GREEN STRATEGY FOR RECLAIMING ECOSYSTEM: MICROBIAL REMEDIATION OF LEATHER INDUSTRY WASTES

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ABSTRACT: Meeting environmental regulations for both liquid and solid wastes are produced during the manufacture of leather items is one of the long-term issues facing the leather industry. Insufficient treatment of these wastes will cause environmental pollution and endanger human health. Trimmings have generally been underutilized among other trash that are produced. Hair is not utilized, however collagen found in trims and garbage. Many organic and inorganic particles together with the discharge of suspended or gas-solid oil and grease, nitrogen-containing compounds, and heavy metals either by themselves or in their reduced salt form, chlorides, sulphates, chemical oxygen demand (COD) and total dissolved solids (TDS) are all considerably generated and influenced by tanning operations. Formaldehyde used in the production of finished leather that are difficult to biodegrade and can cause the production of free formaldehyde, a recognized carcinogen. Microbial bioremediation is a novel technique that may be used in a variety of soil and water environments due to microorganisms' adaptability to remove hazardous pollutants that could offer a safer and affordable strategy. The pollution profile of leather industries, microbial bioremediation for pollution reduction from diverse ecological lattices and interactions between the microbes and contaminants has received substantial attention in this review.

Keywords: Environmental pollutants, leather industry, liquid and solid wastes, human health, re-tanning agent, microbial bioremediation

INTRODUCTION: The production of flexible and durable leather material from putrescible animal raw hide and skin involves a variety of production techniques, from cottage industry to heavy industry. Typically, the skins are trimmed before being processed into leather and the trimmings are discarded as solid waste (Dixit et al. 2014, Sathish et al. 2019). The process of tanning turns unprocessed skin into a durable substance. This stable form, which is ideal for a variety of applications, is dried to a flexible state where the skin does not putrefy or rot (Sivaram et al. 2019).In the process known as crusting, which involves several steps such as wetting back, splitting, shaving, re-chroming, neutralization, re-tanning, dyeing, fat liquoring, filling, stuffing, stripping, whitening, fixating, setting, drying, conditioning, milling, staking, and buffing, raw animal skin from which leather is made is combined with numerous chemicals and dyes to create finished products. These substances cause environmental impact when they are released into the environment as liquid and solid wastes in a large amount (Sivaram et al. 2019, Saxena et al. 2015). The operations involved in finished leather production are depicted in Figure 1.

Fig. 1. Process and operations involved in the production of finished leather in leather industries (China et al. 2020, Dixit et al. 2014)

Due to the complexity of their waste waters, a major source of pollution worldwide is the leather industry (Saxena et al. 2015). The traditional techniques like physical, chemical, and thermal treatments have a number of significant downsides, including the creation of toxic intermediates, the transportation of polluted soil or water for treatment, the high expense of treatment, and the ineffective restoration of natural habitats and fauna. Using biodegradation and bioremediation methods that involve biological systems like microbes (bacteria, fungi and Actinomycetes etc.) or their productsare viable, cost-effective solutions for reducing and neutralizing the contaminants from tannery wastewater through normal biological processes either by aerobic or anaerobic processes (Arora 2018, Saxena et al. 2016).Microbes in a polluted ecosystem can be employed to degrade and clean up large-scale or many polluted locations. Even in heavily polluted habitats, it releases significant amounts of metabolic reaction rates and enzymes. This can significantly enhance the quality of a stressed ecosystem. Bioremediation has a lot of potential, and there have already been several remarkable successes recorded from throughout the world (Arora 2018). In order to leave the next generation with a healthy and sustainable world, we must use green technology to clean up the trash left behind by the activities of leather industry.

MATERIALS AND METHODS: The appropriate material for this review paper was found by searching PubMed, PubMed Central, Google, and published research work and the review articles from around the world on the environmental pollutants produced by the leather industries and the microbial bioremediation strategy to remove the pollutants for a cleaner world. Only published data were considered, and vague statements of exposure were excluded. Information acquired from reputable sources of publications on the subject is part of these inclusion criteria. The study did not include any other languages than English.

RESULTS AND DISCUSSION:

Environmental and health impacts of leather industrial wastes: Leather industry waste produces significant amounts of very hazardous wastewater with high pH, dark brown hue, disagreeable smell, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) and other characteristics. When it comes to aquatic resources, it restricts sunlight penetration, which in turn decreases dissolved oxygen concentration and photosynthetic activity, affecting aquatic life and deteriorating the quality of water bodies. Reduced agricultural yield and worse drinking water quality are the results of increased salinization of rivers and groundwater (Dixit et al. 2014).Furthermore, exposure to it can lead to extremely harmful effects on living things. Tannery wastewater lowers soil alkalinity and it has phytotoxic effects, a high concentration of heavy metals, which puts plants under stress, which affects many metabolic processes and reduces plant growth both vegetative and later reproductively or inhibits seed germination. It also has a significant negative impact on respiration, photosynthesis, shortens mitotic activity, and shortens germ sprouting (Saxena et al. 2020, Tadesse et al. 2017).The tannery wastes contain wastewater, hazardous chemicals that target a number of human organ and organ system including eyes, skin, nose, blood, tissues, respiratory tract, blood, liver, kidney, lungs, gastrointestinal (GI) tract, immune system and reproductive system (Dixit et al. 2014, Saxena et al. 2015). The toxic chemicals used in leather industry are depicted in Figure 2.

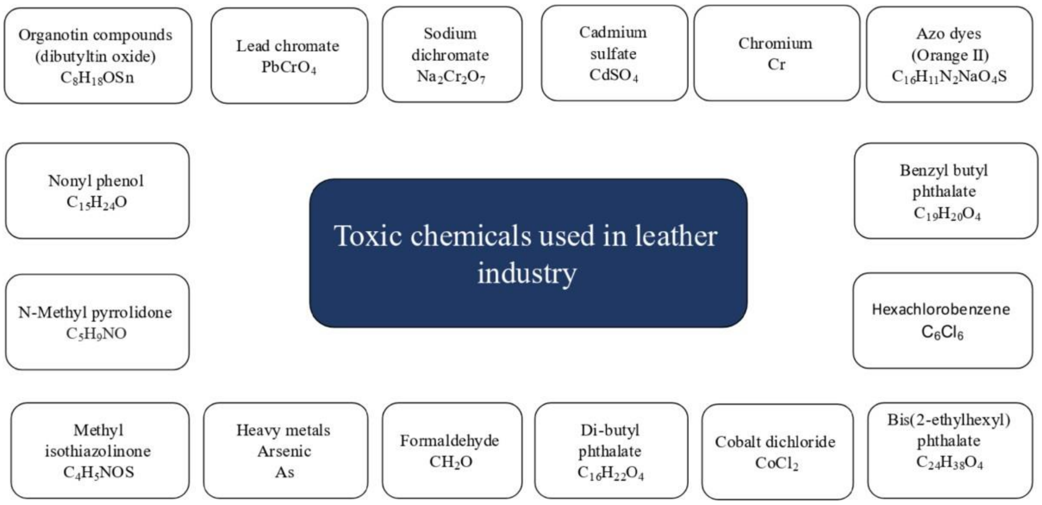

Fig. 2. Toxic chemicals used in leather industry (Sivaram et al. 2019, Saxena et al. 2015, Saxena et al. 2016)

Formaldehyde is used as a re-tanning agent in the production of leather to improve the compaction of the leather. However, these compounds are difficult to biodegrade and can lead to the production of free formaldehyde, a recognized carcinogen (Sathish et al. 2019).The leather industry uses azo dyes, synthetic dyes based on nitrogen, to color leather goods. Several azo dyes are said to release poisonous aromatic amines that might cause cancer and allergies. Tributyl tin, a very poisonous contaminant with hormone-like action, may be found in organotin compounds such as dibutyl tin, which is employed as a catalyst in leather finishing (Sivaram et al. 2019).This hair waste produced by the leather industries is either disposed of at a landfill or thrown into the ground. An international environmental problem that contributes to air pollution and water resource degradation is the disposal of keratin-rich wastes like hair and feathers (Thankaswamy et al. 2018).Thus, utilizing these substances, the ecology is affected by many environmental contaminants released by the leather industry in diverse ways (Tadesse et al. 2017).This hair waste produced by the leather industries is either disposed of at a landfill or thrown into the ground. An international environmental problem that contributes to air pollution and water resource degradation is the disposal of keratin-rich wastes like hair and feathers (Thankaswamy et al. 2018).Workers at tanneries are exposed to more carcinogenic substances, such as chromium salt, arsenic, benzene, formaldehyde, ethanol, toluene, and acetone solvents that can develop skin cancer, testicular cancer, bladder cancer, soft tissue sarcoma, buccal cavity, pancreatic cancer and pharynx cancer also (Hashmi et al. 2017). The impact of leather industry wastes on ecology is depicted in Figure 3.

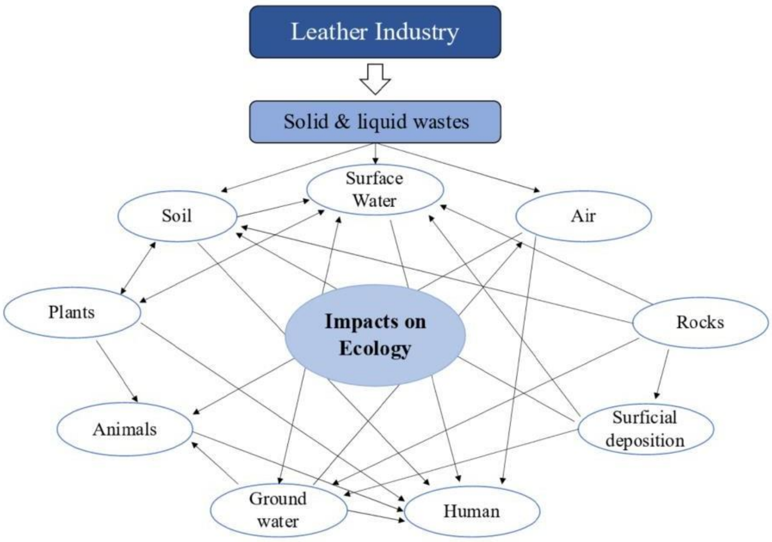

Fig. 3. The flow diagram of harmful substances released into the environment by leather industries and ending up in the biospheres of plants, soil, air, and water as well as in animals and people (Tadesse et al. 2017)

Contaminant profile of the leather industry: The leather processing sector has a detrimental effect on the environment since it generates solid waste and wastewater effluent that contains dangerous compounds including chromium, synthetic tannins, oils, resins, biocides, and detergents (Sivaram et al. 2019).The beamhouse and tanning operations during leather production are the most polluting steps because the beamhouse operation contributes high organic and sulfide content while the tanning operation contributes high salts (of chloride, ammonium, chromium, and sulphate) concentration in Tannery wastewater (TWW), which is a basic, dark brown-colored waste with high COD, BOD, TDS, chromium (III), phenolics, with a high pH and firm smell. The tanning wastewater has a very acidic pH and a high COD content, whereas the wastewater from the beamhouse has an alkaline pH. TWW is often quite rich in nitrogen, especially organic nitrogen, although it is generally deficient in phosphorous. While the wet finishing, re-tanning, dyeing, and fat liquoring processes contribute a low fraction of salt in TWW that is primarily derived from the hide/skins in the soak liquor, the re-tanning and streams have a low BOD and TSS (Total suspended solids), but a high COD and contain trivalent chromium (III), tannins, sulfonated oils, and azo dyes owing to their complicated chemical makeup and xenobiotic nature, which makes them very persistent in nature and causes environmental contamination(Saxena et al. 2016). If the pH is lower than 8.0, alkaline sulfides in tannery effluent emit hydrogen sulfide. Chromium can be found in particulate emissions from the buffing process, handling of basic chromic sulphate powder, or reduction of chromate (Sivaram et al. 2019). In various locations, all of the physio-chemical parameters, including EC, pH, BOD, COD, TDS, TSS, Cl, SO4, oil and grease, and Cr, were found to be over the National Environmental Quality Standards (NEQS) for industrial discharge (Ashraf et al. 2018).While processing animal hides and skins for leather manufacturing, the leather processing industry produces vast amounts of solid waste. 1000 kg of animal skin yields just 200 kg of leather, leaving 70–80% of it as solid waste creation that has a significant negative environmental impact (Muralidharan et al. 2022).Due to the tanned leather's non-biodegradability, a significant amount of sludge produced by tannery factories makes the solid waste management system mostly inactive. Although leather is a slow biodegradable material in and of itself, the use of various chemicals during the tanning process makes it resistant to chemical, thermal, and microbiological deterioration (Sivaram et al. 2019, Dixit et al. 2014). The organic pollutants found in TWW released from leather industries is depicted in Figure 4.

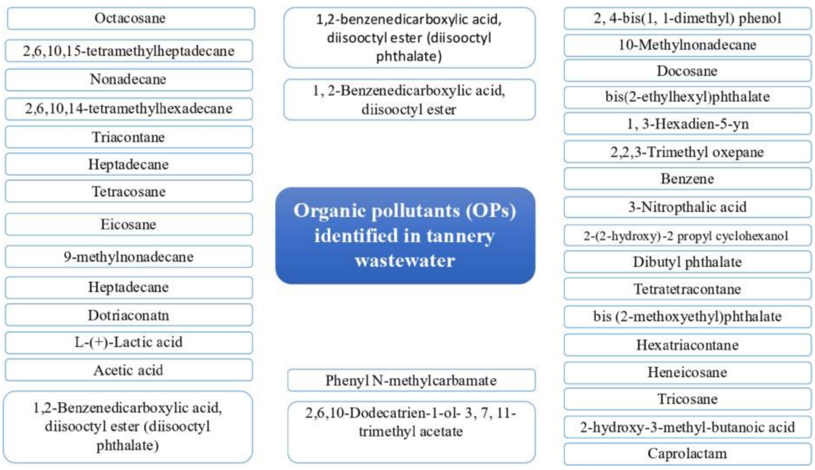

Fig. 4. Organic pollutants (OPs) identified in TWW released from leather industries (Saxena et al. 2016)

Green strategy to reduce risks: Environmental deterioration is widespread, the estimated number of polluted environments is large, and its continuous discovery over recent years has prompted international efforts to clean up many of these environments, either in response to the risk of unfavorable health or environmental effects brought on by pollution or to make the area suitable for redevelopment or restoration for use(Luka et al. 2018, Arora 2018). Concern over environmental contamination brought on by the leather industry necessitates the employment of greener technologies, to reduce pollution and other risks (Saxena et al. 2015).

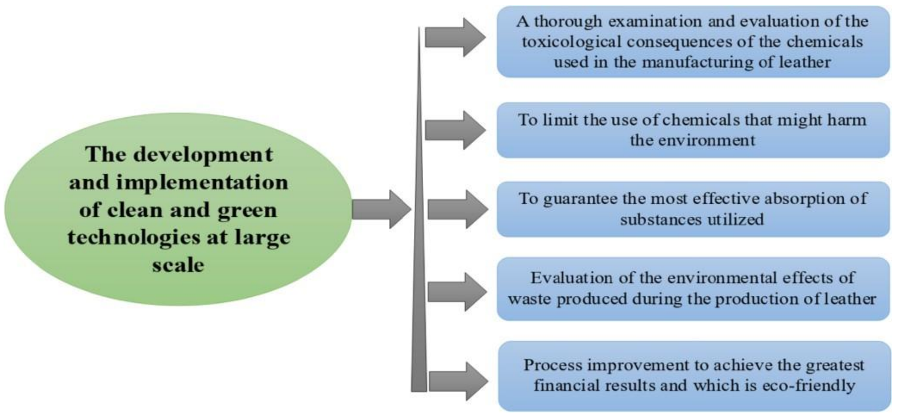

Fig. 5. Strategies to develop and implement of cleaner or greener technologies at large scale to reduce pollutants (Saxena et al. 2015)

The method of bioremediation, used to remediate industrial wastewaters, involves stabilizing waste by converting it into harmless inorganic particles through either aerobic or anaerobic processes. The pace of waste breakdown is quick and unaffected by foul odors in the aerobic process, but a lot of sludge is produced. The activated sludge technique (ASP) is one of the most popular methods for the aerobic biological remediation of TWW. Anaerobic treatment of TWW is a fascinating alternative to aerobic treatment since it uses less energy and produces less sludge, but full-scale implementations have a number of disadvantages. The major methods for the anaerobic treatment of TWW are either upflow anaerobic sludge blanket (UASB) reactors or anaerobic filters (AF) made up of both upflow and downflow anaerobic filters (UAF and DAF). In addition to this, the use of anaerobic baffled reactors (ABR) and expanded granular sludge beds (EGSB) is recommended for the treatment of TWW. (Saxena et al. 2016, Saxena et al. 2015). Utilizing the biodegradation capabilities of microorganisms, bioremediation of pollutants includes natural attenuation. However, it may be improved by designed procedures; either by adding of certain microbes known as bioaugmentation or by biostimulation where nutrients are provided. Additionally, genetic engineered microorganisms (GEM) is utilized to enhance microorganisms' capacity for biodegradation (Joutey et al.2013).

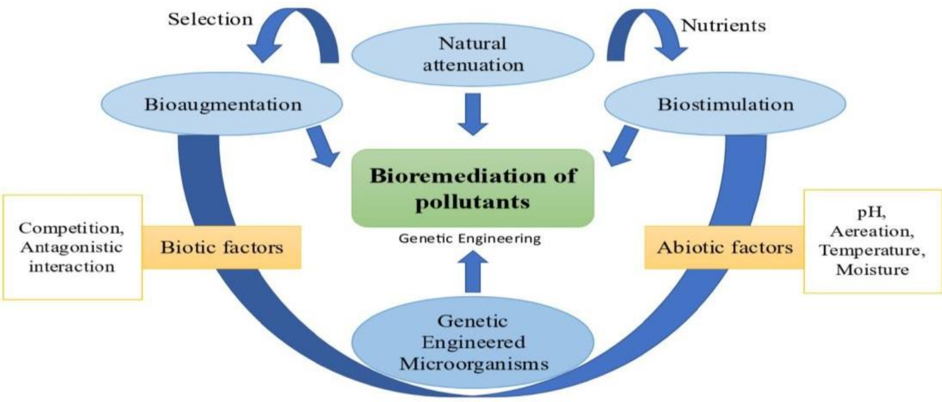

Fig. 6. Utilizing the capacity of microorganisms to degrade materials, bioremediation of pollutants (Joutey et al. 2013)

It has been found that some bacterial species, including *E. coli*, *Arthrobacter*, *Bacillus*, *Pseudomonas*, *Nostoc*, *Vibrio sp.*, and many others microbes have the capacity to bioremediate tannery wastewater (Ashraf et al. 2018). This is depicted in Table 1.

Microorganisms reported in the degradation of pollutants removed from leather industry	
Microorganisms	**Removing substances**
Brachymonas denitrificans	COD (98.3%), Cr (88.5%)
E. coli	COD (90%), BOD (90%), Cr (63.8%)
Bacillus sp.	COD (95.4%), BOD (95.4%), Cr (73.5%)
Fusarium chlamydosporium SPFS2-g	COD (71.80%)
B. subtilis, P. fragi, Vibrio Sp.	COD (87.6%, 85.2%, 87.5%)
Pseudomonas stutzeri M15-10-3, Providencia vermicola W9B-11,Bacillus sp. 58, Bacillus amyloliquefaciens T004, Bacillus sp. PL47, Escherichia coli O7:K1 CE10,	COD (79.16%), Cr (93.66%), (94.14%)
Thiobacillus ferrooxidans	COD (69%), BOD (72%), Cr (5%)
Nostoc sp.	COD (37.8%), BOD (48.6%)
Pseudomonas sp.	COD (96.15%), BOD (75%)
E. homiense, P. aeruginosa, S. aureus,B. flexus, Bacillus aquimaris	COD (80%, 24%)
S. condensate, R. hieroglyphicum	Cr (>75%)
Halophiles	COD (95%)
Microbacterium arborescens	COD (63%), TDS (56%), Cr (54%)
Pseudomonas sp.	TDS (32%)
P. stewartia, Enterobacter sp.	BOD (64%, 61%), Cr (52%, 50%)
Mixed culture of *Pseudomonas aeruginosa, Rhodopseudomonas blastica, Exiguobacterium homiense, Bacillus flexus and Staphylococcus aureus*	COD (>80%)
B. cereus, Sphingomonas sp.	Azo dye
Staphylococcus aureus Tan-2, P. putida Tan-1	Phenol
A. Thiooxidans , Hirsutella sp.,Acenetobacter sp., Trichoderma sp.	Cr (99.7%, 70%, 90%, 97.93%)

Table. 1. Microorganisms reported to remove environmental contaminants released from leather industries (Saxena et al. 2015, Ashraf et al. 2018, Kanagaraj et al. 2014)

Dyes are challenging to remove using traditional methods because of their highwater solubilizing capacity. The degradation of dye is influenced by variables such as pH, temperature, dye structure, soluble salts, heavy metals, nutrition, etc. The degradation of many dyes utilizing microbes has been shown in several papers. (Varjani et al. 2020). A bacteria known as *B. cereus* biodegraded azo-dyes. The bacteriaexhibit azo dye reduction of 80% and 96% under static and agitated conditions, respectively. Three bacterial species, including *Nocordia atlantica*, *Listeria denitrificans*, and*M. luteus* display substantial decolorizing activity, according to published research. *Sphingomonas sp.*, a strain obtained from petroleum waste that was capable of aerobically degrading at least 7 different azo dyes with an efficiency of more than 70%, was used to design a viable technology. According to HPLC examinations of the metabolites of three distinct azo dyes, various sets of metabolites might be formed from these dyes depending on the oxygen availability throughout the dye breakdown process. The biodegradation of phenol was accomplished by *P. putida Tan-1* and *Staphylococcus aureus Tan-2*. Experiments utilizing the aforementioned species revealed degradation rates of 94.2 and 88.1%. (Kanagaraj et al. 2014).Two bacterial strains were found to have been isolated from tannery activated sludge: *Comamonas sp*. 4BC and *Arthrobacter sp*. 2AC., have been found to biodegrade naphthalene-2-sulfonic acid, a key component of the naphthalene sulfonate. Using isolates of *Exiguobacterium homiense, Pseudomonas aeruginosa, Bacillus flexus* and *Staphylococcus aureus* from marine soil, salty lake, salty liquor, soak liquorand seawater, respectively, the biodegradation of tannery soak liquor by these halotolerant bacterial consortia was examined. At 8% (w/v) salinity, a significant COD removal (80%) was discovered for mixed salt tolerant consortia; however, an increase in salt concentration to 10% (w/v) resulted in a decrease in COD removal efficiency. (Lofrano et al. 2013). Hair degrading bacteria were found to be *Brevibacterium luteolum* MTCC 5982 that can degrade keratin produced by the hair pulping process which is slowly degradable in nature, present in the hair waste (Thankaswamy et al. 2018).

CONCLUSION: This is shown through a careful analysis of the traditional leather processes and the underlying principles of each stage. The pre-tanning and tanning procedures account for the majority of the pollution, however post-tanning and finishing activities are equally harmful to the environment. The waste water from the tannery and the sludge produced by leather industries has drastic impact on entire ecology. The necessity for green technology has been highlighted by the detrimental effects of the leather industry. Additionally, the physio-chemical treatment procedures use a lot of chemicals and environmentally friendly. In order to degrade and detoxify the solid wastes and tannery wastewater produced by the leather industries in a way that is safe for the environment, bioremediation technologies may be a good choice which is eco-friendly, cost effective and proposes a promising method to enhance environmental quality. This study shows a number microbes which are reported to show their ability to remove or remediate toxic hazards present in the wastes generated from leather industries. In spite of having so many microbes, successful eco-friendly and cost-effective methods, leather industry wastes and wastewater continue to cause environmental pollution and toxicity issues that are frequently encountered. On that note this study will raise a social massage for the shake of good will of the human population. So that, proper steps can be taken, proper treatment of solid wastes and the tannery waste water which will be eco-friendly and uses of toxic chemicals can be controlled and also draw the sincere attention of the leather industries and the governments about this crucial scenario.

FUTURE SCOPE: It is necessary to look for other efficient microbes for the detoxification and degradation of tannery effluent and more specifically the toxic components that harms the environment, aquatic ecosystem, soil, human health which are still undefined, before its ultimate disposal into environment. In order to design effective bioremediation solutions, it is necessary to understand their genetic make-up and biochemistry. This will help to ensure the long-term viability of natural habitats on land and in the marine.More eco-friendly and cost-effective waste treatment technologies must be used in tanneries.

Conflict of Interest: There is no conflict of interest related to the study.

Author contributions: Acquisition and interpretation of data is done by Rupesh Dutta Banik. Conception, design and revising of the article are done by Dr. Pritha Pal and Dr. Sibashish Baksi.

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