any further investment to ensure environmental compliance issues will increase their manufacturing costs, which may lose their competitiveness in the international market. However, from the interview with the top management of the LPC 4 case company, it is visible that if any leather company invests in ensuring environmental compliance issues, it will increase its competitiveness in the international market where the company can demand a higher price than the traditional leather processing companies. In LPC 4 company, their market shares and unit price of leather has been increased so much after the establishment their own ETP. Nowadays, international buyers of leather, leather goods, and leather footwear are sourcing leather from environmentally compliant tanneries. Therefore, practitioners of the leather industry should come forward with their own ETP and proper PPS to increase their market share.

Among the case companies, unlike LPC 1, LPC 2, and LPC 3, LPC 4 have practiced some of the PPS and thinking of implementing some other practices, which are beneficial for the company in achieving ES. For reducing water consumption and generation of toxic pollutants, LPC 4 practices short float in beam house operations. Additionally, it has modern dehairing techniques to reduce the COD and BOD values in the discharged wastewater. The company (LPC 4) has taken modern steps of separating the hair from liming effluents also, which is mitigating the generation of suspended waste from this tannery. For recycling, they are planning to implement some methods soon. As for recovery criteria, they are utilizing chrome recovery methods, which are helping the company discharge the lowest level of chromium imprint in the environment.

Usage of green hides might seem possible although in the context of Bangladesh, most of the hides/skins are collected and stored on the occasion of Eid-ul-Adha. For preservation techniques, salt curing is preferable as it is a cheap method in comparison with other preservation techniques. The usage of short float in processing operations can be practiced. Green fleshing is not utilized because of the lack of technologies and equipment. For deliming and dehairing of the hides/skins, the companies use conventional chemicals and methods. Advanced technologies, e.g., ammonium-free deliming, enzymatic dehairing, the hair-saving method in dehairing, sulfur stripping dehairing and liming operations are not performed as these practices require skilled human resources, improved machinery, and equipment, maintenance, etc. Though chrome tanning has several adversities in the environment, any other alternative tanning methods are not practiced as chrome tanning is a fast and cheap method of producing great quality leather. As per buyers' requirements, water-based liquors are occasionally used in the finishing operation. The remaining options for reduction environmental pollution load are not feasible in the industry as zero-liquid discharge and mass balancing require improved machinery, equipment, maintenance, skilled human resource, etc. From this study, it is clear that Lack of affordability, lack of awareness, and lack of willingness play a major role not to adopt newer and more efficient technologies in this industry regarding the identified 21 PPS.

In the reuse criteria, the major barrier for not adopting reuse practices is the requirements of advanced equipment and

technologies. Most of the leather processing companies use traditional drums for processing operations. For reusing the waste liquors, e.g., pre-deliming, bating, tanning, and soaking, the liquors should be first stored in a container or pit and then the liquors should be conditioned for further using in the next operations. So, advanced technology will have to be introduced, which is considered a costly and troublesome process for this industry practitioners.

The first three case companies depend on the CETP for their wastewater treatment, having no practices of recycling of their own wastes. Recycling the waste liquors and using them in a loop system and converting the solid wastes for creating by-products require an individual effluent treatment plant, improved machinery, extra cost for processing and maintenance, skilled and additional human resources, which will increase the cost of manufacturing that is not preferable by the practitioners.

Updated technologies, skilled human resources, and affordability is required for recovering valuable materials from different wastes. The government's project about solid waste utilization is under development. So, there is a hope that the solid waste utilization project will improve the waste-to-wealth approach in this industry.

Environmental Benefits and Implications for Achieving Several SDGs

All of the above PPS under 4R practices will benefit the environment in many ways by ensuring a safe ecosystem, improved human life, etc. Reduction practices, i.e., usage of green hides/skins, eco-friendly preservation process instead of salt curing, ammonium-free de-liming, enzymatic dehairing, sulfur stripping in dehairing and liming operations, hair-saving dehairing method, switching to alternative eco-friendly tanning methods rather than basic chromium sulfate (BCS) tanning agent, water-based liquors in the finishing operation will generate fewer pollutants, e.g., reduced carbon products, nitrogenous and phosphorous compounds, VOC, particulate matters, heavy metals, smoke, dust, suspended solids, etc. As a result, COD, BOD, and other pollution load values of wastewater, degradation of land due to unethical landfilling, and the quantity of air pollutants emission will be reduced a great deal. The application of zero liquid discharge (ZLD), mass balancing will decrease the pollutants load in the air, water, and soil. These practices will preserve water quality for aquatic lives and people and air quality for people and animals, which will help in achieving SDG Goal 6: Ensuring clean water and sanitation, SDG Goal 14: Life below water, SDG Goal 11: Sustainable cities and communities.

Furthermore, practicing short float in leather processing operations will reduce water and chemical consumption. Reusing the same liquors several times in an operation, the chemical and water consumption will be reduced. In addition, recovered products can be completely or partially substituted with various chemicals, i.e., usage of recovered chrome in the tanning operation with fresh chrome salts, usage of recovered protein hydrolysates in the re-chroming/fat-liquoring operations as a filler/fat-liquoring agent. In this way, chemical and water consumption will be reduced. Recycling the waste liquors from different stages of leather processing, e.g., liming, pickling, tanning, etc. by different chemical or biological treatments and reusing them in the loop system will reduce water and chemical consumption. Recycling operations will reduce water consumption and lessen the effects of pollutants by releasing nearly pure water into the environment. Conversion of the different solid wastes into by-products will reduce chemical and energy consumption. Thereby, the industry can assist in achieving SDG Goal 12: Responsible consumption and production. Usage of green fleshing will reduce the solid waste's load and biofuel can be generated from these wastes, which can another source of energy in the leather industry. Thus, this biofuel production from leather solid wastes can aid in achieving SDG Goal 7: Affordable and clean energy.

Glue, gelatin, and composite sheets can also be generated from different wastes of the leather industry. Recovering chrome and protein will reduce the quantity of waste produced. Moreover, these recovered products can be reused in different operations

in the same industry reducing the total cost of materials consumed, and can be utilized in other industries to generate profits for the leather industry. In this way, there will be less generation of solid wastes from the leather processing industry, which will create a decent environment for employees' well-being. Alternatively, the conversion of leather solid wastes into value-added products can increase the yearly revenue for the leather industry. Thus, the industry can attain SDG Goal 3: Good health and well-being, and SDG Goal 8: Decent work and economic growth.

The current CETP plant of the Savar Industrial Estate is not functioning properly. As a result, it has become very tough for the leather industry practitioners to ensure environmental compliance issues. Moreover, the practitioners are indifferent to adopting innovative technologies to update the traditional tanning system. Therefore, developing the required infrastructure for the current CETP system as well as the development of individual ETP for every tannery is very urgent for this industry, which will help the leather industry to achieve SDG Goal 9: Industry, innovation, and infrastructure. Being one of the most polluting industries in the world, the leather industry is highly responsible for global warming and for any other climatic change. Proper implementation of the enlisted 21 PPS in this study can mitigate the climate change caused by the leather industry, which will help in achieving SDG Goal 13: Climate action 13.

In order to ensure technology-transfer and knowledge sharing, the leather industry of Bangladesh should work with numerous international organizations and nations, which will allow for the establishment of cleaner processing techniques as well as cutting-edge machinery and equipment for leather processing in a more sustainable way. By bolstering the international partnership as stated in SDG Goal 17: Partnerships for the goals, the leather industry will be able to ensure ES in its product cycle.

Conclusions and Future Scope for Research

This study identified the most relevant and potentially feasible set of 4R practices by a literature review and industry experts' opinions for ensuring ES in the leather industry. This study will certainly guide the practitioners of the leather industry to adopt the identified 21 PPS under reduce, reuse, recycle and recover dimensions with a clear understanding of how these practices can bring several environmental benefits for achieving ES. The findings of this research show that the case leather processing companies did not practice most of the PPS in their operations due to unwillingness in investment for advanced technologies and advanced machinery and equipment. The three case companies did not have any ETP for waste reduction whereas one company had its own ETP that was reducing its environmental impact. The yearly revenue of the LPC 4 companies showed that adopting some sustainable practices can not only bring environmental benefits but also, they can increase any company's economic growth. This study also guides how sustainable practices can help in achieving several SDGs in the leather industry. This study has some limitations that can act as scopes for any future research. The study was limited as the focus of the study was based on the case study of only four leather processing companies. Hence, in the future, more leather processing companies can be taken into account in other case study to compare the 4R practices and to analyze the performance gaps of those companies in the context of ES. Quantitative data could be included for conducting a cost-benefit analysis for estimating the strengths and weaknesses of environmentally sustainable 4R practices to obtain the best approach for achieving ES in the leather industry.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This study did not receive any funding.

REFERENCES

1. Ricky, R., Shanthakumar, S., Ganapathy, G.P., Chiampo, F., Zero Liquid Discharge System for the Tannery Industry—An Overview of Sustainable Approaches, *Recycling*, **2022**, 7, 3, 31, https://doi.org/10.3390/recycling7030031.
2. Asian Development Bank, Developing the Leather Industry in Bangladesh, ADB Briefs NO. 102, **2018**, 102, 1–8, https://dx.doi.org/10.22617/BRF189645-2.
3. Omoloso, O., Mortimer, K., Wise, W.R., Jraisat, L., Sustainability Research in the Leather Industry: A Critical Review of Progress and Opportunities for Future Research, *J Clean Prod*, **2021**, 285, 125441, https://doi.org/10.1016/j.jclepro.2020.125441.
4. Sarker, M.R., Ali, S.M., Paul, S.K., Munim, Z.H., Measuring Sustainability Performance Using An Integrated Model, *Meas: J Int Meas Confed*, **2021**, 184, 109931, https://doi.org/10.1016/j.measurement.2021.109931.
5. Marrucci, L., Corcelli, F., Daddi, T., Iraldo, F., Using a Life Cycle Assessment to Identify the Risk of "Circular Washing" in the Leather Industry, *Resour Conserv Recycl*, **2022**, 185, 106466, https://doi.org/10.1016/J.RESCONREC.2022.106466.
6. Huang, Y., Xiao, H., Pu, H., Xue, N., Hao, B., Huang, X., Shi, B., Self-Driven Directional Dehydration Enabled Eco-Friendly Manufacture of Chrome-Free Leather, *J Leather Sci Eng*, **2022**, 4, 1, 1–12. https://doi.org/10.1186/S42825-022-00089-0.
7. Karuppiah, K., Sankaranarayanan, B., Ali, S.M., Jabbour, C.J.C., Bhalaji, R.K.A, Inhibitors to Circular Economy Practices in the Leather Industry Using an Integrated Approach: Implications for Sustainable Development Goals in Emerging Economies, *Sustain Prod Consum*, **2021**, 27, 1554-1568, https://doi.org/10.1016/J.SPC.2021.03.015.
8. China, C.R., Maguta, M.M., Nyandoro, S.S., Hilonga, A., Kanth, S.V., Njau, K.N., Alternative Tanning Technologies and Their Suitability in Curbing Environmental Pollution from the Leather Industry: A Comprehensive Review, *Chemosphere*, **2020**, 254, 126804, https://doi.org/10.1016/j.chemosphere.2020.126804.
9. Islam, M.H., Sarker, M.R., Hossain, M.I., Ali, K., Noor, K.M.A., Towards Sustainable Supply Chain Management (SSCM): A Case of Leather Industry, *J Oper Strateg Plan*, **2020**, 3, 1, 81–98, https://doi.org/10.1177/2516600X20924313.
10. Moktadir, M.A., Ahmadi, H.B., Sultana, R., Zohra, F.T., Liou, J.J.H., Rezaei, J., Circular Economy Practices in the Leather Industry: A Practical Step Towards Sustainable Development, *J Clean Prod*, **2020**, 251, 119737, https://doi.org/10.1016/J.JCLEPRO.2019.119737.
11. Kanagaraj, J., Senthilvelan, T., Panda, R.C., Kavitha, S., Eco-Friendly Waste Management Strategies for Greener Environment Towards Sustainable Development in Leather Industry: A Comprehensive Review, *J Clean Prod*, **2015**, 89, 1–17, https://doi.org/10.1016/j.jclepro.2014.11.013.
12. Dixit, S., Yadav, A., Dwivedi, P.D., Das, M., Toxic Hazards of Leather Industry and Technologies to Combat Threat: A Review, *J Clean Prod*, **2015**, 87, 39–49, https://doi.org/10.1016/j.jclepro.2014.10.017.
13. Gupta, S., Gupta, S., Dhamija, P., Bag, S., Sustainability Strategies in the Indian Leather Industry: An Empirical Analysis, *Benchmarking*, **2018**, 25, 3, 797–814, https://doi.org/10.1108/BIJ-06-2017-0140.
14. Paul, H.L., Antunes, A.P.M., Covington, A.D., Evans, P., Philips, P.S., Bangladeshi Leather Industry: An Overview of Recent Sustainable Developments, *J Soc Leather Technol Chem*, **2013**, 97, 1, 25–32.
15. Halder, S., Export of Leather Goods Hits Decade High, *The Daily Star*, 07 July, **2022**, https://www.thedailystar.net/business/economy/news/export-leather-goods-hits-decade-high-3065886.

16. The Asia Foundation, **2020**, https://asiafoundation.org/category/in-asia/page/16/
17. Gosh, P.K., Hossain, M.D., Assessment of Tannery Effluent: A Case Study of Dhaleshwari River in Bangladesh, Proceeding of International Conference on Planning, Architechture and Civil Engineering (ICPAC 2019), 07-09 February, **2019**, Rajshahi, Bangladesh, 461–464.
18. Hasan, R., CETP At Savar Tannery Industrial Estate: Colossal Failure, Misuse of Public Funds, *The Daily Star*, 08 March, **2022**, https://www.thedailystar.net/news/bangladesh/news/cetp-savar-tannery-industrial-estate-colossal-failure-misuse-public-funds-2977956.
19. Hasan, M.M., Ahmed, M.S., Adnan, R., Shafiquzzaman, M., Water Quality Indices to Assess the Spatiotemporal Variations of Dhaleshwari River in Central Bangladesh, *Environ Sustain Indic*, **2020**, 8, 100068, https://doi.org/10.1016/J.INDIC.2020.100068.
20. Islam, M.A.S., Hossain, M.E., Majed, N., Assessment of Physicochemical Properties and Comparative Pollution Status of the Dhaleshwari River in Bangladesh, *Earth*, **2021**, 2, 4, 696-714, https://doi.org/10.3390/earth2040041.
21. Masum, S.A., Islam, M.S., A Case Study on Predicting the Environmental Impacts of Untreated Effluent Generated from Tannery Industrial Estate in Dhaka, Bangladesh, *Geo Environ Sustain*, **2020**, 13, 3, 22–31, https://doi.org/10.24057/2071-9388-2019-127.
22. Elkington, J., Partnerships from Cannibals with Forks: The Triple Bottom Line of 21st-Century Business, *Environ Qual Manag*, **1998**, 8, 1, 37–51, https://doi.org/10.1002/tqem.3310080106.
23. Sutton, P., A Perspective on Environmental Sustainability?, Victorian Commissioner for Environmental Sustainability, **2004**, 1-32, http://www.green-innovations.asn.au/.
24. Bob, U., Padayachee, A., Gordon, M., Moutlana, I., Enhancing Innovation and Technological Capabilities in the Management of E-Waste: Case Study of South African Government Sector, *Sci Technol Soc*, **2017**, 22, 2, 332–349, https://doi.org/10.1177/0971721817702293.
25. Morera, J.M., Bartolí, E., Chico, R., Solé, C., Cabeza, L.F., Minimization of the Environmental Impact of Chrome Tanning: A New Process Reusing the Tanning Floats, *J Clean Prod*, **2011**, 19, 17–18, 2128–2132. https://doi.org/10.1016/j.jclepro.2011.07.018.
26. Dutta, N., Narayanan, K., Impact of Environmental Regulation on Technical Efficiency, *Sci Technol Soc*, **2011**, 16, 3, 333–350, https://doi.org/10.1177/097172181101600305.
27. Omoloso, O., Wise, W.R., Mortimer, K., Jraisat, L., Corporate Sustainability Disclosure: A Leather Industry Perspective, *Emerg Sci J*, **2020**, 4, 1, 44–51, https://doi.org/10.28991/esj-2020-01209.
28. Severo, E.A., De Guimarães, J.C.F., Dorion, E.C.H., Nodari, C.H., Cleaner Production, Environmental Sustainability and Organizational Performance: An Empirical Study in The Brazilian Metal-Mechanic Industry, *J Clean Prod*, **2015**, 96, 118–125, https://doi.org/10.1016/j.jclepro.2014.06.027.
29. Tiwari, V., Thakur, S., Environment Sustainability Through Sustainability Innovations, *Environ Dev Sustain*, **2020**, 23, 5, 6941–6965, https://doi.org/10.1007/S10668-020-00899-4.
30. Chin, T.A., Tat, H.H., Sulaiman, Z., Green Supply Chain Management, Environmental Collaboration and Sustainability Performance, *Procedia CIRP*, **2015**, 26, 695–699, https://doi.org/10.1016/j.procir.2014.07.035.
31. de Sousa Jabbour, A.B.L., Frascareli, F.C.D.O., Jabbour, C.J.C., Green Supply Chain Management and Firms' Performance: Understanding Potential Relationships and The Role of Green Sourcing and Some Other Green Practices, *Resour Conserv Recycl*, **2015**, 104, 366–374, https://doi.org/10.1016/j.resconrec.2015.07.017.

32. Gupta, S.K., Gupta, S., Gayathiri, S., "Pollution Prevention" Is the Key to Drive Sustainability: Preliminary Findings from a Tannery Unit in India, *Manag Environ Qual*, **2018**, 29, 3, 416–426, https://doi.org/10.1108/MEQ-10-2017-0124.
33. Ahmad, S., Wong, K.Y., Rajoo, S., Sustainability Indicators for Manufacturing Sectors: A Literature Survey and Maturity Analysis from The Triple-Bottom-Line Perspective, *J Manuf Technol Manag*, **2019**, 30, 2, 312–334, https://doi.org/10.1108/JMTM-03-2018-0091.
34. da Cunha e Silva, D.C., de Oliveira, R.A., Simonetti, V.C., Toniolo, B.P., Sales, J.C.A., Lourenço, R.W., Creation of an Environmental Sustainability Index for Water Resources Applied to Watersheds, *Environ Dev Sustain*, **2022**, 1–21, https://doi.org/10.1007/S10668-022-02527-9.
35. Elleuch, B., Bouhamed, F., Elloussaief, M., Jaghbir, M., Environmental Sustainability and Pollution Prevention, *Environ Sci Pollut Res*, **2018**, 25, 19, 18223–18225, https://doi.org/10.1007/s11356-017-0619-5.
36. Petraru, M., Gavrilescu, M., Pollution Prevention, A Key to Economic and Environmental Sustainability, *Environ Eng Manag J*, **2010**, 9, 4, 597–614, https://doi.org/10.30638/eemj.2010.083.
37. Hu, J., Xiao, Z., Zhou, R., Deng, W., Wang, M., Ma, S., Ecological Utilization of Leather Tannery Waste with Circular Economy Model, *J Clean Prod*, **2011**, 19, 2–3, 221–228, https://doi.org/10.1016/j.jclepro.2010.09.018.
38. Kanagaraj, J.K., Panda, R.C., Vinodh Kumar, M., Trends and Advancements in Sustainable Leather Processing: Future Directions and Challenges—A Review, *J Environ Chem Eng*, **2020**, 8, 5, 104379, https://doi.org/10.1016/J.JECE.2020.104379.
39. Chojnacka, K., Skrzypczak, D., Mikula, K., Witek-Krowiak, A., Izydorczyk, G., Kuligowski, K., Bandrów, P., Kułażyński, M., Progress in Sustainable Technologies of Leather Wastes Valorization as Solutions for The Circular Economy, *J Clean Prod*, **2021**, 313, 127902, https://doi.org/10.1016/J.JCLEPRO.2021.127902.
40. Al-jabari, M., Sawalha, H., Pugazhendhi, A., Rene, E.R., Cleaner Production and Resource Recovery Opportunities in Leather Tanneries: Technological Applications and Perspectives, *Bioresour Technol Rep*, **2021**, 16, 100815, https://doi.org/10.1016/j.biteb.2021.100815.
41. Lazaroiu, G., Pană, C., Mihaescu, L., Cernat, A., Negurescu, N., Mocanu, R., Negreanu, G., Solutions for Energy Recovery of Animal Waste from Leather Industry, *Energy Convers Manag*, **2017**, 149, 1085–1095, https://doi.org/10.1016/J.ENCONMAN.2017.06.042.
42. Teklay, A., Gebeyehu, G., Getachew, T., Yaynshet, T., Sastry, T.P., Conversion of Finished Leather Waste Incorporated with Plant Fibers into Value Added Consumer Products – An Effort to Minimize Solid Waste in Ethiopia, *Waste Manag*, **2017**, 68, 45–55, https://doi.org/10.1016/J.WASMAN.2017.07.024.
43. Zeng, S., Huang, Z.X., Jiang, H., Li, Y., From Waste to Wealth: A Lightweight and Flexible Leather Solid Waste/Polyvinyl Alcohol/Silver Paper for Highly Efficient Electromagnetic Interference Shielding, *ACS Appl Mater Interfaces*, **2020**, 12, 46, 52038–52049, https://doi.org/10.1021/acsami.0c16169.
44. Członka, S., Bertino, M.F., Strzelec, K., Strąkowska, A., Masłowski, M., Rigid Polyurethane Foams Reinforced with Solid Waste Generated in Leather Industry, *Polym Test*, **2018**, 69, 225–237, https://doi.org/10.1016/J.POLYMERTESTING.2018.05.013.
45. Hashem, M.A., Nur-A-Tomal, M.S., Tannery Solid Waste Valorization Through Composite Fabrication: A Waste-To-Wealth Approach, *Environ Prog Sustain Energy*, **2018**, 375, 1722–1726, https://doi.org/10.1002/EP.12860.
46. Liu, B., Li, Y., Wang, Q., Bai, S., Green Fabrication of Leather Solid

Waste/Thermoplastic Polyurethanes Composite: Physically De-Bundling Effect of Solid-State Shear Milling on Collagen Bundles, *Compos Sci Technol*, **2019**, 181, 107674, https://doi.org/10.1016/j.compscitech.2019.06.001.

47. Yorgancioglu, A., Onem, E., Basaran, B., Preparation, Characterization and Application of Lubricating Protein Filler for Sustainable Leather Production, *J Nat Fibres*, **2020**, 18, 11, 1946-1956, https://doi.org/10.1080/15440478.2020.1751374.
48. Parisi, M., Nanni, A., Colonna, M., Recycling of Chrome-Tanned Leather and Its Utilization as Polymeric Materials and in Polymer-Based Composites: A Review, *Polymers*, **2021**, 13, 3, 1–23, https://doi.org/10.3390/polym13030429.
49. Hoque, A., Clarke, A., Greening of Industries in Bangladesh: Pollution Prevention Practices, *J Clean Prod*, **2013**, 51, 47–56, https://doi.org/10.1016/j.jclepro.2012.09.008.
50. Ariram, N., Sathish, M., Madhan, B., Chemical/Water-Free Deliming Process Using Supercritical Carbon Dioxide: A Step Toward Greener Leather Manufacture, *ACS Sustain Chem Eng*, **2020**, 8, 31, 11747–11754, https://doi.org/10.1021/ACSSUSCHEMENG.0C03867.
51. Andrioli, E., Petry, L., Gutterres, M., Environmentally Friendly Hide Unhairing: Enzymatic-Oxidative Unhairing as an Alternative to Use of Lime and Sodium Sulfide, *Process Saf Environ Prot*, **2015**, 93, 9–17, https://doi.org/10.1016/J.PSEP.2014.06.001.
52. Valeika, V., Širvaitytė, J., Bridžiuvienė, D., Švedienė, J., An application of Advanced Hair-Save Processes in Leather Industry as The Reason of Formation of Keratinous Waste: Few Peculiarities of Its Utilization, *Environ Sci Pollut Res*, **2019**, 26, 6, 6223–6233, https://doi.org/10.1007/S11356-019-04142-0.
53. Maguta, M.M., Nyandoro, S.S., Hilonga, A., Kanth, S.V., Njau, K.N., Alternative Tanning Technologies and Their Suitability in Curbing Environmental Pollution from The Leather Industry: A Comprehensive Review, *Chemosphere*, **2020**, 254, 126804, https://doi.org/10.1016/j.chemosphere.2020.126804.
54. Khan, K., Khan, I.H., Khan, I.I., Mahmud, A., Hossain, D., Recovery and Reuse of Chromium from Spent Chrome Tanning Liquor by Precipitation Process, *Am J Eng Res (AJER)*, **2018**, 7, 1, 346–352.
55. Selvakumar, A.M., Vimudha, M., Lawrance, I., Sundaramoorthy, S., Ramanaiah, B., Saravanan, P., Recovery and Reuse of Spent Chrome Tanning Effluent from Tannery Using Electro-Oxidation Technique, *Desalination Water Treat*, **2019**, 156, 323–330, https://doi.org/10.5004/dwt.2019.23825.
56. Kale, R.D., Jadhav, N.C., Utilization of Waste Leather for The Fabrication of Composites and to Study Its Mechanical and Thermal Properties, *SN Appl Sci*, **2019**, 1, 1231, 1-9, https://doi.org/10.1007/s42452-019-1230-9.
57. Jadhav, N.C., Jadhav, A.C., Waste and 3R's in Footwear and Leather Sectors, *Leather and Footwear Sustainability*, Springer Singapore, **2020**, https://doi.org/10.1007/978-981-15-6296-9_10.
58. Kokkinos, E., Proskynitopoulou, V., Zouboulis, A., Chromium and Energy Recovery from Tannery Wastewater Treatment Waste: Investigation of Major Mechanisms in the Framework of Circular Economy, *J Environ Chem Eng*, **2019**, 7, 5, 103307, https://doi.org/10.1016/J.JECE.2019.103307.
59. Vidaurre-Arbizu, M., Pérez-Bou, S., Zuazua-Ros, A., Martín-Gómez, C., From the Leather Industry to Building Sector: Exploration of Potential Applications of Discarded Solid Wastes, *J Clean Prod*, **2021**, 291, 125960. https://doi.org/10.1016/J.JCLEPRO.2021.125960.
60. Mohammed, K., Sahu, O., Recovery of Chromium from Tannery Industry Waste Water by Membrane Separation Technology: Health and Engineering Aspects, *Sci Afr*, **2019**, 4, 96,

https://doi.org/10.1016/j.sciaf.2019.e00096.
61. Shukla, A., Mahmood, Z., Singh, L.K., Studies on Recovery of Heavy Metals from Tannery Wastewater, *Int J Eng Sci Technol*, **2021**, 13, 1, 76–80, https://doi.org/10.4314/ijest.v13i1.11S.
62. Ammasi, R., Victor, J.S., Chellan, R., Chellappa, M., Amino Acid Enriched Proteinous Wastes: Recovery and Reuse in Leather Making, *Waste Biomass Valorization*, **2019**, 11, 11, 5793–5807, https://doi.org/10.1007/S12649-019-00912-6.