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শিশু-কিশোর

সম্পাদনা

কঙ্কনু সহিস

প্রজ্ঞাবিকাশ

৯/৩, রমানাথ মজুমদার স্ট্রিট

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নজরুল সাহিত্যে শিশু সৌরভ

ড. অরুণাভ মুখার্জ্জী

"সব দেবতার আদরের ধন
নিত্যকালের তুই পুরাতন,
তুই প্রভাতের আলোর সমবয়সী।" -রবীন্দ্রনাথ

—শৈশব আমাদের জীবনে মহার্ঘ। বারে বারে আমাদের ইচ্ছে করে এই স্বপ্নের জগতে ফিরে যেতে। কিন্তু সবাই তা পারে না। কেননা শিশু সুলভ মন স্বর্গীয় সুষমার ধারক। তবে কেউ কেউ পারে এই শৈশবের অভিযাত্রী হতে। কাজী নজরুল ইসলাম সেই রকমই এক পরিণত বয়স ও মননের চিরশিশু; তাঁর অনেক রচনাতেই ছড়িয়ে আছে শিশুসৌরভ। বস্তুত ছোটদের নজরুল ভালোবাসতেন। তাই যখন যেটুকু সময় পেয়েছেন, ছোটদের জন্য ছড়া লিখেছেন, গান বেঁধেছেন, নাটিকা লিখেছেন, গল্প শুনিয়েছেন। কচি ও কিশোরদের জন্য কবির দরদী মনের এই পরিচয় ছড়িয়ে রয়েছে তাঁর বিভিন্ন রচনায়।

কাজী নজরুল ইসলাম একাধারে যেমন বিদ্রোহের কবি, প্রেমের কবি, সাম্যের কবি, সাধনার কবি; তেমনই ছিলেন প্রাণোচ্ছল, ফূর্তিবাজ দিলখোলা মানুষ। সর্বোপরি তাঁর মধ্যে ছিল এমন এক শিশুসত্তা, যা তাঁকে উন্মাদের মতো তুরীয়ানন্দে ছুটে চলতে যেমন প্রভাবিত করেছে, তেমনি করে তুলেছে "চির শিশু, চির-কিশোর/... যৌবন-ভীতু পল্লীবালার আঁচর কাঁচুলি নিচোর।" বস্তুত নজরুলের সমস্ত সৃষ্টির মধ্যেই রয়েছে এক ধরণের প্রাণোচ্ছলতার দীপ্তি। শিশু-কিশোরদের জন্য লেখাগুলিতে তাঁর এই প্রাণোচ্ছলতার উদ্ভাস লক্ষ্য করা যায়।

নজরুলের শিশুসৌরভ ছড়িয়ে রয়েছে তাঁর যে সব শিশুতোষ রচনা সমূহে, সেগুলি হল 'পুতুলের বিয়ে' (নাটিকা-১৯৩৩, এপ্রিল, ১৩৪০ চৈত্র প্রথম প্রকাশ), 'ঝিঙেফুল' (কাব্যগ্রন্থ-১৯২৬), 'সঞ্চয়ন', 'সংকল্প', 'মক্তব সাহিত্য', 'নতুন চাঁদ', 'ঝড়' প্রভৃতি। এইসব রচনায় যে বৈশিষ্ট্যগুলি প্রধানভাবে লক্ষ্য করা যায়, তা হল–

ক) চিরায়ত বাংলা লোক সাহিত্যের আন্তরিকতার স্পর্শ।
খ) শিশুর ক্রম বিকাশমান মানবসত্তা।
গ) শিশুর কল্পনা প্রতিভার স্বাভাবিক বিকাশ।
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ঙ) সাধারণ জিনিসকে অসাধারণত্ব দান।
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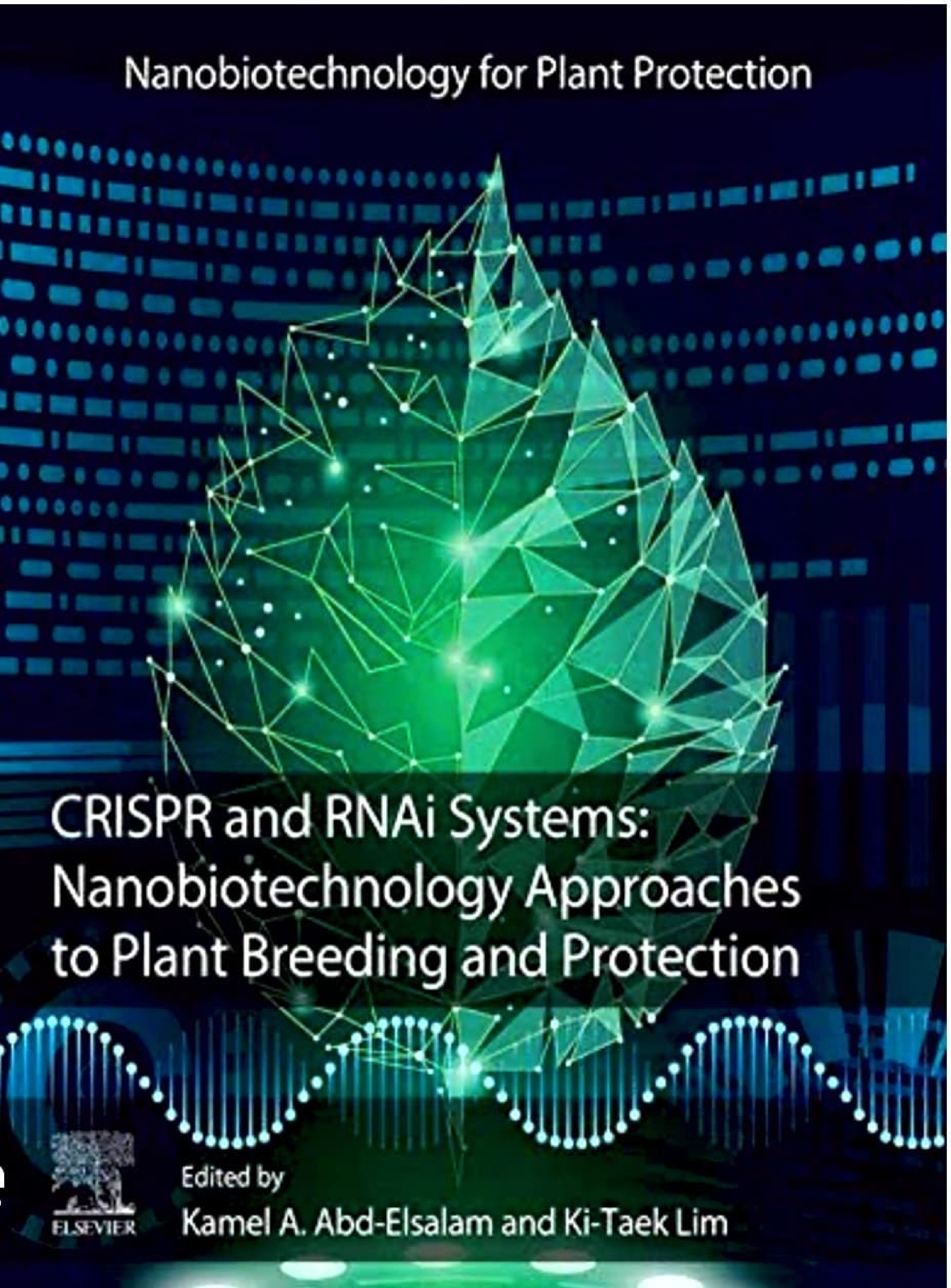
এছাড়াও নীতিশিক্ষা, মনের জাগরণ, সৌন্দর্য সৃষ্টি, দেশপ্রেম, সেবা, অভিযান, ব্যঙ্গরস প্রভৃতি বৈশিষ্ট্যও তাঁর শিশু সাহিত্যে মূর্ত হয়ে উঠেছে। বিশেষত নজরুল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Kamel A. Abd-Elsalam

Plant Pathology Research Institute, Agricultural Research Center (ARC), Giza, Egypt

Ki-Taek Lim

Department of Biosystems Engineering, Kangwon National University, Gangwon-do, South Korea

ELSEVIER

CHAPTER

ARE CRISPR/CAS9 AND RNA INTERFERENCE-BASED NEW TECHNOLOGIES TO RELOCATE CROP PESTICIDES?

4

Md Salman Hyder[1], Sayan Deb Dutta[2], Keya Ganguly[2], Ki-Taek Lim[2]
Department of Botany, Kalyani Mahavidyalaya, City Centre Complex, Nadia, India.[1] Department of Biosystems Engineering, Kangwon National University, Chuncheon, Republic of Korea.[2]

4.1 INTRODUCTION

Pests are the primary cause of the huge destruction of crops worldwide. Insects, plants, bacteria, fungi, weeds, molluscs, birds, mammals, fish, nematodes (roundworms), and other organisms which has economic impacts on crops and compete with humans for food that may be considered as pests (Dayan et al., 2009; Yadav et al., 2015). Pesticides are the only apparent measures to ensure food safety and crop protection, which in turn increase food productivity (McClung, 2014). According to Jeyaratnam, 1990, pesticides are any substance or can be a mixture of various substances having the properties to kill, prevent, or destruct any pest. As pesticide is a general term, it must be classified into various groups for detailed studies. Pesticides can be classified in various ways. Pesticides may be classified by their mode of entry, composition, or type of pests they killed (Drum, 1980). Based on the mode of entry, the pesticides may be classified as systemic, contact, stomach poisons, fumigants, and repellents. Systemic fungicides are those which can be transported to the untreated parts of crops via conducting tissue (Buchel, 1983). On the other hand, nonsystemic or contact pesticides act via direct interaction with the pests and do not translocate to other parts of crops. Fumigants can kill the pest by vaporization. Moreover, a repellent does not kill but destruct the pests (Yadav and Devi, 2017).

Pesticides also classified as herbicides, insecticides, fungicides, rodenticides, molluscicides, and nematicides based on organisms they kill (Agrawal et al., 2010). Pesticides also classified by their chemical composition. Excessive and worldwide use of pesticides harms nontargeted organisms, the environment as well as on human beings. The pesticides may be volatized after use and affect other organisms (Majewski and Capel, 1995). Herbicides may be washed off from crop fields and incorporate in the aquatic ecosystem and kill herbs, which lowers the productivity of oxygen in the aquatic body and imparts overall effect on aquatic organisms (Helfrich et al., 2009). Pesticides may also reach and contaminate groundwater (Pesticides in Groundwater, 2014). Humans can also be affected

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by pesticides. Each year, about 3,000,000 cases of pesticide poisoning and 220,000 deaths have been reported worldwide (Lah, 2011).

In most cases, humans are affected by the consumption of pesticides contaminated foods (Hayo and Werf, 1996). The effect of pesticides in humans includes various physiological and mental disorders (Lah, 2011), damages the immune system (Culliney et al., 1992), etc. The relationship between pesticides and Parkinson's disease and Alzheimer's disease was also established (Casida and Durkin, 2013). The deleterious effect of pesticides is of great concern over the past few decades. The first solution regarding the lousy effect of chemical pesticides is the use of biopesticides. The principal of biopesticides is the use of living organisms to reduce the population of other harmful organisms or pests (Bale et al., 2008). Biopesticides are developed by various biocontrol organisms, which can be fungi, bacteria, viruses, nematodes, predatory parasites, insects, mites, etc., and also may be developed by the natural product isolated from them which are helpful in protection of plants or animals (Bettiol, 2011). The search for new techniques for plant pest management is a prime concern from time to time. Generally, pest management also depends on the resistance power of crop, so the incensement of resistance power with new techniques is always a new concern. The use of RNA interference (RNAi) to control pests is of a new concern over the past few years. In plants, the double-strand RNA (dsRNA) is processed by several enzymes and machinery to produce small interfering RNA (siRNA), which can silence any RNA having similarity with the dsRNA (Baulcombe, 2004; Borges and Martienssen, 2015). The RNAi works via mRNA degradation or chromatin modulation. A dsDNA molecule of ~21–25 bp and with ~2-nt 3′ overhangs processed with an RNase III enzyme DICER into siRNAs. Subsequently, these RNAs incorporate with an Argonaute protein to produce RISC complex, which in turn can degrade the mRNA molecule having complementary to the guide strand of RISC complex (Christiaens et al., 2014; Carthew and Sontheimer, 2009). It is found that RNAi is effective against insects belongs to Coleoptera and sometimes against viruses (Baum et al., 2007). The dsDNA, which targets the functional mRNA of pests after ingestion, downregulates the genes of pests, which results in reduced growth or death of the pest feeding on it (Klumper and Qaim, 2014). In this chapter, we will focus on the comparison between conventional pesticides and RNAi-mediated crop protection and the limitation of the RNAi method. We will also try to find out if the RNAi is a new tool for relocating conventional crop pesticides.

4.2 CONVENTIONAL PESTICIDES: PRESENT STATUS AND CHALLENGES

For the betterment and improvement of agricultural yield and quality, pesticides are surely a solution in modern times (Damalas, 2009). The need and evolution of pesticides have a long history. Primary uses and explosion of pesticides were seen after World War II. Some essential pesticides like Dieldrin, β-benzene hexachloride (BHC), chlordane and endrin, 2,4-dichlorophenoxyacetic acid (2,4-D), Aldrin, dichlorodiphenyltrichloroethane (DDT), etc. was discovered that time (Delaplane, 2000). Although the use of pesticides reaches a peak in 1961, it drastically fell after 1962 for seeing its hazardous effects (Jabbar and Mallick, 1994). But the introduction of "integrated pest management" (IPM) in the late 1960 open a new era in pesticide research (Delaplane, 2000). From the past few years, the careless use of pesticides violating safety norms and other standard protocols affects the environment severely and also causes health risks of humans as well as other organisms (Carvalho, 2017). Synthetic pesticides are considered as most hazardous for having harmful effects on human beings. Initial exposure having various health issues like convulsions, headache, nausea, irritation, diarrhea, and breathing discomfort. Pesticides like organophosphate upon showing respiratory effects give symptoms like wheezing and asthma (Sharma et al., 2020). Using chemical pesticides in the wild also make insects and other pests as pest resistance (Sparks and Nauen, 2015). The search for new alternatives always the primary concern in the research field of pesticides. The conventional pesticide industry and market also underwent significant changes over time to time (Pelaez and Mizukawa, 2017).

One of the significant practices to replace conventional chemical pesticides is the use of biopesticides. Any substances which derived from animal, plants, microbes, or their products and use for pest control are considered as biopesticides (EPA, 2020). The global market is creating with a rate of 10% per year worldwide, as it appears to be a good substitution of chemical-based pesticides. Many microorganisms like fungus and bacteria are used for this purpose. The bacterium *Bacillus thuringiensis* (Bt) is used as the production of more than 90% microbial biopesticides (Kumar and Singh, 2015). Fungus *Talaromyces flavus* is used to control anthracnose caused by *Glomerella cingulata* in the nursery (Ishikawa, 2013). Extract of the species *Clitoria ternatea* shows an inhibitory effect on *Helicoverpa*, which shows a toxicity effect on *Helicoverpa* spp (Mensah et al., 2014). Products of the fungus *Trichoderma harzianum* show a very striking effect against *Fusarium* root rot bacterium (Kirk and Schafer, 2015). *Lactobacillus casei* strain LPT-111 (Tivano) shows effectiveness against angular leaf spot, caused by *Xanthomonas fragariae* (Dubois et al., 2017). Stilbenes isolated from grapevine extracts caused acute mortality of *S. littoralis*. A crop pest (Pavela et al., 2017). *Bacillus thuringinesis produces* endotoxins and causes lysis of insect guts; *Agrobacterium radiobacter* used to control crown gall (Quarles, 2011). Many critical secondary metabolites of plants-like Citronella oil, garlic extract, neem extract, datura, orange oil, tea tree extract, basil, lemongrass, apple mint, mustard, castor, Mahagony, and sesame are used to control the pest. Neem oil and pyrethrins (extracted from *Chrysanthemum cinerariaefolium*) are the two most widely used compounds used in pest control (Chandler et al., 2011). Pesticides may affect humans employing occupational exposure like industrial workers, distributors, deals and farmers, and nonoccupational methods. Exposure through consuming contaminated foods, vegetables, etc. (Sabarwal et al., 2018). Exposure of pesticides to humans causes some serious health issues and disorder includes Hodgkin's disease, nonHodgkin lymphoma (Luo et al., 2016). Parkinson's disease (Brouwer et al., 2017) endocrine disruption, respiratory, and reproductive disorders (Kirkhorn and Schenker, 2002). Biopesticides are considering as safest over conventional chemical pesticides, as this is much safer and fewer detritus and most effectively efficiently affect only target organisms. On the other hand, biopesticides need in a minimal amount and do not leaves any detritus residue.

Nevertheless, it seems that the biopesticides did not completely replace the chemical pesticides as some drawbacks and lack of collaborative research. It is recommended that the chemical and biopesticides must go together to ensure better protection. Extensive research also needed in this field (Damalas and Koutroubas, 2018). Another new way to get a ride from the adverse effects of pesticides is by using nanotechnology. Nanotechnology can help by protecting the biopesticides as an encapsulating agent and also by protecting the degradation of many compounds (De Oliveira et al., 2014). Nanoparticles found effective in protecting neem oil from degradation (Mishra et al., 2017).

4.3 ADVANCEMENT IN GREEN REVOLUTION: THE RNAI TOOLKIT

Although RNAi is a perfect tool for functional gene analysis in vivo and in vitro (Trivedi 2010), it now also effectively used in crop pest control, particularly against insect pest (Huvenne and Smagghe, 2010). The RNAi method may be implanted in the field by either host-induced gene silencing (HIGS) or virus-induced gene silencing (VIGS). The HIGS aims of the expression of dsRNA in crops specific to a pest or pathogen. Gene duplication thought to be a factor for increasing expression of RNAi in coleopteran. It was also proved by Davis-Vogel et al. (2018) that RNAi efficiency varies among different groups of insect orders for which mRNA expression of core machinery genes is also responsible (Christiaens et al., 2019). The first known experiment was reported by Bettencourt et al. (2002), by silencing a gene named *Hemolin* with RNAi technology, which is essential for larval production and embryonic development in *Hyalophora cecropia* has been stopped and causes early death of larva. A knockdown of zygotic genes in offspring was observed when dsDNA was injected in the mother's hemocoel of Tribolium *castaneum* (Bucher et al., 2002). One of the best examples is the development of genetically modified (GM) maize, which expresses vATPaseA dsRNA for control of *Diabrotica virgifera*, the western corn rootworm (Yan et al., 2019). Another evidence came from *Tribolium*, where induction of RNAi in the larval stage gives a functionless adult stage (Tomoyasu and Denell, 2004), which suggests the application of RNAi in a particular stage may affect to another stage. It is found that insects lack RNA-dependent RNA polymerase (RdRP), which suggests insects care not depends on RDRP-based gene silencing, instead maybe adopt another method, but it has to uptake dsRNA continuously (Gordon and Waterhouse, 2007).

An effective way is making transgenic plants that can supply dsDNA continuously. Evidence of reduction of corn root damage was found in a study by Baum et al. by the production of (V-ATPase) dsRNA after infection with corn rootworm (Baum et al., 2007). After feeding on transgenic *Arabidopsis thaliana* or *Nicotiana tobacum* expressing dsRNA specific to a cytochrome P450 gene (*CYP6AE14)*, the level of the gene was knocked down in insect gut causing reduced larval tolerance toward gossypol-containing food (Mao *et al*., 2007). A new way for the implementation of RNAi also found as spray induces gene silencing method. Koch et al. showed that *Arabidopsis* and barley express a dsDNA which can disrupt the fungal membrane integrity by targeting CYP51 genes which were necessary for expression of cytochrome P450 lanosterol C14α-demethylase (Koch et al., 2013) Later on a study, spraying with 791-nt long CYP3-dsRNAs on detached barley leaf was effective against the fungal pathogen (Koch et al., 2016). Similar disease control was also observed in various studies. Wang et al. reported that applying dsRNAs and small RNAs was also successfully suppressed *Botrytis cinerea* from attacks (Wang et al., 2016a,b). Translocation of sRNA in the distal untreated part also reported, and taking up of external dsDNA and sRNA by fungal pathogen was also reported (Wang et al., 2016a,b). Cotton bollworm *Helicoverpa armigera* tolerates gossypol is a polyphenolic compound found in cotton, although it is very toxic to animals. It was found that the gene CYP6AE14 detoxify gossypol after a construct targeting CYP6AE14 was made the cotton worm feeding on transgenic leave found a limited growth (Mao et al., 2007). Several species of Coleoptera, like *Tribolium castaneum*, *Leptinotarsa decemlineata*, and *Diabrotica virgifera*, are found very useful to RNAi (Tomoyasu et al., 2008). Some other successful approaches, including GM crops expressing dsDNA, are GM cotton against *Tetranychus cinnabarinus*, GM tobacco against *Myzus persicae*, and GM potato against *Leptinotarsa decemlineata* (Yan et al., 2019). Transplastomic crops show high efficiency in RNAi-mediated gene transfer, which allows the accumulation of a large amount of stable dsDNA (Yan et al., 2019). Table 4.1 briefly summarizes some of the examples of successful HIGS in plant pathogens.

RNAi may be used either by making transgenic plants or by using products with dsRNA. The delivery method of RNAi is the most crucial concern. One successful method of delivery is making transgenic crops, although it seems to be practically difficult in many aspects, so the tropical application of dsRNA is now considered as an alternative way (Baum et al., 2007; Joga et al., 2016). As RNA can translocate within the whole plant, the tropical application seems to be very useful, two types of pests took after dsRNA from previously treated citrus leaves proves this fact (San Miguel and Scott, 2016). Although the problem may arise during the delivery of naked RNA, which can be overcome by using clay, a type of specialized nanosheets which protects the naked RNA (Mitter et al., 2017), another effective method is VIGS, where a nonpathogenic engineered virus is produced

Table 4.1 List of some conventional RNAi-based techniques for knocking down insect-specific genes.

Species	Genes	Phenotype	Reference
Acyrthosiphon pisum	*C002*	100% mortality after 8 days	Mutti et al. (2006)
Bactericera cockerelli	Actin, v-ATPase	82%–92% mortality	Wuriyanghan et al. (2011)
Cimex lectularius	*cpr*	Increased deltamethrin sensitivity	Zhu et al. (2012)
Laodelphax striatellus	Disembodied	Reduction in EcR expression; impaired development; and decreased survival	Wan et al. (2014)
Lygus lineolaris	*PG1*	No phenotypic effect observed	Walker and Allen (2010)
Myzus persicae	*C002*	Reduction in fecundity	Walker and Allen (2011)
Nephotettix cincticeps	*PGRP12*	95% mortality after 10 days	Tomizawa and Noda (2013)
Nilaparvata lugens	*Hsp70, Argk*	Decreased mortality after triazopos exposure	Ge et al. (2013)
Oncopeltus fasciatus	Hunchback	Parental RNAi and disrupted embryonic development	Liu and Kaufman (2004)
Pyrrhocorris apterus	*Met, kr-h1*	Disturbed metamorphosis and development	Smykal et al. (2014)
Rhodnius prolixus	Nitrophorins1–4	Discolouration of salivary glands	Araujo et al. (2009)
Sogatella furcifera	Disembodied	Reduction in EcR expression; impaired development; and decreased survival	Wan et al. (2014)
Triatoma brasiliensis	Brasiliensin	Reduction in blood feeding	Araujo et al. (2007)

pest-specific RNAi inducer sequence. After exposure of this engineered virus to the pest, the target mRNA becomes silenced (Nandety et al., 2014). One vital aspect of RNAi technology that the cost is reduced day by day, for example, the cost to produce 1 g of dsRNA using NTP synthesis was USD 12,500 in 2008, which is now USD 100 in 2016, and to USD 60 in the present. (Andrade and Hunter, 2016). Another cost-effective (USD 4 per 1 g), the method is using HT115(DE3), a strain of *Escherichia coli*, which lacks dsRNA degrading enzymes that can be used for the production of a large amount of dsRNA which can be used anytime (Andrade and Hunter, 2016). Ingestion of dsRNA targeting *16D10* dsRNA in root-knot nematode results in reducing nematode activity (Huang et al., 2006).

4.4 ADVANTAGES AND DISADVANTAGES OF RNAI-BASED METHODS

The first primary concern is the delivery of dsRNA; various strategies like modification of dsRNA, using various useful vehicles are of present concern. A straight forward way of delivery is micro-injection. Although this is an easy and efficient method for delivery of dsRNA, it seems to be possible only in laboratory conditions and unsuitable for field conditions because it is very laborious and ineffective for a large-scale delivery. Another critical concern regarding RNAi-based pest control is degradation (Christiaens et al., 2014); degradation may occur due to either unstable pH condition or dsRNA degrading enzymes. Lipid-based nanoparticle formulation may help to overcome these situations (Zhang et al., 2010). Use of viruses that upon infection to pest express dsRNA is also helpful for this purpose (Hajeri et al., 2014). Another factor for the success of the RNA-mediated pest control is the presence of proper RNAi machinery components; a variation of this machinery has been found, sometimes even under the same phylum (Miller et al., 2012). An example of Sid1-like genes may be taken into consideration, and this gene varies among different insect species (Bansal and Michel, 2013). A previous report came from *Drosophila* that the Flock house virus (FHV) B2 protein can bind to long siRNA duplexes and inhibits it from forming of RISC complex (Chao et al., 2005), this is an example of suppression of RNAi mechanism by a virus which is also a significant concern as the virus has anti-RNAi defense mechanism (Haasnoot et al., 2007).

Furthermore, the delivery system and other problems many more limitations to be addressed, like its effectiveness, biosafety measures, and ecological safety. Table 4.2 briefly demonstrates the application of dsRNA based on the mode of insect feeding on plants. Several questions like the part of plants where the expression is done, the concentration needed for the purpose should be addressed. When compared to conventional insecticides, the cost, effect, pollution aspects, stability, and uptake rate should be improved for its better acceptance (Zhang, 2012). Details study of length of RNA, sequence, life stage of target insect, and procedures are very complex and need more study (Terenius *et al*., 2011). A report came from recent studies in *Euschistus heros* that by using EDTA, the stability of dsDNA and RNAi, efficiency may be increased (Castellanos et al., 2019).

4.5 ADVANTAGES OF CRISPR/CAS9-BASED SYSTEMS

CRISPRσCas9 is a modern gene-editing tool that has created a new way to study genome editing and various diseases. It stands for clustered regularly interspaced short palindromic repeats (CRISPR)–

Table 4.2 Formulation technique of various dsRNAs during insect feeding on plants.

Species	Genes	Method of application	References
Leptinotarsa dcemlineata	*β*-Actin; protein transport protein sec23	Feeding (larvae)	Zhu et al. (2011)
Phyllotreta striolata	Odorant receptor (*PsOr1*)	Injection (adult)	Zhao et al. (2011)
Lygus lineolaris	Inhibitor of apoptosis gene (*LlIAP*)	Injection	Walker and Allen (2011)
Riptortus pedestris	Circadian clock genes period; cycle	Injection (adult)	Ikeno et al. (2011a, b)
Myzus persica	*MpC002* and *Rack-1*	Transgenic plant	Pitino et al. (2011)
Athalia rosae	*Ar* white gene	Injection (eggs)	Sumitani et al. (2005)
Schistocerca americana	Eye color gene vermilion	Injection (nymph)	Dong and Friedrich (2005)
Gryllus bimaculatus	*Delta; Notch*	Injection (eggs)	Mito et al. (2011)
Gryllus bimaculatus	Insulin receptor; insulin receptor substrate; phosphatase and tensin homolog; target of rapamycin; PRS6-p70-protein kinase; fork head box O; and epidermal growth factor receptor	Injection (nymph)	Dabour et al. (2011)

CRISPR-associated gene Cas9. Genome editing with CRISPR–Cas9 is very stable compare to the RNAi method. Some examples of pests on which CRISPR–Cas9 gene knockout has performed include *Helicoverpa armigera*, *Spodoptera litura*, *Plutella xylostella*, and *Spodoptera littoralis* (Zhu et al., 2016; Wang et al., 2016a,b; Huang et al., 2016). CRISPR–Cas9 has a great success in editing insect genome. Choo et al. demonstrated the mutagenic effect through CRISPR–Cas9 in a crop pest *Bactrocera tryoni* by frameshift-mutation in an ATP-dependent binding cassette transporter (Choo et al., 2017). Therefore the genome editing using site-specific nucleases (SSNs) helps us to understand the transgene experiments that can be carried out in an efficient and precise manner. There are four major classes of SSNs that can be used effectively to edit the genomes, for example, mega-nucleases (MEGA), zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and CRISPR. Fig. 4.1 shows an overview of three major types of genome editing strategies that are used frequently for viral resistance (Zaidi et al., 2016a).

It is interesting to note that this RNA-based guiding technique is cheaper and easier to engineer and one can manipulate a wide range of possible target sequences without error. Despite of gaining significant success in genome editing, it remains to be uncleaned whether this technique could actually work under natural conditions in open field trails or not (Zaidi et al., 2016b). Therefore more detailed and precise analysis of these technologies (CRISPR/Cas9 and RNAi) will eventually led to the development of novel disease resistant crops in the upcoming years.

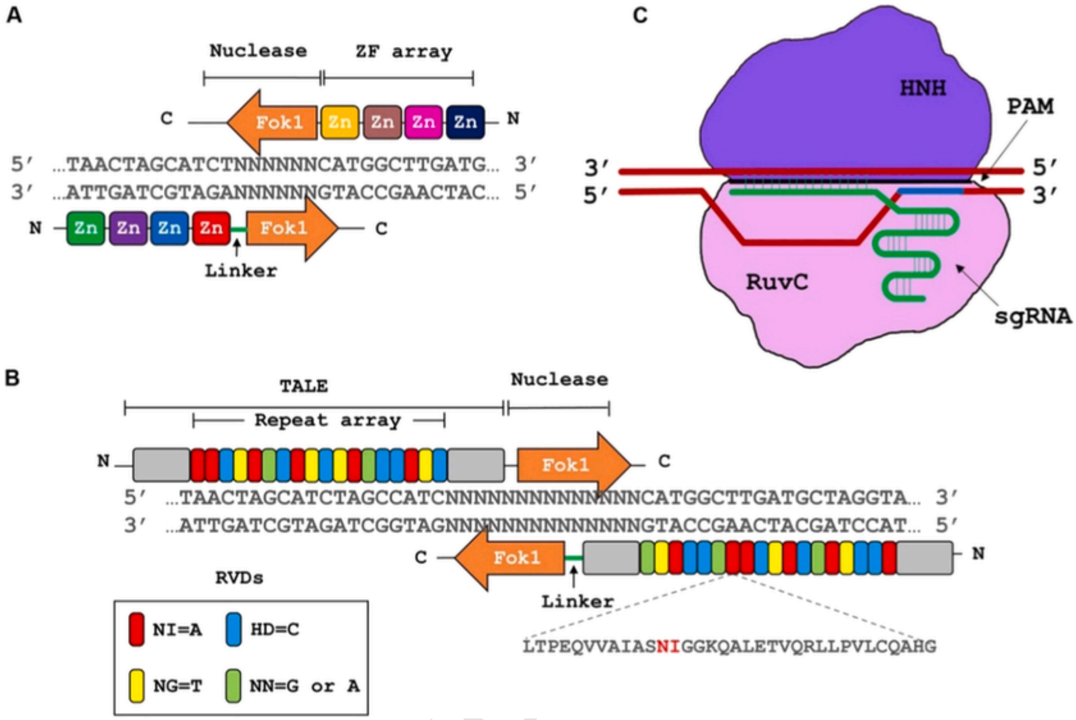

FIGURE 4.1

The major types of CRISPR/Cas9-based genome editing platforms. The proposed structure of site-specific nucleases (SSNs). (A) Zinc-finger nucleases (ZFNs). (B) Transcription activator-like effector nucleases (TALENs), and (C) CRISPR. *CRISPR*, Clustered regularly interspaced short palindromic repeats; *Cas9*, CRISPR–CRISPR-associated gene.

4.6 CONCLUSIONS AND FUTURE PROSPECTS

The crop improvement using traditional pesticide or herbicide-resistant traits or improving the biocompatibility of biopesticides is time-consuming and labor-intensive. Most of the cases, the biopesticides are found inactive environmental conditions or impede the growth and development of agronomic crops. To eliminate such difficulties, the researchers are now switching towards RNAi-based biotechnological technologies for quality traits with enhanced protection against pathogens. However, the critical question comes; for example, can it be effective against the pathogens for a long time? Is it possible to extract and identify the microRNAs in a small volume? Or is there sufficient knowledge about the detailed mode of action of RNAi-based techniques? (Fig. 4.2). Based on these common aspects, the RNA-based technologies remain challenging over conventional pesticides or insecticides that are produced on a large scale. In reality, most of the genetically modified crops approved for commercial use are mainly designed to produce toxic proteins that are harmful to insects. However,

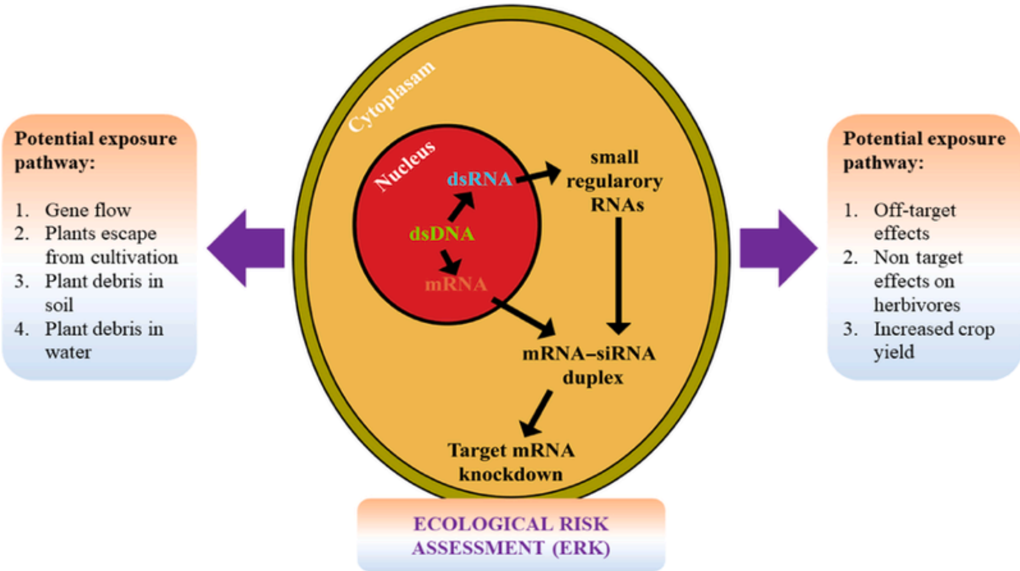

FIGURE 4.2

A hypothetical model demonstrating the ecological risk assessment of RNA-based crop protection.

there is no proper explanation or resources that could support the significant impact of using this new technology for crop improvement. Furthermore, the crop regulatory agencies and risk assessment analysts need to become familiar with this RNAi-based toolkit and its proper application during filed trails. The proper knowledge and understanding of the mode of action in various aquatic and terrestrial ecosystems will be a crucial part of the characterization of these RNAs. Novel diagnostic tools will probably eliminate these problems regarding the successful application of RNAi and genome editing tools soon.

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REFERENCES

Andrade, E.C., Hunter, W.B., 2016. RNA interference—natural gene-based technology for highly specific pest control (HiSPeC). In: Abdurakhmonov, I.Y. (Ed.), RNA Interference. In Tech, Rijeka, pp. 391–409.

Araujo, R., Campos, I., Tanaka, A., Santos, A., Gontijo, N., Lehane, M., et al., 2007. Brasiliensin: a novel intestinal thrombin inhibitor from Triatoma brasiliensis (Hemiptera: Reduviidae) with an important role in blood intake. Int. J. Parasitol. 37, 1351–1358.

Araujo, R.N., Soares, A.C., Paim, R.M., Gontijo, N.F., Gontijo, A.F., Lehane, M.J., et al., 2009. The role of salivary nitrophorins in the ingestion of blood by the triatomine bug Rhodnius prolixus (Reduviidae: Triatominae). Insect Biochem. Mol. Biol. 39, 83–89.

Bale, J.S., Van Lenteren, J.C., Bigler, F., 2008. Biological control and sustainable food production. Philos. Trans. R. Soc. Lond. B: Biol. Sci. 363, 761–776.
Bansal, R., Michel, A.P., 2013. Core RNAi machinery and Sid1, a component for systemic RNAi, in the hemipteran insect, Aphis glycines. Int. J. Mol. Sci. 14, 3786–3801.
Baulcombe, D., 2004. RNA silencing in plants. Nature 431, 356–363.
Baum, J.A., Bogaert, T., Clinton, W., Heck, G.R., Feldmann, P., Ilagan, O., et al., 2007. Control of coleopteran insect pests through RNA interference. Nat. Biotechnol. 25, 1322–1326.
Bettencourt, R., Terenius, O., Faye, I., 2002. Hemolin gene silencing by ds-RNA injected into Cecropia pupae is lethal to next generation embryos. Insect Mol. Biol. 11, 267–271.
Bettiol, W., 2011. Biopesticide use and research in Brazil. Outlooks Pest. Manag. 22 (6), 280–284.
Borges, F., Martienssen, R.A., 2015. The expanding world of small RNAs in plants. Nat. Rev. Mol. Cell Biol. 16, 727–741.
Brouwer, M., Huss, A., van der Mark, M., Nijssen, P.C.G., Mulleners, W.M., Sas, A.M.G., et al., 2017. Environmental exposure to pesticides and the risk of Parkinson's disease in the Netherlands. Environ. Int. 107, 100–110.
Buchel, K.H., 1983. Chemistry of Pesticides. John Wiley and Sons, Inc, New York, USA.
Bucher, G., Scholten, J., Klingler, M., 2002. Parental RNAi in Tribolium (Coleoptera). Curr. Biol. 12, R85–R86.
Carthew, R.W., Sontheimer, E.J., 2009. Origins and mechanisms of miRNAs and siRNAs. Cell 136, 642–655.
Carvalho, F.P., 2017. Pesticides, environment, and food safety. Food Energy Secur. 6, 48–60.
Casida, J.E., Durkin, K.A., 2013. Neuroactive insecticides: targets, selectivity, resistance, and secondary effects. Annu. Rev. Entomol. 58, 99–117.
Chandler, D., Bailey, A.S., Tatchell, G.M., Davidson, G., Greaves, J., Grant, W.P., 2011. The development, regulation and use of biopesticides for integrated pest management. Philos. Trans. R. Soc. Lond. B: Biol. Sci. 366, 1573.
Chao, J.A., Lee, J.H., Chapados, B.R., Debler, E.W., Schneemann, A., Williamson, J.R., 2005. Dual modes of RNA-silencing suppression by Flock House virus protein B2. Nat. Struct. Mol. Biol. 12, 952–957.
Choo, A., Crisp, P., Saint, R., O'Keefe, L.V., Baxter, S.W., 2017. CRISPR/Cas9-mediated mutagenesis of the white gene in the tephritid pest Bactrocera tryoni. J. Appl. Entomology 142 (1-2), 52–58. 10.1111/jen.12411.
Christiaens, O., Swevers, L., Smagghe, G., 2014. dsRNA degradation in the pea aphid (Acyrthosiphon pisum) associated with lack of response in RNAi feeding and injection assay. Peptides 53, 307–314.
Christiaens, O., Whyard, S., Velez, A.M., Smagghe, G., 2019. Double-stranded RNA technology to control insect pests: current status and challenges. Front. Plant Sci. 11, 451. 10.3389/fpls.2020.00451.
Culliney, T.W., Pimentel, D., Pimentel, M.H., 1992. Pesticides and natural toxicants in foods. Agric. Ecosyst. Environ. 41, 297–320.
Dabour, N., Bando, T., Nakamura, T., Miyawaki, K., Mito, T., Ohuchi, H., et al., 2011. Cricket body size is altered by systemic RNAi against insulin signalling components and epidermal growth factor receptor. Dev. Growth Differ. 53, 857–869.
Damalas, C.A., 2009. Understanding benefits and risks of pesticide use. Sci. Res. Essays 4, 945–949.
Damalas, C.A., Koutroubas, S.D., 2018. Current status and recent developments in biopesticide use. Agriculture 8, 13. 10.3390/agriculture8010013.
Dayan, F.E., Cantrell, C.L., Duke, S.O., 2009. Natural products in crop protection. Bioorg. Med. Chem. 17, 4022–4034.
De Oliveira, J.L., Campos, E.V.R., Bakshi, M., Abhilash, P.C., Fraceto, L.F., 2014. Application of nanotechnology for the encapsulation of botanical insecticides for sustainable agriculture: prospects and promises. Biotechnol. Adv. 32, 1550–1561.
Delaplane, K.S., 2000. Pesticide usage in the United States: history, benefits, risks, and trends. Cooperative Extension Service. The University of Georgia, College of Agricultural and Environmental Sciences. Bulletin 1121.http://pubs.caes.uga.edu/caespubs/pubs/PDF/B1121.pdf. (Accessed November 2000).
Dong, Y., Friedrich, M., 2005. Nymphal RNAi: systemic RNAi mediated gene knockdown in juvenile grasshopper. BMC Biotechnol. 5, 25.

Drum, C., 1980. Soil Chemistry of Pesticides. PPG Industries, Inc, USA.

Dubois, C., Arsenault-Labrecque, G., Pickford, J., 2017. Evaluation of a new biopesticide against angular leaf spot in a commercial operation system. Acta Hortic 1156, 757–764.

EPA, 2020. Biopesticides. www.epa.gov/pesticides/biopesticides (Accessed 9 May 2020).

Ge, L.Q., Huang, L.J., Yang, G.Q., Song, Q.S., Stanley, D., Gurr, G., et al., 2013. Molecular basis for insecticide-enhanced thermo tolerance in the brown plant hopper Nilaparvata lugens Stål (Hemiptera: Delphacidae). Mol. Ecol. 22, 5624–5634.

Gordon, K.H.J., Waterhouse, P.M., 2007. RNAi for insect proof plants. Nat. Biotechnol. 25, 1231–1232.

Haasnoot, J., Westerhout, E.M., Berkhout, B., 2007. RNA interference against viruses: strike and counterstrike. Nat. Biotechnol. 25, 1435–1443.

Hajeri, S., Killiny, N., El-Mohtar, C., Dawson, W.O., Gowda, S., 2014. Citrus tristeza virus-based RNAi in citrus plants induces gene silencing in Diaphorinacitri, a phloem-sap sucking insect vector of citrus greening disease (Huanglongbing). J. Biotechnol. 176, 42–49.

Hayo, M.G., Werf, V.D., 1996. Assessing the impact of pesticides on the environment. Agric. Ecosyst. Environ. 60, 81–96.

Helfrich, L.A., Weigmann, D.L., Hipkins, P., Stinson, E.R., 2009. Pesticides and aquatic animals: a guide to reducing impacts on aquatic systems. Virginia Polytechnic Institute and State University. https://pubs.ext.vt.edu/420/420-013/420-013.html.

Huang, G., Allen, R., Davis, E.L., Baum, T.J., Hussey, R.S., 2006. Engineering broad root-knot resistance in transgenic plants by RNAi silencing ofa conserved and essential root-knot nematode parasitism gene. Proc. Natl Acad. Sci. U. S. A. 103, 14302–14306.

Huang, Y., Chen, Y., Zeng, B., Wang, Y., James, A.A., Gurr, G.M., et al., 2016. CRISPR/Cas9 mediated knockout of the abdominal-A homeotic gene in the global pest, diamondback moth (Plutella xylostella). Insect Biochem. Mol. Biol. 75, 98–106.

Huvenne, H., Smagghe, G., 2010. Mechanisms of dsRNA uptake in insects and potential of RNAi for pest control: a review. J. Insect Physiol. 56, 227–235.

Ikeno, T., Numata, H., Goto, S.G., 2011. Circadian clock genes period and cycle regulate photoperiodic diapause in the bean bug Riptortus pedestris males. J. Insect Physiol. 57, 935–938.

Ishikawa, S., 2013. Integrated disease management of strawberry anthracnose and development of a new biopesticide. J. Gen. Plant. Pathol. 79, 441–443.

Jabbar, A., Mallick, S., 1994. Pesticides and Environment Situation in Pakistan (Working Paper Series No. 19). Sustainable Development Policy Institute (SDPI).

Jeyaratnam, J., 1990. Acute Pesticide Poisoning: A Major Global Health Problem.

Joga, M.R., Zotti, M.J., Smagghe, G., Christiaens, O., 2016. RNAi efficiency, systemic properties, and novel delivery methods for pest insect control: what we know so far. Front. Physiol. 7, 553.

Kirk, W.W., Schafer, R.S., 2015. Efficacy of new active ingredient formulations and new biopesticides for managing Fusarium root rot disease of gladiolus hybrids. Acta Hortic. 1105, 55–60.

Kirkhorn, S.R., Schenker, M.B., 2002. Current health effects of agricultural work: respiratory disease, cancer, reproductive effects, musculoskeletal injuries, and pesticide- related illnesses. J. Agric. Saf. Health 8, 199–214.

Klumper, W., Qaim, M., 2014. A meta-analysis of the impacts of genetically modified crops. PLoS ONE 9, e111629.

Koch, A., et al., 2013. Host-induced gene silencing of cytochrome P450 lanosterol C14 alpha-demethylase-encoding genes confers strong resistance to Fusarium species. Proc. Natl. Acad. Sci. U. S. A. 110, 19324–19329.

Koch, A., et al., 2016. An RNAi-based control of Fusarium graminearum infections through spraying of long dsRNAs involves a plant passage and is controlled by the fungal silencing machinery. PLoS Pathog. 12, e1005901.

Kumar, S., Singh, A., 2015. Biopesticides: present status and the future prospects. J. Fertil. Pestic. 6, e129.

Lah, K., 2011. Effects of pesticides on human health. Toxipedia. http://www.toxipedia.org/display/toxipedia/Effects+of+Pesticides+on+Human+Health.

Liu, P.Z., Kaufman, T.C., 2004. Hunchback is required for suppression of abdominal identity, and for proper germband growth and segmentation in the intermediate germband insect Oncopeltus fasciatus. Development 131, 1515–1527.
Luo, D., Zhou, T., Tao, Y., Feng, Y., Shen, X., Mei, S., 2016. Exposure to organochlorine pesticides and non-Hodgkin lymphoma: a meta-analysis of observational studies. Sci. Rep. 6, 25768.
Majewski, M., Capel, P., 1995. Pesticides in the Atmosphere: Distribution, Trends, and Governing Factors. Pesticides in the Hydrologic System 1, Ann Arbor Press Inc., Boca Raton, FL, 118.
Mao, Y.B., Cai, W.J., Wang, J.W., Hong, G.J., Tao, X.Y., Wang, L.J., et al., 2007. Silencing a cotton bollworm P450 monooxygenase gene by plant-mediated RNAi impairs larval tolerance of gossypol. Nat. Biotechnol. 25, 1307–1313.
McClung, C.R., 2014. Making hunger yield. Science 344, 699.
Mensah, R., Moore, C., Watts, N., Deseo, M.A., Glennie, P., Pitt, A., 2014. Discovery and development of a new semiochemical biopesticide for cotton pest management: assessment of extract effects on the cotton pest Helicoverpa spp. Entom. Exp. Appl. 152, 1–15.
Miller, S.C., Miyata, K., Brown, S.J., Tomoyasu, Y., 2012. Dissecting systemic RNA interference in the red flour beetle Tribolium castaneum: parameters affecting the efficiency of RNAi. PLoS ONE 7, e47431.
Mishra, S., Keswani, C., Abhilash, P.C., Fraceto, L.F., Singh, H.B., 2017. Integrated approach of agri-nanotechnology: challenges and future trends. Front. Plant Sci. 8, 471.
Mito, T., Nakamura, T., Bando, T., Ohuchi, H., Noji, S., 2011. The advent of RNA interference in entomology. Entomol. Sci. 14, 1–8.
Mitter, N., Worrall, E.A., Robinson, K.E., Li, P., Jain, R.G., Taochy, C., et al., 2017. Clay nanosheets for topical delivery of RNAi for sustained protection against plant viruses. Nat. Plants 3, 16207.
Mutti, N.S., Park, Y., Reese, J.C., Reeck, G.R., 2006. RNAi knockdown of a salivary transcript leading to lethality in the pea aphid, Acyrthosiphon pisum. J. Insect Sci. 6, 1–7.
Nandety, R.S., Kuo, Y.W., Nouri, S., Falk, B.W., 2014. Emerging strategies for RNA interference (RNAi) applications in insects. Bioeng. Bugs 6, 8–19.
Pavela, R., Waffo-Teguo, P., Biais, B., Richard, T., Mérillon, J., 2017. M. Vitisvinifera canes, a source of stilbenoids against Spodopteralittoralis larvae. J. Pest. Sci. 90, 961–970.
Pelaez, V., Mizukawa, G., 2017. Diversification strategies in the pesticide industry from seeds to biopesticides. Ciênc. Rural 47, e20160007.
Pitino, M., Coleman, A.D., Maffei, M.E., Ridout, C.J., Hogenhout, S.A., 2011. Silencing of aphid genes by dsRNA feeding from plants. PLoS ONE 6, e25709.
Quarles, W., 2011. New Biopesticides for IPM and Organic Production 33, IPM Practitioner, 1–20.
Sabarwal, A., Kumar, K., Singh, R.P., 2018. Hazardous effects of chemical pesticides on human health–cancer and other associated disorders. Environ. Toxicol. Pharmacol. 63, 103–114.
San Miguel, K., Scott, J.G., 2016. The next generation of insecticides: DsRNA is stable as a foliar-applied insecticide. Pest. Manag. Sci. 4, 801–809.
Sharma, A., Shukla, A., Attri, K., Kumar, M., Kumar, P., Suttee, A., et al., 2020. Global trends in pesticides: a looming threat and viable alternatives. Ecotoxicol. Environ. Saf. 201, 110812.
Smykal, V., Daimon, T., Kayukawa, T., Takaki, K., Shinoda, T., Jindra, M., 2014. Importance of juvenile hormone signalling arises with competence of insect larvae to metamorphose. Dev. Biol. 390, 221–230.
Sparks, T.C., Nauen, R., 2015. IRAC: mode of action classification and insecticide resistance management. Pest. Biochem. Physiol. 121, 122–128.
Sumitani, M., Yamamoto, D.S., Lee, J.M., Hatakeyama, M., 2005. Isolation of white gene orthologue of the sawfly, Athaliarosae (Hymenoptera) and its functional analysis using RNA interference. Insect Biochem. Mol. Biol. 35, 231–240.
Terenius, O., Papanicolaou, A., Garbutt, J.S., Eleftherianos, I., Huvenne, H., Kanginakudru, S., et al., 2011. RNA interference in Lepidoptera: an overview of successful and unsuccessful studies and implications for experimental design. J. Insect Physiol. 57, 231–245.

Tomizawa, M., Noda, H., 2013. High mortality caused by high dose of dsRNA in the green rice leafhopper Nephotettix cincticeps (Hemiptera: Cicadellidae). Appl. Entomol. Zool. 48, 553–559.

Tomoyasu, Y., Denell, R.E., 2004. Larval RNAi in Tribolium (Coleoptera) for analyzing adult development. Dev. Genes. Evol. 214, 575–578.

Tomoyasu, Y., Miller, S.C., Tomita, S., Schoppmeier, M., Grossmann, D., Bucher, G., 2008. Exploring systemic RNA interference in insects: a genome-wide survey for RNAi genes in Tribolium. Genome Biol. 9, R10.

Trivedi, B., 2010. Bug silencing: the next generation of pesticides. New Sci. 205, 34–37.

Walker, W.B., Allen, M.L., 2010. Expression and RNA interference of salivary polygalacturonase genes in the tarnished plant bug, Lyguslineolaris. J. Insect Sci. 10.

Walker, W.B., Allen, M.L., 2011. RNA interference-mediated knockdown of IAP in Lyguslineolaris induces mortality in adult and pre-adult life stages. Entomol. Exp. Appl. 138, 83–92.

Wan, P.J., Jia, S., Li, N., Fan, J.M., Li, G.Q., 2014. RNA interference depletion of the halloween gene disembodied implies its potential application for management of plant hopper Sogatella furcifera and Laodelphax striatellus. PLoS ONE 9, e86675.

Wang, J., Zhang, H.N., Wang, H.D., Zhao, S., Zuo, Y.Y., Yang, Y.H., et al., 2016. Functional validation of cadherin as a receptor of Bt-toxin Cry1Ac in Helicoverpa armigera utilizing the CRISPR/Cas9 system. Insect Biochem. Mol. Biol. 76, 11–17.

Wang, M., et al., 2016. Bidirectional cross-kingdom RNAi and fungal uptake of external RNAs confer plant protection. Nat. Plants 2, 16151.

Wuriyanghan, H., Rosa, C., Falk, B.W., 2011. Oral delivery of double-stranded RNAs and siRNAs induces RNAi effects in the potato/tomato psyllid, Bactericercacockerelli. PLoS ONE 6, e27736.

Yadav, I., Devi, N.I., 2017. Pesticides classification and its impact on human and environment. Environ. Sci. Eng. 6, 140–158.

Yadav, I.C., Devi, N.L., Syed, J.H., Cheng, Z., Li, J., Zhang, G., et al., 2015. Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighbouring countries: a comprehensive review of India. Sci. Total Environ. 511, 123–137.

Yan, S., Ren, B., Zeng, B., Shen, J., 2019. Improving RNAi efficiency for pest control in crop species. BioTechniques 68. 10.2144/btn-2019-0171.

Zaidi, S.S.A., Tashkandi, M., Mansoor, S., Mahfouz, M.M., 2016. Engineering plant immunity: using CRISPR/Cas9 to generate virus resistance. Front. Plant Sci. 7, 1–10.

Zaidi, S.S., Mansoor, S., Ali, Z., Tashkandi, M., Mahfouz, M.M., 2016. Engineering plants for geminivirus resistance with CRISPR/Cas9 system. Trends Plant Sci. 21, 279–281.

Zhang, X., Zhang, J., Zhu, K.Y., 2010. Chitosan/double-stranded RNA nanoparticle-mediated RNA interference to silence chitin synthase genes through larval feeding in the African malaria mosquito (Anopheles gambiae). Insect Mol. Biol. 19, 683–693.

Zhao, Y.Y., Liu, F., Yang, G., You, M.S., 2011. PsOr1, a potential target for RNA interference-based pest management. Insect Mol. Biol. 20, 97–104.

Zhu, F., Xu, J.J., Palli, R., Ferguson, J., Palli, S.R., 2011. Ingested RNA interference for managing the populations of the Colorado potato beetle, Leptinotarsa decemlineata. Pest. Manag. Sci. 67, 175–182.

Zhu, F., Sams, S., Moural, T., Haynes, K.F., Potter, M.F., Palli, S.R., 2012. RNA interference of NADPH-cytochrome P450 reductase results in reduced insecticide resistance in the bed bug, Cimex lectularius. PLoS ONE 7, e31037.

Zhu, G.H., Xu, J., Cui, Z., Dong, X.T., Ye, Z.F., Niu, D.J., et al., 2016. Functional characterization of SlitPBP3 in Spodoptera litura by CRISPR/Cas9 mediated genome editing. Insect Biochem. Mol. Biol. 75, 1–9.

FURTHER READING

Christiaens, O., Smagghe, G., 2014. The challenge of RNAi-mediated control of hemipterans. Curr. Opin. Insect. Sci. 6, 15–21.

Hao, Z., Hai-Chao, L., Xue-Xia, M., 2012. Feasibility, limitation and possible solutions of RNAi-based technology for insect pest control. Insect Sci. 1–16. 10.1111/j.1744-7917.2012.01513.x.
Harrison, S.A., 1990. The fate of pesticides in the environment, Agrochemical Fact Sheet # 8, Pennsylvania, USA.
Warsi, F., 2020. How do pesticides affect ecosystems. Pesticides. http://farhanwarsi.tripod.com/id9.html. (Accessed 16 June 2020).

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(संदर्भ : एस. आर. हरनोट कृत 'हिडिम्ब')

श्री गौतम सिंह राणा

समकालीन हिंदी कथाकारों में एस. आर. हरनोट एक जाना-पहचाना नाम है। ये हिमाचली पार्वत्य-पृष्ठभूमि पर विपुलता के साथ लिखनेवाले एक महत्वपूर्ण कथाकार हैं। बीसवीं सदी के नवें दशक से निरंतर सृजनरत इस कथाकार के अब तक कुल आठ कहानी संग्रह, एक उपन्यास; हिडिम्बद्ध एवं हिमाचल की संस्कृति और जनजीवन पर पाँच महत्वपूर्ण पुस्तकों का प्रकाशन हो चुका है। हिमाचल प्रदेश के चनावग गाँव (जिला-शिमला) में जन्मे इस कथाकार ने हिंदी-पाठकों के मन को अपनी कथाओं के मार्फत बहुत ज्यादा आंदोलित किया है क्योंकि बचपन से लेकर अपनी समझदारी की उम्र तक इन्होने जिस नैसर्गिक-सौन्दर्य-संपन्न पहाड़ी जीवन को जिया और साथ ही उसके खुरदुरे यथार्थ को अनुभूत किया, उसे इन्होने जस का तस बड़ी कोमलता के साथ अपनी कथाओं में रख दिया है। तिस पर हिमाचली पार्वत्य समाज में टीस से भरे जीवन जीने को बाध्य दलितों की दूर्दशा के कारणों की परत-दर-परत पड़ताल करने में उनकी लेखनी की तीव्र धार तो देखते ही बनती है।

हरनोट जी ने अब तक कहानियाँ ही ज्यादा लिखी हैं और उनकी अधिकांश कहानियों का विषय या अंतर्विषय हिमाचली पार्वत्य समाज से संबंधित दलितों के त्रासद जीवन के उत्तरदायी तत्वों; व्यक्ति तथा व्यवस्थाद्ध की कलई खोलना रहा है। उनकी कहानियों के दलित प्रसंगों से गुजरते हुए हर एक सहृदय पाठक को अनायास ही इस अकुलाहट से गुजरना पड़ता है कि कहीं न कहीं कुछ कसक रह गई। संभवतः अपनी कहानियों के स्वपाठ ने लेखक को भी इसी स्थिति में डाल दिया; जिसका परिणाम 'हिडिम्ब' के रुप में पाठकों के सम्मुख प्रस्तुत हुआ। इस उपन्यास में उन्होंने बड़े ईतमिनान से विकास और संस्कृति की आड़ में व्यवस्था को हथियार की तरह इस्तेमाल

कर अपना उल्लु सीधा करनेवाली उन ताकतों का पर्दाफाश किया है जिसने हिमाचली समाज में दलितों को नारकीय जीवन जीने के लिए बाध्य किया है।

'हिडिम्ब' की कथा की बुनाहट हिमाचली समाज में संस्कृति व परंपरा के नाम पर लंबे अर्से से चली आ रही 'काहिका' उत्सव के बहाने वहाँ के दलित नड़ जाति के लोगों पर होते आ रहे अमानवीय अत्याचार व शोषण को चित्रित करने के क्रम में हुई है। कथा के केंद्र में शावणु नड़ का परिवार है। इस परिवार में शावणु के अतिरिक्त उसकी पत्नी सुरमा देई, बेटी सूमा एवं बेटा कांसी राम है। इस परिवार की सबसे बड़ी खासियत है कि यह पूरे परगने का एकमात्र नड़ परिवार है। एकमात्र इसलिए क्योंकि इस समाज में काहिका' उत्सव के बहाने इस समुदाय के लोगों को बली चढ़ाने एवं साथ ही कठोर जीवन यापन के कारण इस समदाय के लोगों का दूसरे सहुलियत वाले प्रदेशों में चले जाने का काम काफी लंबे समय से होता आ रहा है। शावणु के पिता भी 'काहिका' उत्सव की बली चढ़ चुके हैं और बालक शावणु ने संस्कृति के नाम पर हुए मौत के निर्मम नृत्य को अपनी आँखों से देखा है। 'काहिका' में बलि चढ़ जाने के एवज में प्राप्त जमीन पर खेती बारी एवं पशुपालन कर शावणु का परिवार पल रहा होता है। इतने में मंत्री जी की लोलुप दृष्टि शावणु के जमीन पर पड़ती है और वह उसे येन-केन-प्रकरेण पाने के हथकंडे अपनाता है। शावणु और उसके परिवार को मानसिक रूप से तोड़ वहाँ से चले जाने को बाध्य करने के लिए मंत्री उसके बेटे को जहर देकर मार डालता है। इसका प्रभाव सबसे अधिक सुरमा देई पर पड़ता है। वह मानसिक रूप से विक्षिप्त होकर घर छोड़कर कहीं मर खप जाती है। ऐसी परिस्थिति में शावणु न चाहते हुए भी अपनी बेटी को मंत्री के कारिंदों से बचाने व उसके जीते जी कुछ समय के लिए ही सही दाम्पत्य सुख में जीते देखने के लिए पहाड पर काम करने आये एक ऑस्ट्रेलियन युवक से कांटेक्ट मैरेज कर देता है। व्यवस्था तंत्र की इतनी ताकत लगाने पर भी जब उसे सफलता नहीं मिलती है तब वह अपने तंत्र की शक्ति का उपयोग संस्कृति को हथियार के रूप में प्रयोग करने के लिए करता है। एकमात्र बचे इस नड़ परिवार के खात्मे के उद्धेश्य से वह असमय ही 'काहिका' उत्सव का आयोजन करता है। शावणु 'काहिका' उत्सव के सामाजिक दवाब से बाध्य होकर उसमें शरीक तो होता है पर ऐन वक्त पर वह अपने घर भाग आता है और मंत्री से छुपते-छुपाते अपनी जमीन को एक चौरिटेबल अस्पताल बनाने के लिए संस्था को दान में दे देता है। इस प्रकार वह बुढ़ापे में घर और भुमिहीन होकर अपना शेष जीवन अकेले ही जीने को बाध्य होता है।

"संस्कृति की आड़ लेकर धर्म का आडम्बरपूर्ण कर्मकांडी रुग्ण पक्ष जिस शातिर आक्रामकता के साथ अपने को ईश्वर, अवतार, और उद्धारक के रूप में प्रस्तुत कर

जन-स्वीकृति पाता है, वह किसी भी सुसंस्कृत प्रबुद्ध समाज के लिए घातक है। लेकिन 'अध्यात्म' के घटाटोप में लिपटे पाखंड को बेनकाब करने का जुर्म कोई कैसे करे? संस्कृति व्यक्ति को मनुष्य के रूप में सिरजने का संस्कार है, और फिर अपने से भिन्न हर दूसरे को तमाम लौकिक-भौतिक भेद भुला कर मनुष्य के रूप में पहचानने की साधना। चूँकि परम्पराएँ समय के साथ नष्ट नहीं होती, बल्कि हर परिवर्तनशील पल के साथ अपने रूप को सुविधानुसार बदल कर वक्त के भीतर मानीखेज हस्तक्षेप करने की ताकत रखती है, इसलिए एक-दूसरे के तालमेल में अपना उल्लू सीधा करते विकास और संस्कृति के मूल मन्तव्यों को जानना भी बेहद जरूरी हो जाता है।"[1]
हरनोट जी रोहिणी अग्रवाल के इस कथन से शत प्रतिशत सहमति रखनेवाले कथाकार हैं। वे भी प्रबुद्ध समाज के प्रति प्रतिबद्ध कथाकार होने के नाते अपना लेखकीय दायित्व भलि-भाँति समझते हैं। यही कारण है कि वे 'काहिका' उत्सव के दौरान नड़ जाति के प्रति होनेवाले अच्छे व्यवहार को सवर्णो का सांस्कृतिक ढोंग समझते हैं और उसके पीछे के काले सच को बयां करते हुए शावणु के बारे में कहते हैं- "वह जानता था कि उसकी 'नड़' जाति ऐसी है जिसकी जरूरत क्षेत्र के लोगों को कभी सात, कभी बारह तो कभी बीस-तीस बरस बाद 'काहिका' के लिए पड़ती है। जो नड़ इस उत्सव का मुख्य पात्र होता उसकी बुलंदी अचानक बर्फ ढकी चाटियों से भी ऊँची हो जाती। किन्नर, कैलाश, मणिकर्णिका और श्रीखण्ड महादेव से भी भव्य। वह ब्राहम्ण हो जाता और फिर देवता बन जाता। यानी सर्वेसर्वा। शायद ईश्वर। जिसके पिदे देवता तक चलते। उनके पुजारी और गूर चलते। कारकुन चलते। गॉव-बेड़ और परगना चलता। बड़े बुजुर्ग चलते। बच्चे और जवान चलते। मंत्री और संतरी चलते। उसका यश आसमान में पहुँच जाता। वह नर से लेकर देवता तक के कष्टों और पापों का संहारक हो जाता। लेकिन जब जब उसकी जरूरत नहीं होती, तो वह अछूत, चंडाल बन जाता। गाँव-बेड़ के पिछवाड़े का एक आवारा कुत्ता। पूजा-पाठ करते हुए ब्राहम्ण देख लें तो हजारों मन गालियाँ देने लगे। पानी छू ले तो अपवित्र हो जाए। देवता हो स्पर्श कर ले तो गुनहगार, अपराधी और कड़े दंड का अधिकारी।"[2]

वर्तमान समय राजनीतिक भ्रष्टता एवं अवसरवाद का समय है। भारत जैसे जनतांत्रिक देश, जहाँ की अच्छी आबादी आज भी अशिक्षित है; में स्थिति और भी अधिक भयावह बनी हुई है। जनता के प्रतिनिधियों ने बड़ी आसानी से पुरी व्यवस्था पर अपनी मजबूत पकड़ बना ली है। न्याय व्यवस्था के प्रति जनता की आस्था बनी हुई रहने के बावजूद उसकी समयसाध्यता के कारण जनता परेशान व दिशाहारा बनी हुई है। ऐसी परिस्थिति में भारतीय समाज जहाँ सदियों से वर्ण-व्यवस्था की मानसिकत की चक्की तले दलित पिस रहे हैं; वहाँ तो उनकी स्थिति काफी कारूणिक बनी हुई

है। आजादी के इतने समय बाद भी नेता-मंत्री इनका शोषण बड़ी आसानी से व्यवस्था-तंत्र को अपना हथियार बनाकर कर पाने में सक्षम बने हुए हैं। हालाँकि कुछ प्रदेश इसके अपवाद भी हैं, जहाँ की जनता प्रबुद्ध समाज गढ़ने के लिए प्रतिबद्ध एवं जागरूक हैं। हरनोट भी अपने समय के जागरूक व प्रतिबद्ध कथाकार हैं। इन्होंने इसी प्रतिबद्धता-निर्वहन के क्रम में इस उपन्यास के कतिपय स्थलों पर इन भ्रष्ट व अवसरवादी जनप्रतिधियों के चेहरे को बेनकाब किया है एवं उनके द्वारा बुनी गई भ्रष्टतंत्र के प्रत्येक तंतु को चिन्हित भी किया है। उपन्यास के एक स्थल पर जहाँ मंत्री को शावणु की जमीन पा लेने की क्षुधा जागती है, वहाँ कथाकार ने ऐसा ही विवरण प्रस्तुत किया है- "जमीन की खूबियाँ उसके मन में बैठ गई। तीव्र अभिलाषा हुई कि किसी भी किमत पर वह जगह हासिल हो जाए। वह उद्विग्न होने लगा। मन अस्त-व्यस्त हो गया। पागललपन के सघन नशे ने उसे जैसे अंधा कर दिया हो। उसी तरह जैसे कभी किसी सुन्दर पहाड़ी यौवना को देख लेता और मन उसे भोगने के लिए व्याकुल हो उठता। तब तक चौन से न बैठ पाता जब तक लड़की उसके शयन कक्ष में न पहुँचाई जाती। उसके लिए वह किसी भी अवरोह को पार कर जाता। ऐसे कार्यों में उसके चमचे बराबर साथ देते। सभी इन्तजाम कर लिया करते। ये लोग कई तरह के मुखौटे पहने साथ होते। कहीं निजी स्टाफ के रूप में। कहीं क्षेत्र के छोटे-मोटे नेता या प्रधान के रूप में। कहीं कलक्टर, तहसीलदार और पटवारी के वेश में तो कहीं जनसेवकों के रूप में।"[3] आगे जबरन हथियाई गई जमीन एवं गायों से गोशाला-निर्माण द्वारा अपनी धर्मात्मा छवि बनानेवाले इन नेता-मंत्रियों के घोर अवसरवादी चरित्र का पर्दाफाश करते हुए कथाकार कहते हैं- "सभी गायों की पीठ पर मंत्री ने अपनी पार्टी का निशान खुदवा लिया। उनकी पीठ पर से बाल काटे गए और एक आधुनिक मशीन से उस जगह पार्टी का चिन्ह अंकित कर दिया गया। यह सिलसिला लगातार चलता रहा। अवसरवादी नेता ने जब भी दल बदला, या सरकारें बदलीं, तभी गायों की पीठ से पुराना निशान मिटा कर नया चिन्ह खुदवा लिया जाता।"[4]

विभिन्न आर्थिक स्तरों पर जी रहे अमूमन एक समुदाय के लोगों के बीच के मनोवैज्ञानिक खिंचाव को नकारा नहीं जा सकता पर जब बात नौकरी, पद, प्रतिष्ठा बचाने की हो तो न चाहते हुए भी एक व्यक्ति के लिए अपने ही समुदाय के अन्य लोगों पर हो रहे अन्याय का विरोध कर पाना मुश्किल हो जाता है। उस उपन्यास में यही स्थिति थानेदार की है। वह भी दलित समुदाय का है। बावजूद इसके वह शावणु को 'काहिका' से भाग आने के कारण मंत्री के षड़यंत्र के तहत मुर्ति के गहनों की चोरी के झूठे आरोप में गिरफतार कर थाने की कोठरी में बंद कर देता है। यहाँ मामला केवल दलित समुदाय से संबंध रखने का नहीं है बल्कि उससे भी बढ़कर इस भ्रष्टतंत्र

में खद्दरधारियों की दुर्दमनीय शक्ति के सम्मुख नतमस्तक होने को बाध्य हो जाने का है। शावणु को उसके ही समुदाय के शोभा द्वारा जमानत पर छुड़ा ले जाते समय थानेदार का हवलदार मनीराम को दिया वक्तव्य इसी मामले की ओर संकेत करता है; जहाँ वह कहता है- "बई मनीराम! देखा तैने...उन दो बूढ़ों को...। हम साले पुलिसवाले कुत्ते से भी बदतर होते हैं। ...पर तु बता मनीराम, हम कर भी क्या सकते हैं...हमारे उपर जो ये साले खद्दरधारी बैठे हैं न, सारे खटमल हैं खटमल। हमारा ही खून चूसेंगे और हमारे ही बिस्तर में दुबक जाएंगे...लाख ढूंढ़ो...नहीं मिलते साले...। इनकी न सुनो तो बदली...। तु बता मनीराम मैं जैसा इस वर्दी में दिखता हूँ भीतर से भी वैसा ही हूँ? नहीं मनीराम नहीं...मैं वैसा नहीं हूँ...मैं...मनीराम...तेरी तरह हूँ...। सच मनीराम जब उस बूढ़े को मैंने कल शाम गालियाँ दीं तो मन से नहीं दी...।"[5]

हरनोट जी एक विनम्र कथाकार हैं, लेकिन समय की क्रुरता को वे अपनी कथाओं में बड़ी सख्ती से पकड़ने की काशिश करते हैं। इनकी सबसे बड़ी खासियत है कि इन्होंने अपनी कथाओं में पहाड़ पर पहुँची मशीनी सभ्यता के बरक्स वहाँ के प्राकृतिक, सामाजिक एवं सांस्कृतिक वातावरण में आए क्षरण और उसके कुप्रभाव को बड़ी शिद्दत के साथ प्रस्तुत किया है। दैत्याकार मशीनों ने पहाड़ का सीना चीरकर जितना प्राकृतिक असंतुलन पैदा कर दिया है, उससे कहीं अधिक इसके साथ पहुँची नशाखोरी ने युवा पीढ़ी को बर्बाद किया है। इस नशाखोरी का दंश सबसे अधिक वहाँ के औसतन कम शिक्षित व कम जागरूक दलित समुदाय को झेलना पड़ा है। एक ओर इसने दलित युवाओं के भविष्य को चौपट तो किया ही है, दूसरी ओर नेता-मंत्री को इसे अपना हथियार बनाकर अपना स्वार्थ आसानी से साध लेने की सुविध भी मुहैया करवा दिया हैं; जिससे दलितों का जीवन और भी अधिक कष्टमय बना हैं। इस उपन्यास में दलित पात्र शोभा के एकमात्र पुत्र का नशाखोरी के कारण मर जाना और नशाखोरी को हथियार बनाकर मंत्री द्वारा शावणु के पुत्र की हत्या का प्रसंग इसी बात की गवाही देता है। इन सब कारणों से पहाड़ में जो भयावह अजनबीयत की स्थिति बनी है, उसका चित्रण करते हुए कथाकार उपन्यास के एक स्थल पर कहता है- "शावणु को अब इधर-उधर आते-जाते लगने लगा था कि वह किसी अजनबी जगह पर आ गया है। यहाँ न पगडंडियाँ अपनी है न हाट-घराट। इस घाटी के गाँव-बेड़, जमीन-मिट्टी में एक अजनबीपन पसर गया है। नदी, घाटी, खेत-खलिहान की सुगंध जो हर तरफ फैली रहती उसमें भाँग-सुलफे की बास घुस गई है। न अपनापन, न अपनी बोली। देखते-देखते सब कुछ बदल गया है।"[6]

हरनोट जी इस उपन्यास के मार्फत हिमाचली पार्वत्य समाज के फ्रेम में हमारे वक्त की बदनुमा सच्चाई को पिरोने का काम करते हैं। इस क्रम में वे हिमाचली

सामाजिक संरचना में दोहरा अभिशाप झेल रही स्त्रियों की दशा का भी चित्रण करते हैं। कट्टर जातिवादी मानसिकता के कारण हिमाचली समाज में जी रही दलित स्त्रियों की कारूणिक दशा का पता उपन्यास के स्त्री पात्रों- सूरमादेई और सूरमा से चलता है। पुत्रवियोग का दंश झेलती सूरमादेई अपना मानसिक संतुलन खोकर घर और समाज से दूर चली जाती है, तीस पर लोग उसके मर-खप जाने का अंदेशा लगाकर उसकी सुधी तक नहीं लेते हैं। सूरमा को घर पर अकेला छोड़कर जाने और मंत्री के कारिंदों के भ्रष्ट चरित्र की बात सोचकर शावणु भी उसे खोजने दूर तक निकल नहीं पाता है। सूरमा की स्थिति तो उससे भी अधिक दयनीय है। विवाह के योग्य उम्र तक पहुँचने के बावजूद उस परगने में एकमात्र नड़ परिवार की आत्मजा होने के कारण उसका विवाह तक नहीं हो पाता है। मंत्री से बिगाड़ होने के कारण उसके कारिंदों से उसकी ईज्जत बचाने के लिए शावणु एक आस्ट्रेलियन युवक से उसका काटैक्ट मैरेज करवाने के लिए बाध्य हो जाता है। न चाहते हुए भी परिस्थिति के आगे बाध्य होकर सूरमा को बेसहारा शावणु को बुढ़ापे में अकेले ही छोड़कर आस्ट्रेलिया जाना पड़ता है। किस प्रकार संस्कृति और व्यवस्था की मिलीभगत समाज में स्त्रियों को नारकीय जीवन जीने को बाध्य करता है, सूरमादेई तथा सूरमा का चित्रण इसका दृष्टांत है।

इस प्रकार हम देखते हैं कि 'हिडिम्ब' उपन्यास में हरनोट जी ने एक प्रबुद्ध अन्यायविहीन समाज के निर्माण के प्रति अपनी प्रतिबद्धता के बरक्स उसके मार्ग में रोड़ा बने हुए जनतंत्र एवं संस्कृति के पहरेदारों की कलई परत दर परत खोला हैं और साथ ही हिमाचली समाज में जीनेवाले दलितों के नारकीय जीवन के मूल कारणों को मनुष्य की मनोवृत्तियों में खोजने का महत्वपूर्ण कार्य किया है। इसके कारण उनका यह उपन्यास संस्कृति व व्यवस्था के तानों-बानों में दम तोड़ती टीस से भरी दलित जीवन की गाथा के रूप में हमारे समक्ष प्रस्तुत हुआ है।

संदर्भ सूची :

1. अग्रवाल, रोहिणी, हिन्दी कहानी : वक्त की शिनाख्त और सृजन का राग, वाणी प्रकाशन, नयी दिल्ली, प्रथम संस्करण, 2015, पृष्ठ-85
2. हरनोट, एस.आर., हिडिम्ब, आधार प्रकाशन, पंचकुला, हरियाणा, द्वितीय संस्करण, 2011, पृष्ठ-38
3. वही, पृष्ठ-11
4. वही, पृष्ठ-13
5. वही, पृष्ठ-243
6. वही, पृष्ठ-72

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Tuhin Subhra Santra
Loganathan Mohan *Editors*

Nanomaterials and Their Biomedical Applications

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Nanomaterials and Their Biomedical Applications

Springer

Editors
Tuhin Subhra Santra
Department of Engineering Design
Indian Institute of Technology Madras
Chennai, Tamil Nadu, India

Loganathan Mohan
Department of Mechanical Engineering
Toyohashi University of Technology
Toyohashi, Aichi, Japan

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Preface

Nanomaterials are defined based on their size, which is one-billionth of a meter (10^{-9} m) in any one of its dimensions. In other words, "the materials with any external dimension or having an internal structure or surface structure in the nanoscale range." In such extremely small size, materials exhibit unique and spectacular performance due to an increment of the surface to volume ratio. Materials, usually in the size range of 1–100 nm, show different physicochemical properties from their bulk. In the past two decades, several engineered nanomaterials have been established for different application purposes. After the rapid development of micro and nanotechnologies, fabrication of nanoscale structures and devices with exceptional sights of the supramolecular association has grown interest into a systematic way, and this has enhanced their perspective for an innovative connection in a huge variety of research areas, such as biology, chemistry, physics, engineering, computer science, etc. Nanoscale materials are progressively creating a foremost influence on human health, and they are used increasingly further for therapeutic and diagnostic applications. Nanotechnology plays a vital role in the current technological developments and plays an important role in diagnosing diseases, drug delivery, designing drugs, etc. This book intends to bring science and advanced nanotechnology together and their applications in cell biology and biomedical engineering. From a nanoscale and nanomaterial perspective, it highlighted different nanostructured material design, synthesis, processing, characterization, and potential applications. This book also covers different nanoscale and nanostructured materials for biomedical applications such as therapeutics, diagnostic, prosthesis, implant, drug discovery, and drug delivery, etc. An overview of nanomaterials' progress and prospects and its biomedical applications are discussed with a series of reasoning and practical considerations.

This book contains 17 chapters, covering an extensive range of the critical aspects of nanomaterials for biomedical applications. Each chapter is contributed by professionals in their fields, and these chapters deliver technical information based on their valuable knowledge and skills. Possible glitches and challenges, as well as potential keys, are also deliberated with importance on prospects. Chapter "Nanomaterials: An Introduction" narrates brief advancement of nanotechnology to date. The different health-related problems that arise due to the application of nanotechnology in medicine, food, agriculture, etc., are reported. Environmental nano pollution and its effect on society, social–economic disruption due to the rapid use of nanotechnology, safety and security of nanotechnological developments, and its future direction is also discussed. Chapter "Metallic Nanoparticles for Biomedical Applications," discusses the top-down and bottom-up approach and current trends in the synthesis of *metallic nanoparticles* for biomedical purposes. Further, it describes how the parameters can be tuned to get metallic nanoparticles with the desired shape, size, and crystallinity. Chapter "Size and Shape-Selective Metal Oxide Nanomaterials: Preparation, Characterization and Prospective Biomedical Applications," describes the different preparation methods for *metal-oxide nanomaterials* (MONMs), characterization techniques, and MONMs usage in different biomedical applications. The mechanism of interaction between nanomaterials and internal structures of microorganisms and institutes working on the nanomaterials standardizations is deliberated. Chapter "Nanofibers and Nanosurfaces" discusses the different synthesis routes associated with the development of nanofibers for cartilage regeneration. The fabrication and effect of nanosurfaces on metallic implants for enhanced chondrocyte conductivity are also highlighted. Chapter "Nanoceramics: Synthesis, Characterizations and Applications," narrates in detail the nanoceramics, their preparation methods, available characterization techniques, their unique properties, and their widespread biomedical applications arising due to their excellent properties. Chapter "Biomedical Applications of Carbon-Based Nanomaterials," discusses briefly carbon-based nanomaterials like Nanodiamonds (NDs), Carbon nanotubes (CNTs), Buckminsterfullerene (C_{60}), Carbon quantum dots (CQDs), Carbon nanohorns (CNs), and its biomedical applications. Chapter, "Solution Combustion Synthesis of Calcium Phosphate-Based Bioceramic Powders for Biomedical Applications," gives an overview of the solution combustion synthesis of pure and doped hydroxyapatite powders and their characterization. This chapter also discusses the solution combustion synthesis of plasma sprayable hydroxyapatite powder, fabrication of coating, and characterization of the developed plasma-sprayed coating. Chapter "Nanomaterials in Medicine," outlines the various types of nanomaterials and their applications in the field of nanomedicine. The clinical applications of the nanomaterials in sepsis therapy, chemotherapy, and applications of nanomaterials in heart, kidney, lungs, brain diseases, etc., are discussed. Chapter "Hydrogels: Biomaterials for Sustained and Localized Drug Delivery," illustrates the synthesis, functionalization, tailoring mechanism of hydrogel matrix, followed by *in-vitro, ex-vivo,* and *in-vivo* characterization and drug loading/delivery efficiency. The different classifications of the hydrogel, along with its crosslinking chemistry, hydrogel nanocomposites biomedical perspective, and hydrogel applications ranging from lab scale to industrial level, are also discussed. Chapter "Nanomaterials: Versatile Drug Carriers for Nanomedicine" highlights the recent advancements and applications of nanocarriers for drug delivery in medicine, especially wound healing therapeutics and also different approaches to enhance drug cargo capacity, to improve cell entry efficiency, to avoid host immune systems and to achieve specific tissue targeting. Chapter "Nanomaterials for Medical Implants," discusses the general consideration of using nanomaterials in implantable devices, dental implants/prosthodontics, spinal orthopedic implants, and hip and knee replacements, cardiovascular implants, others—phakic intraocular lens and cosmetic implants. Chapter "Fabrication of Nanostructured Scaffolds for Tissue Engineering Applications" addresses different categories of biomaterials used to fabricate nanostructured scaffolds for tissue regeneration applications. The desired properties required for various tissue engineering scaffolds and its fabrication methods, merits and demerits, current development, and future directions of these methodologies are discussed. In addition to that, the special emphasis given on three dimensional (3D printing) technologies to manufacture tissue engineering scaffolds using various nanomaterials are also discussed in this chapter. Chapter "Nanomaterials for Medical Imaging and In Vivo Sensing," is devoted to nanomaterials for medical imaging techniques. The extensive information about the current developments in imaging systems, its advantages & disadvantages, the science behind individual imaging systems and the basic instrumentation, how the nano-based contrast agents are helpful in various biomedical applications are systematically discussed. Chapter "Nanomaterials: Surface Functionalization, Modification, and Applications," presents the various surface modifications and functionalization of nanomaterials, including metallic nanoparticles, carbon nanomaterials, nano-ceramics, and self-assembled materials for biomedical applications. Chapter "Laser-Induced Micro/Nano Functional Surfaces on Metals for Biomedical Applications" emphasizes the recent research works on laser processing such as selective laser melting (SLM), laser surface melting (LSM), laser surface patterning of various metallic implant materials and surface characteristics, and biomedical applications of processed surfaces are summarized. Chapter "Surface Nanostructuring of Metallic Materials for Implant Applications," provides detailed coverage of surface mechanical attrition treatment (SMAT) of stainless steels, Ti alloys, Ni-Ti alloy, CoCrMo alloy, and how the nanostructured surface enables an improvement in the characteristic properties that are suitable for biomedical applications. Chapter "Tailoring the Surface Functionalities of Titania Nanotubes for Biomedical Applications," deliberates the key electrochemical factors that control the nanotube geometry and demonstrate various surface functionalization approaches for tailoring the surface properties of TiO_2 nanotubes to develop new functional biomaterials for biomedical applications.

We hope this book can be pleasant reading material and, at the same time, a handy resource for students, scientists in academia, and professionals in industries working on various traits of nanomaterials.

Chennai, India Tuhin Subhra Santra
Toyohashi, Japan Loganathan Mohan

Contents

Nanomaterials: An Introduction

Tarun Kumar Barik, Gopal Chandra Maity, Pallavi Gupta, L. Mohan, and Tuhin Subhra Santra

Abstract Nanotechnology offers a significant advantage in science, engineering, medicine, medical surgery, foods, packing, clothes, robotics, and computing from the beginning of the twenty-first century. As the potential scientific discovery always contains some good and bad effects on human civilization and the environment, nanotechnology is not an exception. The major drawbacks include economic disruption along with imposing threats to security, privacy, health, and environment. The introduction of the chapter discusses the historical background of nanotechnology. Later it also discusses the advancement of nanotechnology to date with its benefits. Major drawbacks of nanotechnology arise in human health due to the enormous involvement in medicine, food, agriculture, etc. This chapter also deals with environmental nano pollution and its effect on society, highlighting the social-economic disruption due to the rapid use of nanotechnology. Nano pollution affects not only human beings but also other living beings like microorganisms, animals and plants, which are briefly reviewed. This chapter also demonstrates the safety and security of nanotechnological developments, current policy and regulation status, challenges, and future trends. Finally, it is concluded, while nanotechnology offers more efficient power sources, faster and modern computers and technologies, life-saving medical treatments, but due to some negative impacts, it bounds us to think twice before any further advanced technological applications.

T. K. Barik (✉)
Department of Physics, Achhruram Memorial College, Jhalda, Purulia, West Bengal, India
e-mail: tarun.barik2003@gmail.com

G. C. Maity
Department of Chemistry, Abhedananda Mahavidyalaya, Sainthia, Birbhum, India

P. Gupta · L. Mohan · T. S. Santra
Department of Engineering Design, Indian Institute of Technology Madras, Chennai, India

L. Mohan
Department of Mechanical Engineering, Toyohashi University of Technology, Toyohashi, Japan

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1 Introduction

Nanotechnology is an emerging field of science and technology with numerous applications in biomedical and manufacturing engineering [1–3]. In the last two decades, nanotechnology integrates with mechanical and electronic engineering to develop Micro/Nano-electromechanical systems (MEMS/NEMS) devices, which have diverse applications in different fields of science and engineering. These devices are potentially applicable for various sensing, actuating, and biomedical analysis purposes [4–13]. Recently, quantum dots have increased much attention in biological fields due to their unique size, tunable light absorption, and emission properties [14]. Further, biocompatible nanomaterials have many applications in biomedical purposes such as orthopedic, cardiovascular, contact lenses, catheter, prosthetic replacement, etc., [15–21]. Among noble metals, Ag and Au nanoparticles synthesis via marine algae are used as a broad-spectrum antimicrobial agent towards a variety of pathogens in the biomedical field [22]. Nowadays, nanomaterials are produced by industries for commercial applications with enormous benefits. While there lies a vast potential of nanomaterials for fulfilling individual requirements, it also represents potential risks to human health [23].

The green synthesis of nanoparticles attracts many researchers and industries. Many microorganisms are utilized for the synthesis of nanoparticles. Biosynthesis of nanoparticles has been reported using photoautotrophic microorganisms such as cyanobacteria, eukaryotic algae, and fungi. The biogenic fabrication of nanoparticles via microalgae is a non-toxic, and eco-friendly, green chemistry method with a large variety of compositions and physicochemical properties. Biosynthesis of nanoparticles by plant extracts is currently under exploitation. Plant extracts are a better source of nanomaterials compared to the various biological processes often considered eco-friendly substitutes of chemical and physical methods [1, 17]. Seaweeds contain different organic and inorganic substances that can benefit human health [24]. The green seaweed is used widely in agriculture, pharmaceutical, biomedical, and nutraceutical industries for its presence of a high amount of vitamins and minerals [25]. Among several genera of microalgae, *Spirulina platensis* is blue-green algae of the cyanobacteria family grown in temperate water in the whole world. A blue-green alga has served as food with high protein content and nutritional value from ancient times [26]. The algae produce novel and potentially useful bioactive compounds [27, 28]. The bioactive materials have gained significant attention in recent years and have been used considerably in developing new pharmaceutical products, food products, renewable bio-energy, and biomedical applications [29–31]. However, a new global health problem has been arisen as in discriminant antibiotic use and the remarkable ability of bacteria to acquire resistance to lower these drugs' effectiveness via genetic mutation or gene acquisition. Therefore, new classes of antibiotics with novel structures are needed to combat this trend. Food preservation is now dealing with the severe concern of microorganisms mediated spoilage and fall in quality and nutrition worldwide [32]. Hence, increasing the continuous demand for pathogen control measures to combat resistant microorganisms against multiple antimicrobial agents. However, nanoparticles own large surface area to volume ratio, unique quantum size, magnetic properties, heat conductivity in addition to some catalytic and antimicrobial properties [33]. In this regard, nanomaterials, including metal nanoparticles, carbon nanotubes, quantum dots, and other active nanomaterials can be used to develop biosensors against a broad spectrum of microorganisms for the formulation of a new generation of antimicrobial agents.

2 Historical Background of Nanotechnology

The first experiment of nanotechnology was shown in 1857 when Michael Faraday introduced 'gold colloid' samples to the Royal Society. He added phosphorous to a solution of gold chloride and, after a short while, noted that the blue color of the solution changed to a ruby red dispersion, without knowing the actual cause of color changing. Indeed, the resulting suspension of nanosized gold particles in solution appeared transparent at some frequencies, but others could look colored (ruby, green, violet, or blue). Since then, many experiments and theoretical studies have been carried out to explain similar systems' unique properties, which in today's terminology are called low-dimensional systems. Nearly after 100 years, in 1959, Richard Feynman inspired the field of nanotechnology in his lecture at the American Physical Society (APS) meeting, Caltech, saying the meaningful words "There's Plenty of Room at the Bottom." From the late 1980s, we find there is a growth of activity on these low dimensional materials. In general, low dimensional systems are categorized as follows: (a) two dimensional (2D) systems, in which the electrons are confined in a plane (e.g., Layered structures, quantum wells and superlattices); (b) one dimensional (1D) systems, in which electrons are free to move only in one dimension (e.g., linear chain-like structures, semiconductor quantum wires), and (c) zero-dimensional (0D) systems, where electrons are confined in all three dimensions (e.g., quantum dots, clusters, and nanosized colloidal particles) [34–41].

The dimension of these materials in the direction of confinement lies in the nanometer scale, given the name nanomaterials. In this length scale, classical physics fails to explain the behavior of these materials. Instead, one needs quantum mechanical concepts. Interestingly, due to quantum effects, the physical properties of nanomaterials change drastically from their corresponding bulk behavior. This unique feature of nanomaterials has been exploited by modern technology in various applications. The link between human life and nanotechnology is as old as Ayurveda, a 5000-year-old Indian medicine system.

Moreover, twenty-first century modern science marks the beginning of nanoscience, while it existed from ancient times of Vedas, much before even the term “nano” was coined [42, 43]. As per strict nanometer terminology, any objects with dimensions in the nm range can be termed as a nanoparticle or a “nano” object, as TiO_2 dust in the study mentioned above [44]. Nanotechnology not only combines engineering, physics, and chemistry but also integrates with biology [45]. A physicist generally tries to identify and quantify nanomaterials’ fundamental interactions with different surrounding systems such as the thermodynamics, the interface of the nanoparticles with the liquid, and the role of mechanical properties (e.g., stiffness, elasticity, adhesion), etc.

Past three decades, extensive work has been performed to develop new drugs from natural products, because of the resistance of microorganisms to the existing drugs [46]. Researchers from the Indian Institute of Technology Bombay, India, have discovered that the age-old complementary medicines of Homeopathic pills and Ayurvedic Bhasmas are having metal nanoparticles such as gold, silver, copper, platinum, tin, and iron [46, 47]. Metallic nanoparticles (mainly silver and gold) have unique optical, electrical, and biological properties, that have attracted significant attention due to their potential use in many applications, such as catalysis, ultra-sensitive chemical and biological sensors, bio-imaging, targeted drug delivery and nanodevice fabrication [13, 48–57]. Recently, various industries like electronics, aerospace, cosmetics, textile, and even food use nanoparticles. Consequently, the chance of human exposure to nanoparticles rises, heading towards the time when nanoparticles are eventually present in blood circulation and interacting with immune blood cells.

Nanoparticles can be synthesized via various chemical and physical routes such as chemical reduction, [58–60] photochemical reduction, [61–65] electrochemical reduction, [66, 67] heat evaporation, [68, 69], etc. In all the above-mentioned methods, the reagents can be from different properties, i.e. inorganic such as sodium or potassium borohydrate, hydrazine, and salts of tartrate, or organic ones like sodium citrate, ascorbic acid, or amino acids, capable of getting oxidized. Various options are also available to work as a stabilizing agent. Several studies have reported shape and size dependency of silver nanoparticles formation on capping agents such as dendrimer, [70] chitosan, [71] ionic liquid, [72], and poly (vinylpyrrolidone) PVP [73]. These capping agents control the nanoparticle growth via reaction confinement within the matrix or preferential adsorption on specific crystal facets. Since these approaches are costly, hazardous, toxic, and non-environment friendly, hence, evaluation of the risk of these nanoparticles to human health becomes critical. Multiple studies have shown the increase in the number of leukocytes, mainly neutrophils, in the lungs and bronchoalveolar lavages during airway exposure of nanoparticles *in-vivo* models of inflammation. The neutrophil counts act as biomarkers for inflammation. Therefore, the selection of a synthesis route that minimizes the toxicity and increases nanoparticle stability leads to enhanced biomedical applications of silver and gold nanoparticles. The development of better experimental procedures for the synthesis of nanoparticles employing a variety of chemical compositions and controlled polydispersity offers considerable advancement [74]. Methods of nanoparticle production through different physical and chemical routes, as stated above, have their demerits as they produce enormous environmental contaminations and hazardous byproducts. Thus, there is a need for "green chemistry" that ensures clean, non-toxic, and environment-friendly nanoparticles production [75].

In recent years, environment-friendly approaches have been developed to fabricate stable nanoparticles with well-defined morphology and configured constricted sizes [76]. Additionally, owing to the high demand for precious metals (like silver and gold) and metal oxides in electronics, catalysis, medical, and other industrial applications, its recovery from primary and secondary sources is of considerable significance and interest. Biological recovery of these precious metals by preparing their nanoparticle is a green alternative to the conventional physical and chemical methods [77, 78]. Bio-inspired synthesis of nanoparticles is an advanced, cost-effective, environment-friendly approach over chemical and physical processes, without any inclusion of high pressure, energy, temperature, and toxic chemicals [79]. For example, the plant leaf extract is used for the biosynthesis of silver and gold nanoparticles for pharmaceutical and biomedical applications, without employing any toxic chemicals in the synthesis protocols [80]. An environmentally acceptable solvent system, eco-friendly reducing and capping agents are considered to be an essential element for an ultimately "green" synthesis [81]. The green synthesis techniques are generally utilizing relatively non-toxic chemicals to synthesize nanomaterials. The fabrication process also includes the use of non-toxic solvents such as water, biological extracts, biological systems, etc. In this technique, generally, microwave maintains a constant temperature of solvent systems. The conventional extraction technique using hexane, ethanol, and water was used to collect bioactive molecules [82]. However, they are immensely problematic due to instability as well as environmental and health hazards [83]. To overwhelm this problem, researchers developed a new approach, i.e., supercritical fluid (SCF) extraction technology for avoiding toxic organic solvents in green technology. SCF possesses physical properties intermediate between CO_2 gas and a liquid at a temperature and pressure above its critical point. Since supercritical CO_2 is non-polar, non-toxicity, non-flammability, and low critical temperature.

3 Benefits of Nanotechnology

Recently, research and development in nanotechnology have seen exponential growth due to advantages in different fields, i.e., drug delivery, cell imaging, material improvement, and medical devices for diagnosis and treatment. More powerful computers are being designed using nanomaterials in a smaller size, faster in speed, and consuming very less power, having long-life batteries. Circuits consisting of carbon nanotubes can maintain the computer system advancement. Carbon nanotubes are also commercially used in sports equipment, to increase their strength while maintaining a low weight. Nanoparticles or nanofibers in fabrics improve the water-resistance, stain resistance, and flame resistance, without putting on extra weight, stiffness, or thickness of the material. Nanoparticles are used in medical products for dermal, oral or inhalation applications, and pharmaceuticals. These are also used in various consumer products, including cosmetics, food, and food packaging. The nanomaterials having potential uses in cosmetics include nanosilver, nanogold, nanoemulsions, nanocapsules, nanocrystals, dendrimers, fullerenes, liposomes, hydrogels, and solid lipid nanoparticles. Smaller the size, corresponding to the higher surface area of nanomaterials offer greater strength, stability, chemical, physical, and biological activity. Nanomaterials present in the human environment can be primarily classified into four categories: carbon-based nanomaterials, metal-based nanomaterials, dendrimers, and composites. The carbon-based nanomaterials (fullerenes and nanotubes) are employed in thin films, coatings, and electronics.

The metal-based nanomaterials (i.e., nanosilver, nanogold, and metal oxides (i.e., titanium dioxide (TiO_2)) are useful for food, cosmetics, and drug-related products. The dendrimers are nano-polymers, an ideal candidate for drug delivery. Composites such as nanoclays are formed with a combination of nanoparticles with other nanosize or larger particles. Many beverage bottles are made up of plastics with nanoclays. The nanoclay reinforcement increases permeation resistance to oxygen, carbon dioxide, moisture, and thus retaining carbonation, pressure with increased shelf life by several months. Nanoclays are also being used in packaging materials.

Different classes of nanomaterials are composed of nanoparticles with different shape, size, and chemistry and biology. Nanotechnology helps to improve vehicle fuel efficiency and corrosion resistance by building vehicle parts from Diamond-Like-Nanocomposite (DLN) materials that are lighter, stronger, and more chemically resistant than metal [84–88]. The DLN film exhibits biocompatibility in nature, which has potential applications as a coating material for biomedical purposes [89, 90].

A few nanometers wide water filters can remove nanosized particles, including virtually all viruses and bacteria, which can revolutionize the water filtration method. These cost-effective, portable water-treatment systems are ideal for the improvement of drinking water quality in developing countries. Nowadays, most sunscreens also contain nanoparticles for effective absorption of light, including the more dangerous ultraviolet range and passing the other wavelengths, which is healthy for the skin. Recently, nanosensors can be programmed to detect a particular chemical at low levels, such as a single-molecule detection, out of billions of molecules. This capability is ideal for security systems and surveillance at labs, industrial sites, and airports. In medical science, the detection of single biomolecules has tremendous DNA/RNA sequencing and disease analysis applications. The nanobiosensors can be used to precisely identify particular cells or substances in the body for different diagnostics purposes. Current research is focused on preparing the smaller, highly sensitive, and cost-efficient biosensors. The new biosensors are updated to even detect odors specific diseases for medical diagnosis, pollutant detection, and gas leaks for environmental protection. Figure 1 shows the technological tsunami that occurs due to nanotechnology in energy storage, defense & security, metallurgy & materials, electronics, optical engineering & communication, biomedical & drug delivery, agriculture & food, cosmetics & paints, biotechnology, textile, etc. [91]. According to Zion market research analysis in 2017 [92], there is a rapid increase of global nanomaterials market volume (in kilo tons) and revenue (in USD Billion), which is estimated from 2014 to 2022, is shown in Fig. 2a. Other statistical surveys

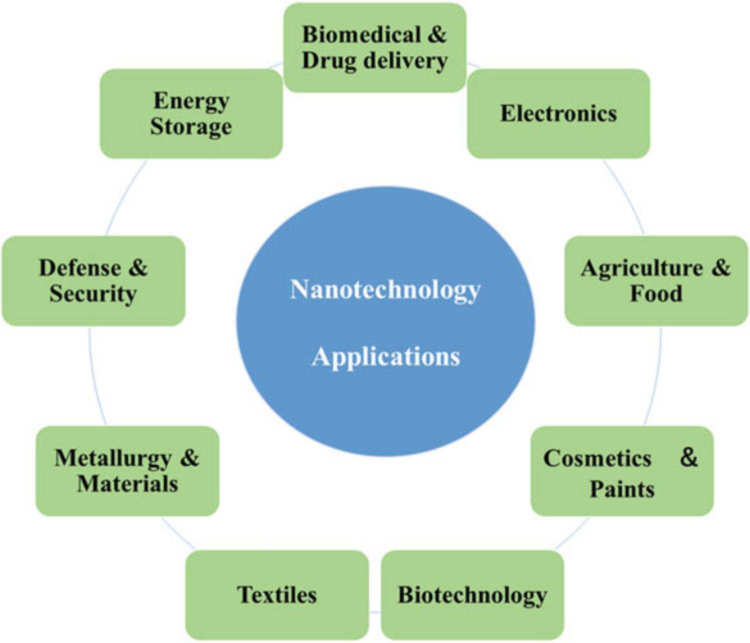

Fig. 1 Technological tsunami due to nanotechnology. Redrawn from [91]

from two different agencies (see Fig. 2b and c (BCC research)) also confirmed the rapid increase of the global nanotechnology market of nanomaterials, nanotools, and nanodevices, etc. [93, 94].

4 Nanotechnology in Health

4.1 Potential Routes for Nanomaterials to Enter into the Human Body

Nanomaterials can enter into the human body in various ways. Potential routes nanomaterials enter the human body are ingestion, inhalation, and skin absorption [95–97]. Many nanomaterials are employed in drug transport or cell imaging via intravenous entry to the human body. In the body, nanomaterials are translocated throughout the body by blood circulation. For the purpose, the nanoparticles must fulfill the requirement of permeability across the barrier of the blood vessel wall. Absorption through the skin serves as an alternate route of entry for nanoparticles inside a human body. The skin is the largest organ of the human body, provides a large surface area for interactions with the external environment. TiO_2 nanoparticles can take either

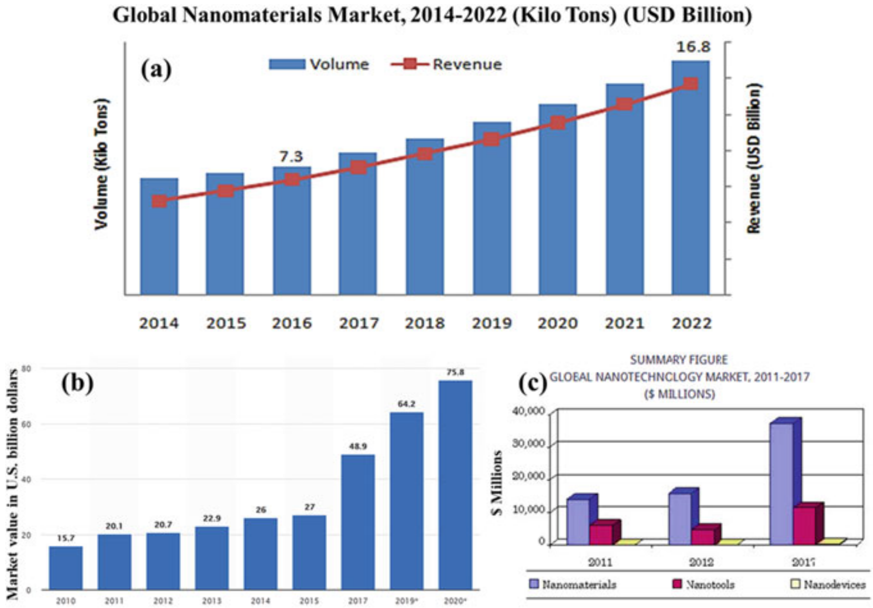

Fig. 2 **a** Rapid increase in global nanomaterials market volume (Kilo Tons) and revenue (USD Billion) for the period of 2014–2022 [92]. *Source* Zion market research analysis, 2017. **b** The global market value of nanotechnology from 2010 to 2020 (in Billion USD) [93]. **c** Global nanotechnology review for nanomaterials, nanotools, and nanodevices market from 2011 to 2017 (in Million USD). *Source* BCC Research [94]

route for entry, i.e., the lungs or gastrointestinal tract. Nanomaterials can enter the body through the skin for various reasons, such as the use of medicine, cosmetics, ointments, and use of clothes containing nanomaterials, occupational contact in the industry, etc. Soaps, shampoos, toothpaste, hair gels, creams, and some cosmetics containing the nanosilver, which can enter into the body through the skin.

Cream or solution containing Silver nanoparticles is used to treat wounds, burns, etc. to prevent infections and damaged skin. The penetrating ability depends on the size of the nanoparticles. The smaller the nanoparticle, has the more exceptional penetrating ability. The inhaled particulate matter gets accumulate in the human respiratory tract, while one significant portion of those inhaled particles gets deposited in the lungs. Nanoparticles also can travel across the placenta in pregnant women to the fetus along with other organs, i.e., brain, liver, and spleen. The effects of inhaled nanoparticles in the body may include lung inflammation and heart disease problems [95]. The pulmonary injury and inflammation resulting from the inhalation of nano-sized urban particulate matter appear due to the oxidative stress imposed by these particles in the cells [98–101]. The first reported nanoparticle is nanosilver, which can damage DNA molecules. Silver nanoparticles have the most harmful effects on the most sensitive biological groups [98, 102–105]. This nanoparticle can enter into the blood through the skin. Silver binds with the thiol group of some proteins. If silver complexes with thiol groups are located near-skin region, it gets readily available to get reduced either by visible or UV light into metallic nanosilver particles. Therefore, the immobilization of silver nanoparticles takes place in the skin. Further, the effect of nano copper-induced renal proximal tubule necrosis in kidneys has been reported by Liao and Liu [106].

4.2 Nanomaterials for Therapy and Diagnostics

Nanoparticles in pharmaceutical products facilitate improved absorption within the human body and easy delivery, often in association with medical devices. For example, magnetite, a metal oxide, has high potential applications in nanomedicine. Nanoparticles can assist the targeted delivery of chemotherapy drugs to specific cells, i.e., cancer cells. Superparamagnetic iron oxide nanoparticles (SPIONs) and ultra-small superparamagnetic iron oxide (USPIO) have also proved its significance for targeted drug delivery [107]. Nanoparticles improve the solubility of poorly water-soluble drugs, increase drug half-life, modify pharmacokinetics, improve bioavailability, diminish drug metabolism, assist controlled and targeted, and combined drug delivery [98, 108–111]. According to the International Agency for Research on Cancer (IARC) data, estimates of nearly 13.1 million deaths due to cancer by 2030. It is evident that the low survival rate occurs not because of the scarcity of potent, natural, or synthetic antitumor agents but owing to inadequate drug delivery systems. Hence develops the requirement of technology advancement to establish carriers and delivery systems capable of targeted and efficient delivery of the chemotherapeutic agents without unwanted systemic side effects [112]. The solid lipid nanoparticles and nanoemulsions are the most employed lipid-based drug delivery particles. However, nanosilver based commercial products are capturing the market. The newly developed nanomaterials for theranostics are being employed alone or in association with “classical” drugs, e.g., cytostatic drugs, or antibiotics. Theranostics is a combined term for nanomaterials with diagnostic and therapeutic properties [111].

5 Drawbacks of Nanotechnology

Nanomaterials are being employed in different industries and everyday life. Therefore, the interplay of nanomaterials and social surroundings is worth scientific exploration. Nanomaterials with several benefits can be toxic. Various studies also confer the effects, as mentioned above, indicating the potential toxicological effects on the human environment [98]. Different toxic and hazardous effects of nanotechnology are briefly discussed below.

5.1 *Toxicity of Nanomaterials*

Greater human exposure of nanomaterials presents in the environment; more significant is the harmful effect on human health. The assessment of the cytotoxicity of nanomaterials assists in the proper elucidation of the biological activity. Gerloff et al. reported the cytotoxicity of various nanoparticles, such as zinc oxide (ZnO), SiO_2, and TiO_2, on human Caco-2 cells [113]. Shen et al. [114] showed the human immune cells are prone to toxicity due to ZnO nanoparticles [115]. The ZnO nanoparticles damage mitochondrial and cell membranes in rat kidney, ultimately leading to nephrotoxicity [115]. Generally, the nanomaterial toxicity mechanism comprises reactive oxygen species formation and genotoxicity. However, as described earlier, the toxicity of ZnO nanoparticles mainly affects immune cells. Various nanomaterials with their diverse sizes alter mitochondrial function. For example, ZnO nanoparticles generate Zn^{2+} ions, which disrupts charge balance in the electron transport chain in the mitochondria and therefore triggers reactive oxygen species generation. Nanosilver particle has a genotoxic effect. A 20-nm nanosilver has a genotoxic effect on human liver HepG2 and colon Caco2 cells. It has also increased mitochondrial injury and the loss of double-stranded DNA helix in both cell types [116]. Inhalation of TiO_2 nanoparticles resulted in pulmonary overload in rats and mice with inflammation [117, 118]. The cytotoxic and genotoxic effects of TiO_2 nanoparticles on the human lung were reported by Jugan et al. [119]. TiO_2 nanoparticles are genotoxic, and it can induce pathological damage of the liver, kidney, spleen, and brain. Du et al. reported cardiovascular toxicity of silica nanoparticles in rats [120]. The surface coating of quantum dots causes toxicity to the skin cells, including cytotoxicity and immunotoxicity [121]. Nanosilver is used in wound dressings, affects both keratinocytes and fibroblasts. Fibroblasts show higher sensitivity towards nanosilver than by keratinocytes. Again, iron oxide nanoparticles rapidly get endocytosis on cultured human fibroblasts and interrupt the function. Citrate/gold nanoparticles have shown toxicity on human dermal fibroblasts [122]. Carbon nanotubes have high toxicity and produce harmful effects on humans. The nanoparticles can penetrate the lungs, then reached the blood and acted as a barrier for the circulation of blood into the brain. They can also enter inside other organs like bone marrow, lymph nodes, spleen, or heart. Sometimes, nanoparticles can incite inflammation, oxidant and antioxidant activities, oxidative stress, and change in mitochondrial distribution. These effects depend on the type of nanoparticles and their concentrations [101]. Copper nanoparticles (diameters 40 nm and 60 nm) harm brain cells at low concentrations. It activated the proliferation of the endothelial cells in brain capillaries. Ag nanoparticles (25, 40, or 80 nm) influenced the blood-brain barrier, causing a pro-inflammatory reaction, which might induce a brain inflammation with neurotoxic effects [123]. Smaller Ag nanoparticles (25 nm and 40 nm diameter) can induce cytotoxic effect at a higher rate than larger nanoparticles. Nanoparticles also have harmful effects on the brain cell of the mouse and rat. The high concentration of nanoparticles can affect brain blood fluxes, with consequent cerebral edema. Pathogenic effects of Ag-nanoparticles (25, 40, and 80 nm diameter), Cu-nanoparticles (40 and 60 nm), and Au-nanoparticles

(3 and 5 nm) on the blood-brain barrier of the pig have been reported [124]. Silver nanoparticles (45 nm) influenced the acetylcholine activity via nitric oxide generation; it induces hyperactivity of rat tracheal smooth muscle [125]. It is also reported that Ag- nanoparticles (25 nm) produced oxidative stress after the injection into the mouse. The nanoparticles were aggregated in the kidneys, lungs, spleen red pulp, and the nasal airway, with no observable morphological changes apart from the nasal cavity [126].

Very few cells do not undergo morphological changes after withstanding the air-liquid interface culture for an extended duration. Au-nanoparticles (5 nm and 15 nm diameter) penetrated the mouse fibroblasts, where they remained stocked. Only the presence of 5 nm Ag-nanoparticles disrupted cytoskeleton resulting in narrowing and contraction of cells. Many engineered nanomaterials, such as TiO_2, magnetite iron, CeO_2, carbon black, SWCNTs, and MWCNTs, also might cause different levels of inflammatory reactions, including enhanced pro-inflammatory cytokines expression, target inflammation-related genes, and micro-granulomas formation [127, 128]. The intra-tracheal administration of MWCNTs with variable length and iron content in hypertensive rats Led to the lung inflammation with increased blood pressure and lesions in abdominal arteries along with accumulation in multiple organs i.e., liver, kidneys, and spleen post seven days and 30 days exposure [129]. Maneewattanapinyo et al. studied acute toxicity of colloidal silver nanoparticles administered in laboratory mice and observed no mortality any acute toxicity symptoms after a limited dose of 5.000 mg/kg post 14 days of oral administration. No differences could be observed among groups after hematological and biochemical assessment and the histopathological study. The instillation of silver nanoparticles at the concentration of 5.000 ppm developed a transient eye irritation for 24 h. The application of these nanomaterials on the skin did not produce any micro or macroscopic toxicity [130]. The schematic mechanism of silver nanoparticle's toxicity in the human body is shown in Fig. 3 [131]. The liver and spleen are maximum exposed organs to nanomaterials owing to the prevalence of phagocytic cells in the reticuloendothelial system. Also, the organs with high blood flow, such as kidneys and lungs, can be affected.

5.2 Health Hazards in Human

Despite having many benefits and using nanomaterials, it may cause health hazards to humans due to a tiny size. The broad absorption surface of the lung, the thinner air–blood barrier, and comparatively less inactivation of enzymes leads to faster entry for particles into the systemic blood circulation at higher drug concentrations. Additionally, intended uptake, exposure of airborne particles from the environment, and nanoparticles released during the manufacturing process may also cause health hazards for humans. Usually, nanomaterials' biological effects are based on their size, composition, shape, and even on their electronic, magnetic, optical, and mechanical

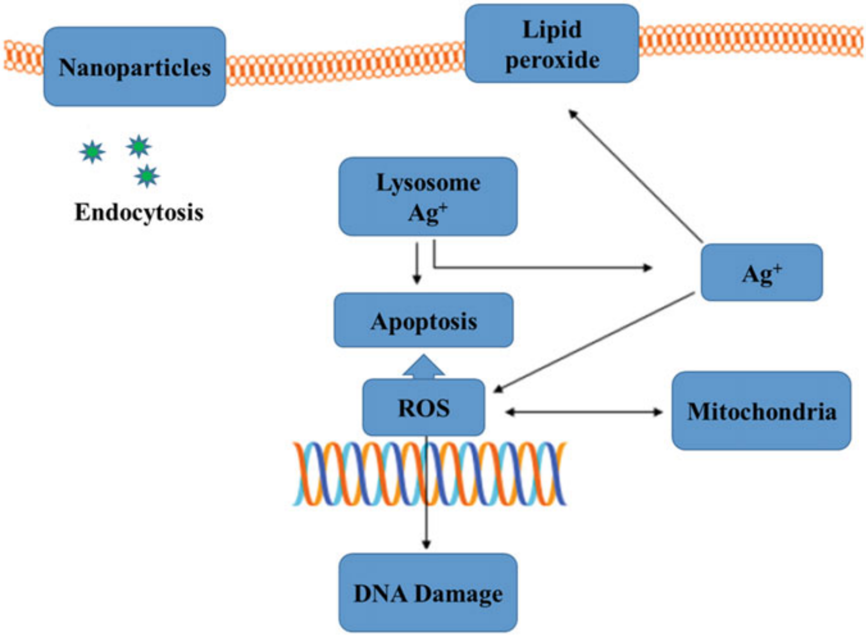

Fig. 3 Mechanism of silver nanoparticles toxicity (Abbreviations: NPs—nanoparticles; ROS—reactive oxygen species; Ag+—silver ions) Redrawn from [131]

properties. Presently, the influence of nanotechnology on human health and the environment is still controlled. Most of the studies assessed the outcomes of unintentional and accidental exposure (inhalation, medical procedures, or accidental ingestion) and focused only on local effects [98, 99]. Though, along with introducing nanomaterial-based biomedical methods, it is mandatory to analyze their toxicity at a systemic level. Centuries before, Paracelsus said, "everything is a poison, and nothing is a poison, it is only a matter of a dose." For nanomaterials, it is applicable in both the aspects of dose and particle size [100]. There is a massive demand for nanomaterials in various applications, ranging from diagnostic technology, bio-imaging, to gene/drug delivery [132–145]. Therefore, intended or unintended human exposure to nanomaterials is unavoidable and has higher prospects of exposure. Thus, a branch of science is developing, named "nanotoxicology", the study of the toxicity of nanomaterials. Nanotoxicology assesses the role and safety of nanomaterials on human health. Several anthropogenic sources, like power plants, internal combustion engines, and other thermo-degradation reactions also generate nanoparticles and develop the need to assess them [101].

5.2.1 Hazards in Nanomedicine

The nanomaterials represent a variety of biomedical applications. However, there is some potential risks factor related to the toxic issue. For example, oxidative stress, cytotoxicity, genotoxicity, and inflammation have been reported on in vitro and in vivo models for testing nanoparticles. The difference in the size of nanomaterial and bulk comes with the differences in properties and toxicity. Nanomaterials are tremendously beneficial yet can be toxic. Ag, ZnO, or CuO nanoparticles are frequently used as bactericides [102]. Nevertheless, waste disposal in the environment can also negatively affect non-target organisms.

5.2.2 Hazards in Medical Instrumentation

Nanomaterials are involved in medical interventions like prevention, diagnosis, and treatment of diseases. More functional and accurate medical diagnostic equipment are being designed for easy and safe operation. The lab-on-a-chip technology facilitates real-time point-of-care testing, enhancing the standards of medical care. Nanomaterial based thin films on implant surfaces improve the wear and resist infection. However, until now, these medical nanodevices are not 100% hazard free due to manufacturing processes, not following guidelines of nanotoxicity, and operating without the assessment of long term effects of nanotoxicity.

5.2.3 Hazards in Food Product

Nanotechnology is used to produce advanced food products and smart packaging technology [146–148]. In this way, the possibility of direct exposure to nanomaterials with human beings is enhanced, and different types of long-term or short-term toxicity may occur [149–151]. Nanoparticles and diamond-like nanocomposite (DLN) thin films are used in food packaging to reduce UV exposure and prolonged shelf life. Due to very few articles being reported in this area, further research is needed to fully explore the potential use of these nanoparticles for food products and medical treatments.

6 Environmental Nanopollution and Its Effect in Society

Environment conservation is a challenging task. Its vastness and complexity make this even more difficult. As nanomaterials' production is growing, multiple issues concerning nanotechnology arise as environmental pollution and industrial exposure. Nanoparticles serve as pollutants in diesel exhaust or welding fumes, presenting new toxicological mechanisms [152, 153]. It also makes us face pollution in macro, micro, and nanoscale. New branches of electronics are also creating new sources of occupational exposure hazard. The circumstances produce new challenges for both classical toxicology and nanotoxicology. Though nanotechnology improves the living standard, a simultaneous increase in water and air pollution has also occurred. As the origin of this pollution lies in nanomaterials hence termed "Nanopollution." Nanopollution is exceptionally lethal to both underwater flora and fauna and organisms living on soil. The pollutants can enter the human body in multiple ways. Cellular mechanisms can get affected by nanomaterial toxicity, which mainly comprises reactive oxygen species generation and genotoxicity [153–155]. The nanoparticle's exposure on humans can occur accidentally by environmental particles (e.g., air pollution) and intentionally because of a variety of consumer products, cosmetics, and medical products containing nanoparticles. The release of nanoparticles during the manufacturing process may result in exposure to workers via dermal, oral, and inhalation routes. Exposure to air pollutants, such as ultrafine particles, is known to cause inflammatory airway diseases and cardiovascular problems in humans [156]. Pope et al. [157] stated that even low levels of ambient nanoparticle exposure have a significant effect on mortality. To decrease nano pollution, scientists and researchers used nanotechnology to develop nanofilters, eliminating almost all airborne particles [158].

7 Social-economic Disruption Due to Rapid Use of Nanotechnology

As the speed of nanotechnology development is growing, as a consequence, the job opportunities are decreasing, arising the problem of unemployment in fields like industrial sector, manufacturing, and traditional farming [159, 160]. Nanotechnology-based devices and machines have replaced humans to furnish the job more rapidly and efficiently, which has pointed out the importance of human resources in practical work. Increasing growth and instant performance of nanotechnology have compromised the worth of commodities like diamond and oil. As an alternative technology, i.e., Nanotechnology has a detrimental effect on demand as substitutes have more efficiency and do not need fossil fuels. Diamonds are losing the worth due to greater availability from nanotechnology-based fabrication methods. Currently, manufacturing companies are equipped to produce the bulk of these products at a molecular scale, followed by disintegration to create new components.

At present, nanotechnology involves high investment technologies, raising the cost daily. The high price is the result of intricate molecular structure and processing charges of the product. The whole process makes it difficult for manufacturers to produce dynamic products using nanotechnology randomly. Currently, it is an unaffordable business owing to the massive pricing of nanotechnology-based machines. Hence, nanotechnology can also bring financial risks as manufacturers have to invest a large sum of money for setting up nanotech plants. The manufacturers have to face a considerable loss if, by any chance, the manufactured products fail to satisfy the customers. Alternate options such as the recovery of the original product or maintenance of the nanomaterials are also a costly and tedious affair.

Further, nanotechnology does not leave any byproducts or residues, generally based on small industries, therefore creating a considerable risk of extinction for small scale industries. As an outcome, the quantity of sub-products of coal and petroleum is deteriorating. Another massive threat, like the Covid-19 pandemic situation, may be born with the arrival of nanotechnology. It can make the easy accessibility of bio-chemical weapons or nano-bio engineered biological weapons. Nanotechnology is making these weapons more powerful and destructive. Unauthorized criminal bodies or corrupt politicians can steal the formulations and may reach these dangerous weapons easily, and they can quickly destroy our civilization [161].

8 Effect of Nanotechnology on Microorganisms, Animals, and Plants

Some nanomaterials are hazardous to human beings and are also harmful to the existence of different microorganisms, animals, and plants. Human-made nano pollution is very unsafe for living microorganisms, animals, and plants under the water or on the earth. As a result, many of microorganism's families have entirely disappeared from the world. Due to the rapid application of nanotechnology in the agriculture sector without proper nanotoxicological analysis, many plants are directly exposed to nanotoxicity, and animals are indirectly exposed. Thus, in the last two decades, a vast number of valuable plants and animals are entirely disappeared from our world.

9 Safety and Security of Nanotechnological Developments

Nanotechnology is an extensively expanding field. Researchers, scientists, and engineers are getting high success in producing nanoscale materials and taking advantage of enhanced properties, such as higher strength, lighter weight, increased electrical conductivity, and chemical reactivity compared to their larger-scale equivalents [162, 163].

Human health concerns are also growing due to nanomaterials. The attempts of technological manipulations raise the vocational risk to the workers in case of accidental exposures. The ethical issues regarding the poisoning of mass material are processed at a nanoscale, causing adverse effects on the health and industry. Mass poisoning occurs in the case of toxic micro particles coatings on the products. These microparticles penetrate inside the brain, while in contact with humans. Academic and industry experts suggest that there exists ambiguity regarding the toxic effects of releasing nanoparticles into the environment. It is also noteworthy that there is a lack of knowledge of nanoparticles interactions with humans and the environment. Similar to most of the emerging technologies, nanotechnology, and nanochemistry industries have both benefits and challenges. To obtain maximum benefits, the problems must be overcome, managed, and endured. In combination with other inorganic or organic counterparts, mesoporous silicates have been extensively explored for targeted drug delivery and cancer treatment. Even though the long-term toxicity of the nanoparticles is subjected to controversies and doubts, the use of gold and silver nanoparticles have provided more advantages in comparison to other actual alternatives (cytostatics).

Consequently, there is a growing interest in developing in vitro assays for nanotoxicology study [164]. It is strongly encouraged to use primary human cells as a source for in vitro study with nanoparticles since different origins of cancerous cell lines complicate data interpretation for human risk evaluation. Till now, the environmental effects and the toxicity of nanomaterials to organisms are in the infancy state. The evaluation methods need to be cost-effective rapid, and quantity efficient.

10 Current Policy and Regulation Status

The social implications of nanotechnology comprise many fundamental aspects like ethics, privacy, environment, and security. Occasionally, the negative impacts on the environment are too averse to handle that the people simply give up. However, nanoscience researchers are still optimistic about seeing the light of hope on the other side of the tunnel. Environmental clean-up is possible via the design and manipulation of the atomic and molecular scale of materials. It would develop cleaner energy production, energy efficiency, water treatment, and environmental remediation. Nanoscale fluid dynamics decipher the flow of nanoparticles in the environment as a result of interactions with biological and ecological systems. Researchers are keen to understand the transportation of nanomaterials in association with environmental contaminants through groundwater systems. For food authenticity, safety, and traceability, every food company should need to use smart labels at more robust and innovative functional lightweight packaging. Each developed and developing countries have a separate policy and regulation for the use of nanotechnological products and applications. Explicit initiatives on nanotechnology must be needed to promise that the opportunity provided by nanotechnology is not misused, and research does not become fragmented. The uncertainty, complexity, and diversity of nanotechnology mean that any initiative should not be a strictly preconceived closed program. Flexibility will be needed to stay side by side of development as they arise.

11 Challenges and Future Trends in Using Nanomaterials in Humans

Nanotechnology-based production uses minimal human resources, land, maintenance, and it is cost-effective, high productivity with modest requirements of materials and energy. The extensively growing field offers scientists and engineers an excellent opportunity to manipulate or alter the nanoscale materials to yield benefit of enhanced material characteristics like increased strength, lightweight, higher electrical conductivity, and chemical activity in comparison to their large-scale counterparts. However, for biomedical applications, the toxicity evaluation of nanomaterials should be performed. Broadly, detailed physicochemical characterization of nanomaterial should be performed before and during any toxicity study. Essential properties can control nanomaterial-induced toxicity, including size and shape of the nanomaterials, coating, chemical composition, crystal growth, nanomaterials purity, structure, surface area, surface chemistry, surface charge, agglomeration, and solubility should also be taken care. Measurements should be performed in a sufficiently stable state of nanomaterials in the most suitable test medium, i.e., aggregation status and ion release from metallic nanomaterials. Various engineered materials should be tested for their multidisciplinary tiered toxicity using diverse models and experiments [165, 166]. Therefore, the first step in genotoxicity is an assessment of the physicochemical properties of nanomaterials. The validation of the proposed tiered approaches still waits for the future. The researchers are continuously trying to increase the relevant database with an increasing number of publications (papers, reviews, or even patents) every year [167], particularly the market share of the nanotechnology products is also growing up to thousands of billions of Euros [168]. Balanced use of the nanotechnologies/nanomaterials must be arranged to optimize the opportunities/risks factors.

Further studies related to the influence of size and shape, capping agents, receptors immobilization onto the metal nanoparticles are still necessary. Varying sizes can tune surface plasmon resonance, the shape of the nanomaterials and different surface functionalization of both silver and gold nanoparticles can reduce the toxicity and enhance a variety of biomedical applications in the future. For example, CNT toxicity can be reduced via functionalization, surface coating, and stimulation of the autophagic flux. The amino functionalization decreases the CNT toxicity to the cells [169] and albumin coating for SWCNTs [170]. We have summarized some comparative points about the advantages and disadvantages of nanotechnology discussed throughout our review in the form of the following Table 1.

12 Conclusions

Nanoparticles can enter and get distributed around the human body very easily. After entering into humans, it moves within the body and creates cellular toxicity. Then it attacks the respiratory system, cardiovascular system, brain, skin, gut, and other

Table 1 Comparative discussion about advantages and disadvantages of nanotechnology

Advantages	Disadvantages
Early-stage detection of some diseases	Still at its infancy stage
Reduction of the size of any material, machine or equipment	More research and developmental work need to be done
Reduction of the amount of energy and resource	Expensive technology till now
Helps to clean up the existing nano-pollution	Creates environmental nano pollution
Able to secure the economy once it can be fully implemented	It can create social-economic disruption in society
Applicable and implementable to most of the applications ever existed	The huge initial cost for implementation
Can alter the basis of technology for human, in its matured phase	Resistance from a culture perspective, activists, journalists and even within the government
Improvement of the therapeutic drug index by increasing efficacy and/or reducing toxicities	Knowledge limitation from many industries and misperception among many fields about its capabilities.
Targeted delivery of drugs in a tissue-, cell- or organelle-specific manner	The government does not regulate nanomaterials
Enabling sustained or stimulus-triggered drug release	Requirement of significant investment and research but yield is still a limiting factor
More sensitive cancer diagnosis and imaging	Some nanoparticles may be toxic to humans
Better pharmaceutical properties (i.e. stability, solubility, circulating half-life and tumor accumulation) of therapeutic molecules	Nanotechnology made weapons are more powerful and more destructive by increasing the explosion potential
Provision of new approaches for the development of synthetic vaccines	Lack of employment in the fields of traditional farming, manufacturing, and industrial sector

organs. Some nanomaterials kill harmful bacteria within the body, and some kill good bacteria and live-cells of the human body. Nanoparticles with different substances are used in SIM cards of cell phones or sunscreens. When these are used, free nanoparticles get released in the environment (air, water, or soil). Engineering fields like civil and electronics also create new occupational health risks, making new, potentially toxic nanomaterials. The toxicity of nanoparticles depends on their shape, size, and chemical composition. Centuries before, Paracelsus quoted, "everything is a poison, and nothing is a poison, it is only a matter of a dose." In regards to nanomaterials, the quotes hold value for both dose and particle size. The new interdisciplinary investigations explore the potentially harmful effects of these useful NPs and help in environmental preservation. Owing to a smaller size, the inhalation of nanomaterials imposes an adverse impact on human health. The inhalation causes severe injury to the lungs and can also become fatal. The deterioration of lungs can be observed even after the 60s of nanoparticle inhalation. Therefore, for sustainable nanotechnology development, it is mandatory to evaluate and spread knowledge about the short term and long term exposure benefits and hazards for nanomaterials.

To conclude, nanotechnology has the potential to impact society, both positively or negatively. Its consumers, producers, and dealers include all the community members and all stakeholders, so we should collectively raise the voice in its various growth and commercialization phases. Nanotechnology is currently in its infancy stage, with a significant lack of awareness about its effects on humans and the environment. As civilization moves forward, the vital query is: how should we manage the risks and uncertainties of this emergent technology? Is anyhow the COVID-19 pandemic situation human-made? If not, we can face such circumstances due to the careless application of nanotechnology in different fields.

References

1. Santra TS, Tseng F-G (Kevin), Barik TK (2015) Biosynthesis of silver and gold nanoparticles for potential biomedical applications—a brief review. J Nanopharmaceutics Drug Deliv 2:249–265. https://doi.org/10.1166/jnd.2014.1065
2. Kalantar-Zadeh K, Fry B (2008) Nanotechnology-enabled sensors. Springer, US
3. Bhushan B (2010) Introduction to nanotechnology. Springer handbook of nanotechnology. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp 1–13
4. Jha AR (2008) MEMS and nanotechnology-based sensors and devices for communications, medical and aerospace applications. CRC Press
5. Bakhoum EG Micro- and nano-scale sensors and transducers
6. (2020) Handbook of single cell technology + reference. Springer
7. Microfluidics and BioMEMS: Devices and applications—1st Edition—Tu. https://www.routledge.com/Microfluidics-and-BioMEMS-Devices-and-Applications/Santra/p/book/9789814800853. Accessed 9 June 2020
8. Tseng F-G, Santra TS essentials of single-cell analysis: concepts, applications and future prospects
9. Tseng F-G, Santra TS (2015) Micro/nano fluidic devices for single cell analysis. MDPI AG Basel, Switz
10. Santra TS (2020) Bio-MEMS and bio-NEMS: devices and applications. Jenny Stanford Publisher Pvt. Ltd., Singapore
11. Shinde P, Kar S, Mohan L, Chang H-Y, Tseng F-G, Nagai M, Santra TS (2020) Infrared pulse laser activated highly efficient intracellular delivery using titanium micro-dish device. ACS Biomater Sci Eng. https://doi.org/10.1021/acsbiomaterials.0c00785
12. Santra TS, Kar S, Chang H-Y, Tseng F-G (2020) Nano-localized single-cell nano-electroporation. Lab Chip 17. https://doi.org/10.1039/d0lc00712a
13. Illath K, Narasimahan, AK, Nagai M, Wankhar S, Santra TS (2020) Microfluidic based metallic nanoparticle synthesis and applications. In: Microfluidics and bio-MEMS: devices and applications. Jenny Stanford Publisher Pte. Ltd
14. Medintz IL, Uyeda HT, Goldman ER, Mattoussi H (2005) Quantum dot bioconjugates for imaging, labelling and sensing. Nat. Mater
15. Oshida Y (2010) Bioscience and bioengineering of titanium materials. Elsevier
16. Mohan L, Anandan C, Grips VKW (2012) Corrosion behavior of titanium alloy Beta-21S coated with diamond like carbon in Hank's solution. Appl Surf Sci 258:6331–6340. https://doi.org/10.1016/j.apsusc.2012.03.032
17. Santra TS, Tseng F-G, Barik TK (2014) Green biosynthesis of gold nanoparticles and biomedical applications. Am J Nano Res Appl 2:5–12. https://doi.org/10.11648/j.nano.s.2014020602.12

18. Mohan L, Durgalakshmi D, Geetha M, Narayanan TSNS, Asokamani R (2012) Electrophoretic deposition of nanocomposite (HAp + TiO2) on titanium alloy for biomedical applications. Ceram Int 38:3435–3443
19. Mohan L, Anandan C (2013) Wear and corrosion behavior of oxygen implanted biomedical titanium alloy Ti-13Nb-13Zr. Appl Surf Sci 282:281–290. https://doi.org/10.1016/j.apsusc.2013.05.120
20. Mohan L, Anandan C, Rajendran N (2015) Electrochemical behaviour and bioactivity of self-organized TiO2 nanotube arrays on Ti-6Al-4 V in Hanks' solution for biomedical applications. Electrochim Acta 155:411–420. https://doi.org/10.1016/j.electacta.2014.12.032
21. Mohan L, Kar S, Nandhini B, Dhilip Kumar SS, Nagai M, Santra TS (2020) Formation of nanostructures on magnesium alloy by anodization for potential biomedical applications. Mater Today Commun: 101403. https://doi.org/10.1016/j.mtcomm.2020.101403
22. [PDF] A review of current research into the biogenic synthesis of metal and metal oxide nanoparticles via Marine Algae and Seagrasses|Semantic Scholar. https://www.semanticscholar.org/paper/A-Review-of-Current-Research-into-the-Biogenic-of-Fawcett-Verduin/04a57915cbbe6701fb08de0464260d5a3af7e3a7. Accessed 9 June 2020
23. Maynard AD (2007) Nanotechnology: the next big thing, or much ado about nothing? Ann Occup Hyg 51:1–12. https://doi.org/10.1093/annhyg/mel071
24. Cox S, Abu-Ghannam N, Gupta S (2010) An assessment of the antioxidant and antimicrobial activity of six species of edible Irish seaweeds. Int Food Res J 17:205–220. https://doi.org/10.21427/D7HC92
25. De Pádua M, Growoski Fontoura PS, Mathias AL (2004) Chemical composition of Ulvaria oxysperma (Kützing) bliding, Ulva lactuca (Linnaeus) and Ulva fascita (Delile). Brazilian Arch Biol Technol 47:49–55. https://doi.org/10.1590/s1516-89132004000100007
26. Kumari P, Kumar M, Gupta V, Reddy CRK, Jha B (2010) Tropical marine macroalgae as potential sources of nutritionally important PUFAs. Food Chem 120:749–757. https://doi.org/10.1016/j.foodchem.2009.11.006
27. Ravikumar S, Krishnakumar S, Inbaneson SJ, Gnanadesigan M (2010) Antagonistic activity of marine actinomycetes from Arabian Sea coast
28. Krishnakumar S, Premkumar J, Alexis RR, Ravikumar S (2011) Optimization of potential antibiotic production by salt-tolerant Actinomycetes streptomyces sp.-MSU29 isolated from marine sponge. Int J Appl Bio-Eng 5:12–18. https://doi.org/10.18000/ijabeg.10079
29. Manivasagan P, Venkatesan J, Kim S-K (2015) Marine algae: an important source of bioenergy production. In: Marine Bioenergy. CRC Press, pp 45–70
30. Ermakova S, Kusaykin M, Trincone A, Tatiana Z (2015) Are multifunctional marine polysaccharides a myth or reality? Front Chem 3:39. https://doi.org/10.3389/fchem.2015.00039
31. Venkatesan J, Bhatnagar I, Manivasagan P, Kang KH, Kim SK (2015) Alginate composites for bone tissue engineering: a review. Int J Biol Macromol 72:269–281
32. Fayaz AM, Balaji K, Girilal M, Yadav R, Kalaichelvan PT, Venketesan R (2010) Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria. Nanomed Nanotechnol Biol Med 6:103–109. https://doi.org/10.1016/j.nano.2009.04.006
33. Ra M, Gade A, Gaikwad S, Marcato PD, Durán N (2012) Biomedical applications of nanobiosensors: the state-of-the-art. J Braz Chem Soc 23:14–24
34. Kar S, Mohapatra DR, Freysz E, Sood AK (2014) Tuning photoinduced terahertz conductivity in monolayer graphene: optical-pump terahertz-probe spectroscopy. Phys Rev B Condens Matter Mater Phys 90:165420. https://doi.org/10.1103/PhysRevB.90.165420
35. Kar S, Nguyen VL, Mohapatra DR, Lee YH, Sood AK (2018) Ultrafast spectral photoresponse of bilayer graphene: optical pump-terahertz probe spectroscopy. ACS Nano 12:1785–1792. https://doi.org/10.1021/acsnano.7b08555
36. Kar S, Mohapatra DR, Sood AK (2018) Tunable terahertz photoconductivity of hydrogen functionalized graphene using optical pump-terahertz probe spectroscopy. Nanoscale 10:14321–14330. https://doi.org/10.1039/c8nr04154g

37. Kar S, Su Y, Nair RR, Sood AK (2015) Probing photoexcited carriers in a few-layer MoS2 laminate by time-resolved optical pump-terahertz probe spectroscopy. ACS Nano 9:12004–12010. https://doi.org/10.1021/acsnano.5b04804
38. Kar S, Jayanthi S, Freysz E, Sood AK (2014) Time resolved terahertz spectroscopy of low frequency electronic resonances and optical pump-induced terahertz photoconductivity in reduced graphene oxide membrane. Carbon N Y 80:762–770. https://doi.org/10.1016/j.carbon.2014.09.030
39. Li BL, Wang J, Zou HL, Garaj S, Lim CT, Xie J, Li NB, Leong DT (2016) Low-dimensional transition metal dichalcogenide nanostructures based sensors. Adv Funct Mater 26:7034–7056. https://doi.org/10.1002/adfm.201602136
40. Kar S, Sood AK (2019) Ultrafast terahertz photoresponse of single and double-walled carbon nanotubes: optical pump-terahertz probe spectroscopy. Carbon N Y 144:731–736. https://doi.org/10.1016/j.carbon.2018.12.081
41. Chiara R, Ciftci YO, Queloz VIE, Nazeeruddin MK, Grancini G, Malavasi L (2020) Green-emitting lead-free Cs4SnBr 6 zero-dimensional perovskite nanocrystals with improved air stability. J Phys Chem Lett 11:618–623. https://doi.org/10.1021/acs.jpclett.9b03685
42. Dubey SP, Lahtinen M, Sillanpää M (2010) Tansy fruit mediated greener synthesis of silver and gold nanoparticles. Process Biochem 45:1065–1071. https://doi.org/10.1016/j.procbio.2010.03.024
43. Prasad TNVKV, Elumalai EK (2011) Biofabrication of Ag nanoparticles using Moringa oleifera leaf extract and their antimicrobial activity. Asian Pac J Trop Biomed 1:439–442. https://doi.org/10.1016/S2221-1691(11)60096-8
44. Leela A, Vivekanandan M (2008) Tapping the unexploited plant resources for the synthesis of silver nanoparticles. African J Biotechnol 7:3162–3165. https://doi.org/10.5897/AJB08.425
45. Hedenborg M (1988) Titanium dioxide induced chemiluminescence of human polymorphonuclear leukocytes. Int Arch Occup Environ Health 61:1–6. https://doi.org/10.1007/BF00381600
46. Savithramma N, Linga Rao M, Ankanna S, Venkateswarlu P (2012) Screening of medicinal plants for effective biogenesis of silver nanoparticles and efficient antimicrobial activity. Int J Pharm Sci Res. https://ijpsr.com/bft-article/screening-of-medicinal-plants-for-effective-biogenesis-of-silver-nano-particles-and-efficient-anti-microbial-activity/. Accessed 9 June 2020
47. Chikramane PS, Suresh AK, Bellare JR, Kane SG (2010) Extreme homeopathic dilutions retain starting materials: a nanoparticulate perspective. Homeopathy 99:231–242. https://doi.org/10.1016/j.homp.2010.05.006
48. Aslan K, Leonenko Z, Lakowicz JR, Geddes CD (2005) Fast and slow deposition of silver nanorods on planar surfaces: application to metal-enhanced fluorescence. J Phys Chem B 109:3157–3162. https://doi.org/10.1021/jp045186t
49. Diao JJ, Cao Q (2011) Gold nanoparticle wire and integrated wire array for electronic detection of chemical and biological molecules. AIP Adv 1:012115. https://doi.org/10.1063/1.3568815
50. Lim JK, Imura K, Nagahara T, Kim SK, Okamoto H (2005) Imaging and dispersion relations of surface plasmon modes in silver nanorods by near-field spectroscopy. Chem Phys Lett 412:41–45. https://doi.org/10.1016/j.cplett.2005.06.094
51. Hutter E, Maysinger D (2011) Gold nanoparticles and quantum dots for bioimaging. Microsc Res Tech 74:592–604
52. Biological applications of colloidal nanocrystals—IOPscience. https://iopscience.iop.org/article/10.1088/0957-4484/14/7/201/pdf. Accessed 9 June 2020
53. Schider G, Krenn R, Hohenau A, Ditlbacher H, Leitner A, Aussenegg R, Schaich L, Puscasu I, Monacelli B, Boreman G (2003) Plasmon dispersion relation of Au and Ag nanowires. Phys Rev B Condens Matter Mater Phys 68:155427. https://doi.org/10.1103/PhysRevB.68.155427
54. Lou X, Zhang Y, Qin J, Li Z (2011) A highly sensitive and selective fluorescent probe for cyanide based on the dissolution of gold nanoparticles and its application in real samples. Chem A Eur J 17:9691–9696. https://doi.org/10.1002/chem.201100389
55. Pingarrón JM, Yáñez-Sedeño P, González-Cortés A (2008) Gold nanoparticle-based electrochemical biosensors. Electrochim Acta 53:5848–5866. https://doi.org/10.1016/j.electacta.2008.03.005

56. Geddes CD, Parfenov A, Gryczynski I, Lakowicz JR (2003) Luminescent blinking of gold nanoparticles. Chem Phys Lett 380:269–272. https://doi.org/10.1016/j.cplett.2003.07.029
57. Dey K, Kar S, Shinde P, Mohan L, Bajpai SK, Santra TS (2020) *Microfluidic electroporation and applications*. Jenny Stanford Publisher
58. Yu DG (2007) Formation of colloidal silver nanoparticles stabilized by Na+-poly(γ-glutamic acid)-silver nitrate complex via chemical reduction process. Colloids Surf B Biointerfaces 59:171–178. https://doi.org/10.1016/j.colsurfb.2007.05.007
59. Tan Y, Wang Y, Jiang L, Zhu D (2002) Thiosalicylic acid-functionalized silver nanoparticles synthesized in one-phase system. J Colloid Interface Sci 249:336–345. https://doi.org/10.1006/jcis.2001.8166
60. Petit C, Lixon P, Pileni MP (1993) In situ synthesis of silver nanocluster in AOT reverse micelles. J Phys Chem 97:12974–12983. https://doi.org/10.1021/j100151a054
61. Vorobyova SA, Lesnikovich AI, Sobal NS (1999) Preparation of silver nanoparticles by interphase reduction. Colloids Surf A Physicochem Eng Asp 152:375–379. https://doi.org/10.1016/S0927-7757(98)00861-9
62. Mallick K, Witcomb MJ, Scurrell MS (2005) Self-assembly of silver nanoparticles in a polymer solvent: formation of a nanochain through nanoscale soldering. Mater Chem Phys 90:221–224. https://doi.org/10.1016/j.matchemphys.2004.10.030
63. Kéki S, Török J, Deák G, Daróczi L, Zsuga M (2000) Silver nanoparticles by PAMAM-assisted photochemical reduction of Ag+. J Colloid Interface Sci 229:550–553. https://doi.org/10.1006/jcis.2000.7011
64. Pileni MP (2000) Fabrication and physical properties of self-organized silver nanocrystals. Pure Appl Chem, pp 53–65
65. Sun YP, Atorngitjawat P, Meziani MJ (2001) Preparation of silver nanoparticles via rapid expansion of water in carbon dioxide microemulsion into reductant solution. Langmuir 17:5707–5710. https://doi.org/10.1021/la0103057
66. Liu YC, Lin LH (2004) New pathway for the synthesis of ultrafine silver nanoparticles from bulk silver substrates in aqueous solutions by sonoelectrochemical methods. Electrochem Commun 6:1163–1168. https://doi.org/10.1016/j.elecom.2004.09.010
67. Sandmann G, Dietz H, Plieth W (2000) Preparation of silver nanoparticles on ITO surfaces by a double-pulse method. J Electroanal Chem 491:78–86. https://doi.org/10.1016/S0022-0728(00)00301-6
68. Bae CH, Nam SH, Park SM (2002) Formation of silver nanoparticles by laser ablation of a silver target in NaCl solution. In: Applied Surface Science. Elsevier, pp 628–634
69. Smetana AB, Klabunde KJ, Sorensen CM (2005) Synthesis of spherical silver nanoparticles by digestive ripening, stabilization with various agents, and their 3-D and 2-D superlattice formation. J Colloid Interface Sci 284:521–526. https://doi.org/10.1016/j.jcis.2004.10.038
70. Esumi K, Isono R, Yoshimura T (2004) Preparation of PAMAM- and PPI-Metal (Slver, Platinum, and Palladium) nanocomposites and their catalytic activities for reduction of 4-nitrophenol. Langmuir 20:237–243. https://doi.org/10.1021/la035440t
71. Murugadoss A, Khan A, Chattopadhyay A (2010) Stabilizer specific interaction of gold nanoparticles with a thermosensitive polymer hydrogel. J Nanoparticle Res 12:1331–1348. https://doi.org/10.1007/s11051-009-9668-0
72. Zhang H, Li X, Chen G (2009) Ionic liquid-facilitated synthesis and catalytic activity of highly dispersed Ag nanoclusters supported on TiO2. J Mater Chem 19:8223–8231. https://doi.org/10.1039/b910610c
73. Sun Y, Xia Y (2002) Shape-controlled synthesis of gold and silver nanoparticles. Science (80-) 298:2176–2179. https://doi.org/10.1126/science.1077229
74. Bhattacharya R, Mukherjee P (2008) Biological properties of "naked" metal nanoparticles. Adv Drug Deliv Rev 60:1289–1306
75. Raghunandan D, Borgaonkar PA, Bendegumble B, Bedre MD, Bhagawanraju M, Yalagatti MS, Huh DS, Abbaraju V (2011) Microwave-assisted rapid extracellular biosynthesis of silver nanoparticles using carom seed (Trachyspermum copticum) extract and in vitro studies. Am J Anal Chem 02:475–483. https://doi.org/10.4236/ajac.2011.24057

76. Kathiresan K, Manivannan S, Nabeel MA, Dhivya B (2009) Studies on silver nanoparticles synthesized by a marine fungus, Penicillium fellutanum isolated from coastal mangrove sediment. Colloids Surf B Biointerfaces 71:133–137. https://doi.org/10.1016/j.colsurfb.2009.01.016
77. Konishi Y, Tsukiyama T, Ohno K, Saitoh N, Nomura T, Nagamine S (2006) Intracellular recovery of gold by microbial reduction of AuCl 4-ions using the anaerobic bacterium Shewanella algae. Hydrometallurgy 81:24–29. https://doi.org/10.1016/j.hydromet.2005.09.006
78. (PDF) Biosynthesis of silver, gold and bimetallic nanoparticles using the filamentous fungus Neurospora crassa | Alfredo R Vilchis-Nestor—Academia.edu. https://www.academia.edu/22627587/Biosynthesis_of_silver_gold_and_bimetallic_nanoparticles_using_the_filamentous_fungus_Neurospora_crassa. Accessed 9 June 2020
79. Goodsell DS (2004) Bionanotechnology: lessons from nature. Wiley-Liss
80. Thakur NS, Dwivedee BP, Banerjee UC, Bhaumik J (2017) Bioinspired synthesis of silver nanoparticles: characterisation, mechanism and applications. In: Silver Nanoparticles for Antibacterial Devices. CRC Press, pp 3–36
81. Xie J, Lee JY, Wang DIC, Ting YP (2007) Silver nanoplates: from biological to biomimetic synthesis. ACS Nano 1:429–439. https://doi.org/10.1021/nn7000883
82. Mendiola JA, Rodriguez-Meizoso I, Señoráns FJ, Reglero G (2017) Advanced Microalgal Technologies for a Circular Economy. ALGATEC-CM View project. Project Allergy Car-Union European View project
83. Wenqiang G, Shufen L, Ruixiang Y, Yanfeng H (2006) Comparison of composition and antifungal activity of Artemisia argyi Lévl. et Vant inflorescence essential oil extracted by hydrodistillation and supercritical carbon dioxide. Nat Prod Res 20:992–998. https://doi.org/10.1080/14786410600921599
84. Santra TS, Bhattacharyya TK Diamond-Like Nanocomposite (DLN) Films for Microelectro-Mechanical System (MEMS). IJCA
85. Santra TS, Bhattacharyya TK, Tseng FG, Barik TK (2012) Influence of flow rate on different properties of diamond-like nanocomposite thin films grown by PECVD. AIP Adv 2:022132. https://doi.org/10.1063/1.4721654
86. Santra TS, Bhattacharyya TK, Patel P, Tseng FG, Barik TK (2011) Structural and tribological properties of diamond-like nanocomposite thin films. Surf Coatings Technol 206:228–233. https://doi.org/10.1016/j.surfcoat.2011.06.057
87. Santra TS, Liu CH, Bhattacharyya TK, Patel P, Barik TK (2010) Characterization of diamond-like nanocomposite thin films grown by plasma enhanced chemical vapor deposition. J Appl Phys 107:124320. https://doi.org/10.1063/1.3415548
88. IJCA—Diamond-like Nanocomposite (DLN) Films for Microelectro-Mechanical System (MEMS). http://sandbox.ijcaonline.org/proceedings/isdmisc/number6/3478-isdm132. Accessed 9 June 2020
89. Biomedical applications of diamond-like nanocomposite thin films: ingenta connect. https://www.ingentaconnect.com/content/asp/sam/2012/00000004/00000001/art00014. Accessed 9 June 2020
90. Das T, Ghosh D, Bhattacharyya TK, Maiti TK (2007) Biocompatibility of diamond-like nanocomposite thin films. J Mater Sci Mater Med 18:493–500. https://doi.org/10.1007/s10856-007-2009-x
91. Nanotechnology applications (With images) | Nanotechnology, Nano science, Nanotechnology art. https://in.pinterest.com/pin/574842339921055473/. Accessed 9 June 2020
92. Global Nanomaterials Market Worth USD 16.8 Billion by 2022. https://www.zionmarketresearch.com/news/nanomaterials-market. Accessed 9 June 2020
93. Nanotechnology global market value 2020 | Statista. https://www.statista.com/statistics/1073886/global-market-value-nanotechnology/. Accessed 9 Jun 2020
94. Global Nanotechnology Market To Reach $48.9 Billion In 2017. https://www.bccresearch.com/pressroom/nan/global-nanotechnology-market-reach-$48.9-billion-2017. Accessed 9 June 2020

95. Elsaesser A, Howard CV (2012) Toxicology of nanoparticles. Adv Drug Deliv Rev
96. Pridgen EM, Alexis F, Farokhzad OC (2015) Polymeric nanoparticle drug delivery technologies for oral delivery applications. Expert Opin Drug Deliv
97. Kafshgari M, Harding F, Voelcker N (2015) Insights into cellular uptake of nanoparticles. Curr Drug Deliv. https://doi.org/10.2174/1567201811666140821110631
98. De Jong WH, Borm PJA (2008) Drug delivery and nanoparticles: applications and hazards. Int J Nanomedicine 3:133–149
99. Papp T, Schiffmann D, Weiss D, Castranova V, Vallyathan V, Rahman Q (2008) Human health implications of nanomaterial exposure. Nanotoxicology 2:9–27. https://doi.org/10.1080/17435390701847935
100. Likus W, Bajor G, Siemianowicz K (2013) Nanosilver-does it have only one face?
101. Oberdörster G, Oberdörster E, Oberdörster J (2005) Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. Environ Health Perspect 113:823–839
102. Love SA, Maurer-Jones MA, Thompson JW, Lin Y-S, Haynes CL (2012) Assessing nanoparticle toxicity. Annu Rev Anal Chem. https://doi.org/10.1146/annurev-anchem-062011-143134
103. Ahamed M, AlSalhi MS, Siddiqui MKJ (2010) Silver nanoparticle applications and human health. Clin. Chim, Acta
104. Manke A, Wang L, Rojanasakul Y (2013) Mechanisms of nanoparticle-induced oxidative stress and toxicity. Biomed Res, Int
105. Beer C, Foldbjerg R, Hayashi Y, Sutherland DS, Autrup H (2012) Toxicity of silver nanoparticles-Nanoparticle or silver ion? Toxicol Lett. https://doi.org/10.1016/j.toxlet.2011.11.002
106. Liao MY, Liu HG (2012) Gene expression profiling of nephrotoxicity from copper nanoparticles in rats after repeated oral administration. Environ Toxicol Pharmacol 34:67–80. https://doi.org/10.1016/j.etap.2011.05.014
107. La Francesca S (2012) Nanotechnology and stem cell therapy for cardiovascular diseases: potential applications. Methodist Debakey Cardiovasc J 8:28–35
108. Singh R, Lillard JW (2009) Nanoparticle-based targeted drug delivery. Exp. Mol, Pathol
109. Wang AZ, Langer R, Farokhzad OC (2012) Nanoparticle delivery of cancer drugs. Annu Rev Med. https://doi.org/10.1146/annurev-med-040210-162544
110. Prow TW, Grice JE, Lin LL, Faye R, Butler M, Becker W, Wurm EMT, Yoong C, Robertson TA, Soyer HP, Roberts MS (2011) Nanoparticles and microparticles for skin drug delivery. Adv Drug Deliv, Rev
111. Xie J, Lee S, Chen X (2010) Nanoparticle-based theranostic agents. Adv Drug Deliv, Rev
112. Brannon-Peppas L, Blanchette JO (2004) Nanoparticle and targeted systems for cancer therapy. Adv Drug Deliv Rev 56:1649–1659
113. Gerloff K, Albrecht C, Boots AW, Frster I, Schins RPF (2009) Cytotoxicity and oxidative DNA damage by nanoparticles in human intestinal Caco-2 cells. Nanotoxicology 3:355–364. https://doi.org/10.3109/17435390903276933
114. Relating cytotoxicity, zinc ions, and reactive oxygen in ZnO nanoparticle-exposed human immune cells. | Semantic Scholar. https://www.semanticscholar.org/paper/Relating-cytotoxicity%2C-zinc-ions%2C-and-reactive-in-Shen-James/95df5b01a4a932d2c233884e7a4c9e8dcd942169. Accessed 9 June 2020
115. Yan G, Huang Y, Bu Q, Lv L, Deng P, Zhou J, Wang Y, Yang Y, Liu Q, Cen X, Zhao Y (2012) Zinc oxide nanoparticles cause nephrotoxicity and kidney metabolism alterations in rats. J Environ Sci Heal Part A 47:577–588. https://doi.org/10.1080/10934529.2012.650576
116. Sahu SC, Zheng J, Graham L, Chen L, Ihrie J, Yourick JJ, Sprando RL (2014) Comparative cytotoxicity of nanosilver in human liver HepG2 and colon Caco2 cells in culture. J Appl Toxicol 34:1155–1166. https://doi.org/10.1002/jat.2994
117. Semmler M, Seitz J, Erbe F, Mayer P, Heyder J, Oberdörster G, Kreyling WG (2004) Long-term clearance kinetics of inhaled ultrafine insoluble iridium particles from the rat lung, including transient translocation into secondary organs. In: Inhalation Toxicology, pp 453–459

118. Ferin J, Oberdorster G, Penney DP (1992) Pulmonary retention of ultrafine and fine particles in rats. Am J Respir Cell Mol Biol 6. https://doi.org/10.1165/AJRCMB/6.5.535
119. Jugan ML, Barillet S, Simon-Deckers A, Sauvaigo S, Douki T, Herlin N, Carrière M (2011) Cytotoxic and genotoxic impact of TiO2 nanoparticles on A549 cells. J Biomed Nanotechnol 7:22–23. https://doi.org/10.1166/jbn.2011.1181
120. Du Z, Zhao D, Jing L, Cui G, Jin M, Li Y, Liu X, Liu Y, Du H, Guo C, Zhou X, Sun Z (2013) Cardiovascular toxicity of different sizes amorphous silica nanoparticles in rats after intratracheal instillation. Cardiovasc Toxicol 13:194–207. https://doi.org/10.1007/s12012-013-9198-y
121. Shi H, Magaye R, Castranova V, Zhao J (2013) Titanium dioxide nanoparticles: a review of current toxicological data. Part Fibre Toxicol 10:1–33
122. Landsiedel R, Ma-Hock L, Hofmann T, Wiemann M, Strauss V, Treumann S, Wohlleben W, Gröters S, Wiench K, Van Ravenzwaay B (2014) Application of short-term inhalation studies to assess the inhalation toxicity of nanomaterials. Part Fibre Toxicol 11:16. https://doi.org/10.1186/1743-8977-11-16
123. Silver Nanoparticle induced blood-brain barrier inflammation and increased permeability in primary rat brain microvessel endothelial cells | Toxicological Sciences | Oxford Academic. https://academic.oup.com/toxsci/article-abstract/118/1/160/1664864?redirectedFrom=fulltext. Accessed 9 June 2020
124. Trickler WJ, Lantz-Mcpeak SM, Robinson BL, Paule MG, Slikker W, Biris AS, Schlager JJ, Hussain SM, Kanungo J, Gonzalez C, Ali SF (2014) Porcine brain microvessel endothelial cells show pro-inflammatory response to the size and composition of metallic nanoparticles. Drug Metab Rev 46:224–231
125. González C, Salazar-García S, Palestino G, Martínez-Cuevas PP, Ramírez-Lee MA, Jurado-Manzano BB, Rosas-Hernández H, Gaytán-Pacheco N, Martel G, Espinosa-Tanguma R, Biris AS, Ali SF (2011) Effect of 45 nm silver nanoparticles (AgNPs) upon the smooth muscle of rat trachea: Role of nitric oxide. Toxicol Lett 207:306–313. https://doi.org/10.1016/j.toxlet.2011.09.024
126. Genter MB, Newman NC, Shertzer HG, Ali SF, Bolon B (2012) Distribution and systemic effects of intranasally administered 25 nm silver nanoparticles in adult mice. Toxicol Pathol 40:1004–1013. https://doi.org/10.1177/0192623312444470
127. Tsuda H, Xu J, Sakai Y, Futakuchi M, Fukamachi K (2009) Toxicology of engineered nanomaterials—a review of carcinogenic potential. Asian Pac J Cancer Prev 10:975–980
128. Park EJ, Kim H, Kim Y, Yi J, Choi K, Park K (2010) Inflammatory responses may be induced by a single intratracheal instillation of iron nanoparticles in mice. Toxicology 275:65–71. https://doi.org/10.1016/j.tox.2010.06.002
129. Chen R, Zhang L, Ge C, Tseng MT, Bai R, Qu Y, Beer C, Autrup H, Chen C (2015) Subchronic toxicity and cardiovascular responses in spontaneously hypertensive rats after exposure to multiwalled carbon nanotubes by intratracheal instillation. Chem Res Toxicol 28:440–450. https://doi.org/10.1021/tx5004003
130. Maneewattanapinyo P, Banlunara W, Thammacharoen C, Ekgasit S, Kaewamatawong T (2011) An evaluation of acute toxicity of colloidal silver nanoparticles. J Vet Med Sci 73:1417–1423. https://doi.org/10.1292/jvms.11-0038
131. Clichici S, Filip A (2015) In vivo assessment of nanomaterials toxicity. In: Nanomaterials—toxicity and risk assessment. InTech
132. Shinde P, Kumar A, Kavitha, Dey K, Mohan L, Kar S, Barik TK, Sharifi-Rad J, Nagai M, Santra TS (2020) Physical approaches for drug delivery. In: Delivery of drugs. Elsevier, pp 161–190
133. Kumar A, Mohan L, Shinde P, Chang H, Nagai M, Santra TS Mechanoporation Toward single cell approaches
134. Santra TS, Chang H-Y, Wang P-C, Tseng F-G (2014) Impact of pulse duration on localized single-cell nano-electroporation. Analyst 139:6249–6258
135. Santra TS, Wang PC, Chang HY, Tseng FG (2013) Tuning nano electric field to affect restrictive membrane area on localized single cell nano-electroporation. Appl Phys Lett 103. https://doi.org/10.1063/1.4833535

136. Manoj H, Gupta P, Loganathan M, Nagai M, Wankhar S, Santra (2020) Microneedles: current trends & applications. In: Microfluidics and bio-MEMS: devices and applications. Jenny Stanford Publisher
137. Kar S, Shinde P, Nagai M, Santra TS (2020) Optical manipulation of cells. In: Microfluidics and bio-MEMS: devices and applications. Jenny Stanford Publisher
138. Santra TS, Wu TH, Chiou EPY (2016) Photothermal microfluidics. In: Optical MEMS for chemical analysis and biomedicine. Institution of Engineering and Technology, pp 289–323
139. Santra TS, Tseng F-G (2016) Electroporation for single-cell analysis, pp 55–83
140. Santra TS, Wang P-C, Tseng FG (2013) Electroporation based drug delivery and its applications. In: Advances in Micro/Nano Electromechanical Systems and Fabrication Technologies. InTech
141. Shanmugam MM, Santra TS (2016) Microinjection for single-cell analysis. Springer, Berlin, Heidelberg, pp 85–129
142. Santra TS, Kar S, Chen C-W, Borana J, Chen T-C, Lee M-C, Tseng F-G (2020) Near-infrared nanosecond-pulsed laser-activated high efficient intracellular delivery mediated by nano-corrugated mushroom-shaped gold-coated polystyrene nanoparticles. Nanoscale. https://doi.org/10.1039/d0nr01792b
143. Shinde P, Mohan L, Kumar A, Dey K, Maddi A, Patananan AN, Tseng F-G, Chang H-Y, Nagai M, Santra TS (2018) Current trends of microfluidic single-cell technologies. Int J Mol Sci 19. https://doi.org/10.3390/ijms19103143
144. Kar S, Loganathan M, Dey K, Shinde P, Chang H-Y, Nagai M, Santra TS (2018) Single-cell electroporation: current trends, applications and future prospects. J Micromechanics Microengineering 28:123002. https://doi.org/10.1088/1361-6439/aae5ae
145. Narasimhan AK, Lakshmi SB, Santra TS, Rao MSR, Krishnamurthi G (2017) Oxygenated graphene quantum dots (GQDs) synthesized using laser ablation for long-term real-time tracking and imaging. RSC Adv 7:53822–53829. https://doi.org/10.1039/c7ra10702a
146. Silvestre C, Duraccio D, Cimmino S (2011) Food packaging based on polymer nanomaterials. Prog. Polym, Sci
147. Mihindukulasuriya SDF, Lim LT (2014) Nanotechnology development in food packaging: a review. Trends Food Sci Technol. https://doi.org/10.1016/j.tifs.2014.09.009
148. Sekhon BS (2010) Food nanotechnology—an overview. Nanotechnol Sci Appl
149. Bajpai VK, Kamle M, Shukla S, Mahato DK, Chandra P, Hwang SK, Kumar P, Huh YS, Han YK (2018) Prospects of using nanotechnology for food preservation, safety, and security. J. Food Drug Anal
150. Chaudhry Q, Scotter M, Blackburn J, Ross B, Boxall A, Castle L, Aitken R, Watkins R (2008) Applications and implications of nanotechnologies for the food sector. Food Addit Contam Part A Chem Anal Control Expo Risk Assess
151. Sharma C, Dhiman R, Rokana N, Panwar H (2017) Nanotechnology: an untapped resource for food packaging. Front Microbiol
152. Ibrahim RK, Hayyan M, AlSaadi MA, Hayyan A, Ibrahim S (2016) Environmental application of nanotechnology: air, soil, and water. Environ Sci Pollut Res
153. Mehndiratta P, Jain A, Srivastava S, Gupta N (2013) Environmental pollution and nanotechnology. Environ Pollut. https://doi.org/10.5539/ep.v2n2p49
154. Zhang B, Misak H, Dhanasekaran PS, Kalla D, Asmatulu R (2011) Environmental impacts of nanotechnology and its products. Am Soc Eng Educ
155. Karn B, Kuiken T, Otto M (2009) Nanotechnology and in situ remediation: a review of the benefits and potential risks. Environ Health Perspect
156. Van Hee VC, Kaufman JD, Scott Budinger GR, Mutlu GM (2010) Update in environmental and occupational medicine 2009. Am J Respir Crit Care Med 181:1174–1180
157. Pope AC, Burnett RT, Krewski D, Jerrett M, Shi Y, Calle EE, Thun MJ (2009) Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke shape of the exposure-response relationship. Circulation 120:941–948. https://doi.org/10.1161/CIRCULATIONAHA.109.857888
158. Bernd N (2010) Pollution prevention and treatment using nanotechnology. In: Nanotechnology

159. Wood S, Geldart A, Jones R (2003) The social and economic challenges of nanotechnology. TATuP - Zeitschrift für Tech Theor und Prax. https://doi.org/10.14512/tatup.12.3-4.72
160. Roco MC, Bainbridge WS (2005) Societal implications of nanoscience and nanotechnology: maximizing human benefit. J Nanoparticle Res. https://doi.org/10.1007/s11051-004-2336-5
161. Khan A (2015) Ethical and social implications of nanotechnology. QScience Proc. https://doi.org/10.5339/qproc.2015.elc2014.57
162. Springer handbook of nanotechnology
163. (2012) Encyclopedia of nanotechnology
164. Arora S, Rajwade JM, Paknikar KM (2012) Nanotoxicology and in vitro studies: the need of the hour. Toxicol Appl Pharmacol 258:151–165. https://doi.org/10.1016/j.taap.2011.11.010
165. Savolainen K, Alenius H, Norppa H, Pylkkänen L, Tuomi T, Kasper G (2010) Risk assessment of engineered nanomaterials and nanotechnologies—a review. Toxicology 269:92–104
166. Kumar A, Dhawan A (2013) Genotoxic and carcinogenic potential of engineered nanoparticles: an update. Arch Toxicol 87:1883–1900
167. Scopus—Document search | Signed in. https://www.scopus.com/search/form.uri?display=basic. Accessed 9 June 2020
168. Nanomaterials: toxicity and risk assessment—Google Books. https://books.google.co.jp/books?id=ammQDwAAQBAJ&pg=PA18&lpg=PA18&dq=Rodgers,+P.,+Chun,+A.,+Cantrill,+S.,+Thomas,+J.+Editorial,+Small+is+different,+Natur+Nanotechnol.+1,+1,+2006.&source=bl&ots=NX2ybJWdwk&sig=ACfU3U0mIa1_5cq6sbgJJpAeR7SQxHn7Ig&hl=en&sa=X&ved=2ahUKEwjP8L2Kj_TpAhVrw4sBHQE4DLUQ6AEwAHoECAoQAg#v=onepage&q=Rodgers%2CP.%2CChun%2CA.%2CCantrill%2CS.%2CThomas%2CJ.Editorial%2CSmallisdifferent%2CNaturNanotechnol.1%2C1%2C2006.&f=false. Accessed 9 June 2020
169. Chen W, Xiong Q, Ren QX, Guo YK, Li G (2014) Can amino-functionalized carbon nanotubes carry functional nerve growth factor? Neural Regen Res 9:285–292. https://doi.org/10.4103/1673-5374.128225
170. Liu Y, Ren L, Yan D, Zhong W (2014) Mechanistic study on the reduction of SWCNT-induced cytotoxicity by albumin coating. Part Part Syst Charact 31:1244–1251. https://doi.org/10.1002/ppsc.201400145

Forest Resources Resilience and Conflicts

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Chapter 27

Effects of Sonajhuri (*Acacia auriculiformis*) plantation on soil health in Purulia district, West Bengal, India

Manoj Kumar Mahato*, **Narayan Chandra Jana**
Department of Geography, The University of Burdwan, Bardhaman, West Bengal, India
**Corresponding author*

1 Introduction

Due to their multifarious uses, Australian *Acacia auriculiformis* (Sonajhuri) has been widely introduced across the tropics (Tassin, Rangan, & Kull, 2012; Dubliez, Freycon, Marien, Peltier, & Harmand, 2018) for the last 50 years (PROTA, 2016). *A. auriculiformis* species are planted as forestry and agroforestry to increase the soil fertility (particularly nitrogen) to integrate carbon and to restore soil nutrient in the degraded forests and degraded lands (Bernhard-Reversat, 1993; Franco et al., 1994; Parrotta & Knowles, 1999; Fuentes-Ramirez, Pauchard, Cavieres, & Garcia, 2011; Bouillet et al., 2013; Sitters, Edwards, & Venterink, 2013; Permadi, Burtona, Pandita, Walker, & Race, 2017). One of the fastest growing tree species, *A. auriculiformis* is planted for agroforestry, commercial forestry (ISC, 2020), well decoration purposes, fuel, charcoal, and supply of wood (Sitters et al., 2013; Permadi et al., 2017). The presence of nitrogen-fixing species (NFS) similar to the Australian acacias usually increases forest production and crop production at nitrogen deficiency sites (Binkley, 1992; Khanna, 1998; Bouillet et al., 2013; Nambiar & Harwood, 2014; Paula et al., 2015; Dubliez et al., 2018). The Australian *A. auriculiformis* has the ability to sequestrate carbon in both biota and soil that also involved in climate modification (Binkley, 1992; Kaye, Resh, Kaye, & Chimner, 2000; Resh, Binkley, & Parrotta, 2002; Lee, Ong, King, Chubo, & Su, 2015; Forrester, Pares, O'Hara, Khanna, & Bauhus, 2013). However, in some cases, soil carbon storage by this species may not be ensured (Voigtlaender et al., 2012; Oelofse et al., 2016). *A. auriculiformis* species has been most dangerous for soil health and forest ecosystem through reduction of soil moisture, soil fertility, and under growth in Purulia district.

Soil health is considered as an important factor for the improvements of agricultural production (Sarvade et al., 2019). According to FAO (2015), soil health is continued capacity of soil to existing living system, which preserved the biological productivity, environmental excellence, and promotes the plant and animal health. Healthy soil helps to maintain soil biota and plant life, decompose organic matter, amassment and cycle of water and nutrients, neutralize toxic compounds, soothe microbes, and conserve the quality of water (Slavich, 2001). Due to rapid growth of human population and reduction in land holding, soil health is depleting through overexploitation of land resources and nutrient (Sarvade, Singh, Prasad, & Prasad, 2014).

Agroforestry is considered as a sustainable land use system as it can conserve soil and enrich various properties of soil (physical, chemical, and biological) through multifunctional mechanism (Pandey, 2007; Das, Deb, & Arunachalam, 2011; Anju & Koppad, 2013; Mandal et al., 2013; Sarvade et al., 2014; Guleria et al., 2014; Nair, 2014; Sarvade & Singh, 2014; Berhe & Retta, 2015) (Fig. 27.1). In the tropics, Agroforestry systems can converse land degradation problem through their positive effects on soil (Tornquista, Hons, Feagley, & Haggar, 1999). The amount of litter accumulation, class of litter, frequency of decomposition, and improvement of soil properties are controlled by the kind of tree species, their age, and density. (Isaac & Nair, 2006; Nair, 2007; Xiong, Xia, Li, Cai, & Fu, 2008; Sarvade et al., 2014).

Some of the exotic species, such as *A. auriculiformis*, are more risky among a variety of plant species that can degrade soil health (Kidanu, Mamo, & Stoosnijder, 2005). *A. auriculiformis* competes with different plants to obtain the moisture of soil (Kidanu et al., 2005; Forrester, Theiveyanathan, Collopy,

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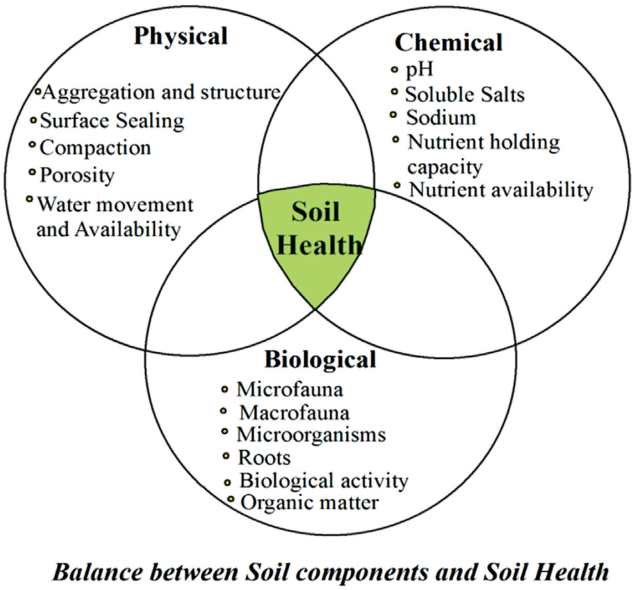

FIGURE 27.1 Relation between soil components and soil health.

& Marcar, 2010; Albaugh, Dye, & King, 2013) and acquires topsoil nutrients (Gupta, 1993; Guo, Sims, & Horne, 2002). Therefore, these species adversely affect biodiversity and can reduce plant diversity (Huttel & Loumeto, 2001). This tendency of plants represents as allelopathy (Lisanework & Michelsen, 1993; Paul, Polglase, Nyakuengama, & Khanna, 2002; Hartemink, 2006; EDDMapS, 2016). Modifications in the structural variety of soil microorganisms (Mycorrhizal fungi and Rhizobia) interrupt the growth of innate plants in Purulia district. *A. auriculiformis* establishes strongly optimistic plant–soil reactions that are essential systems for its further annexation (Gaertner et al., 2014) and indicates the competitive ability as a threat compared to the native plants (Rodriguez-Echeverria, Afonso, Correia, Lorenzo, & Roiloa, 2013). *A. auriculiformis* have also harmful effects on fixates of soil nutrients and neighboring plant species (Liu et al., 2017; Meira-Neto et al., 2018). Often in some water-limited or drought-prone areas, the introduction of exotic NFS species similar to the Australian *A. auriculiformis* can change the seasonal water availability of the soil (Rascher, Grobe-Stoltenberg, Maguas, & Werner, 2011; Siddiq & Cao, 2016).

2 Materials and methods

2.1 Study area

Bounded by the latitudes of 22°40′N to 23°42′N and the longitudes of 85°49′E to 86°54′E, in eastern fringe of the Chota Nagpur Plateau (Fig. 27.2), funnel-shaped Purulia district is located in the westernmost part of the West Bengal. The district is bounded by the state of Jharkhand in north, west, and south; and in eastern part by the districts of Bardhaman, Bankura, and Jhargram of West Bengal, India.

The geological structure of the region has been adorned with various stratigraphic units from the earliest Precambrian (Archaeans) period to younger Tertiary–Quaternary period (Dunn, 1929). From the topographical point of view, this region is very much diversified as it is endowed with numerous dome-shaped inselbergs, escarpments, spurs, undulating upland, and erosional plain (Mahato & Jana, 2019). The elevation of different parts of Purulia ranges between 78 and 699 m above the mean sea level with its much more diversity of the polycyclic landscape through the undulating Archean plateau (Dunn & Dey, 1942). As the Purulia district is a part of the Chota Nagpur granite-gneiss tract, it has not felt any severe diastrophic movement in its prolonged geological history, but it has been greatly affected by the orogenic forces (Dunn, 1929; Singh, 1969; Ray, 1982; Ghosh, 2012). The study area occupies on the eastern edge of the Precambrian granite-gneiss tract of the Chota Nagpur Plateau (Singh, 1969).

Climatologically, Purulia district is characterized by subtropical monsoon type of climate with very high day temperatures during the summer months reaching up to 46°C, whereas the minimum temperature drops to 3°C during the winter months and the region feels the plentiful cool (Bhattacharya et al., 1985; Datta & Chakraborty, 2017). The evaporation rate of the district is very high during the summer months due to mean monthly average temperature of 32°C, while the average monthly temperature in winter months is 11°C. The average long-term annual rainfall between the periods of 1960–61 and 2014–15 is 132 cm of which 80% rainfall occur during June to September (Bhattacharya et al., 1985; Datta & Chakraborty, 2017). The soil of the area is infertile laterite and red gravelly type, which is characterized by infertile, unproductive, erosion prone, lack of soil nutrients, and lower water holding capacity (NBSS & LUP, 2010).

2.2 *Acacia auriculiformis* and its distribution in the district

A. auriculiformis is widely introduced as a commercial plantation to supply different yields such as firewood, charcoal, pulp, and construction equipment; moreover, it is used for soil conservation and ecological restoration (Awang & Taylor, 1993; Franco & de Faria, 1997; Otsamo, Adjers, Hadi, Kuusipalo, & Vuokko, 1997; Midgley & Turnbull, 2003; Eyles et al., 2008; Kull & Rangan, 2008; Coetzee et al., 2011; Hai, Duong, Toan, & Ha, 2015). This tree species was brought to India from Australia in 1946 (Kushalapa, 1991) and planted for forestry to extended monoculture tree plantations. *A. auriculiformis* has been widely cultivated in Purulia district by government and private initiatives for its ability to grow in poor soils. At present, *A. auriculiformis* has been planted in Purulia over an extensive area for vegetation restoration, reduction of

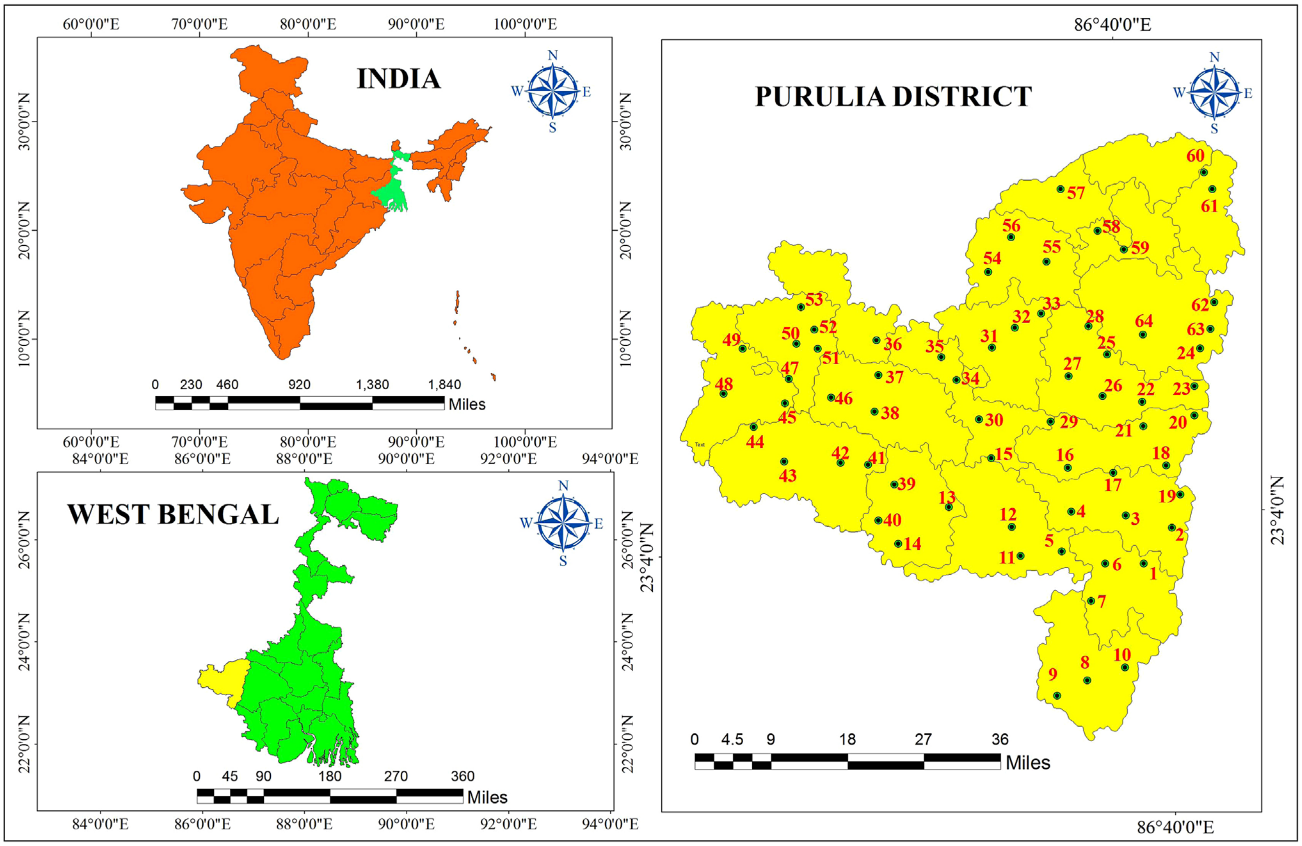

FIGURE 27.2 Location of the study area with 64 soil-sampling sites.

wastelands, conservation of soil, production of pulp, wood, firewood, construction materials, and ornamental purposes (Fig. 27.3 and Table 27.1).

Government and private organizations have taken initiatives for the plantation of *A. auriculiformis* in most of the fallow lands and wastelands of the district for environmental sustainability and its multipurpose uses, but this initiative did not properly address the district's indigenous environment. This species becomes harmful to environment for reduction of soil nutrients, soil moisture, soil fertility, atmospheric moisture, and undergrowth, but recently the rate of *A. auriculiformis* plantation is constantly increasing (Table 27.1).

2.3 Sampling design

Soil samples were taken during November to December 2019 using a 4-cm diameter auger. Samples were collected randomly from four sites under <5, 6–10, 10–15, and >15 years old *A. auriculiformis* plantation area (AG <5, AG 6–10, AG 11–15, and AG >15, respectively) and two sites under the inexistent of *A. auriculiformis* species such as scrub grassland sites and native forest sites. All these sites were selected for exhaustive analysis of the altered chemical properties of topsoil (0–20 cm) and subsoil (20–40 cm). Aboveground litter layer removed before the collection of samples. Samples have been collected from the top layer of soil because this layer is very much affected by the growing vegetation cover (Jobbagy & Jackson, 2001). In total, 64 sample sites [(AG <5)-10, (AG 6–10)-10, (AG 11–15)-10, (AG >15)-10, scrub grassland sites-9 and native forest sites-15] were selected in the study area for testing and validation of chemical characteristics (Fig. 27.2 and Table 27.2). At each site, two samples were taken such as one from topsoil and another from subsoil (n = 2); therefore, total number of sample is 64 × 2 = 128. All the selected sites are located on homogenously well-drained and sandy soils of the rolling plateau fringe and characterized by a gentle to moderately inclined topography (Elevation 157-182 m).

2.4 Analytical methods

Air-dried fine soil samples were taken for testing and analysis of chemical characteristics and charge properties

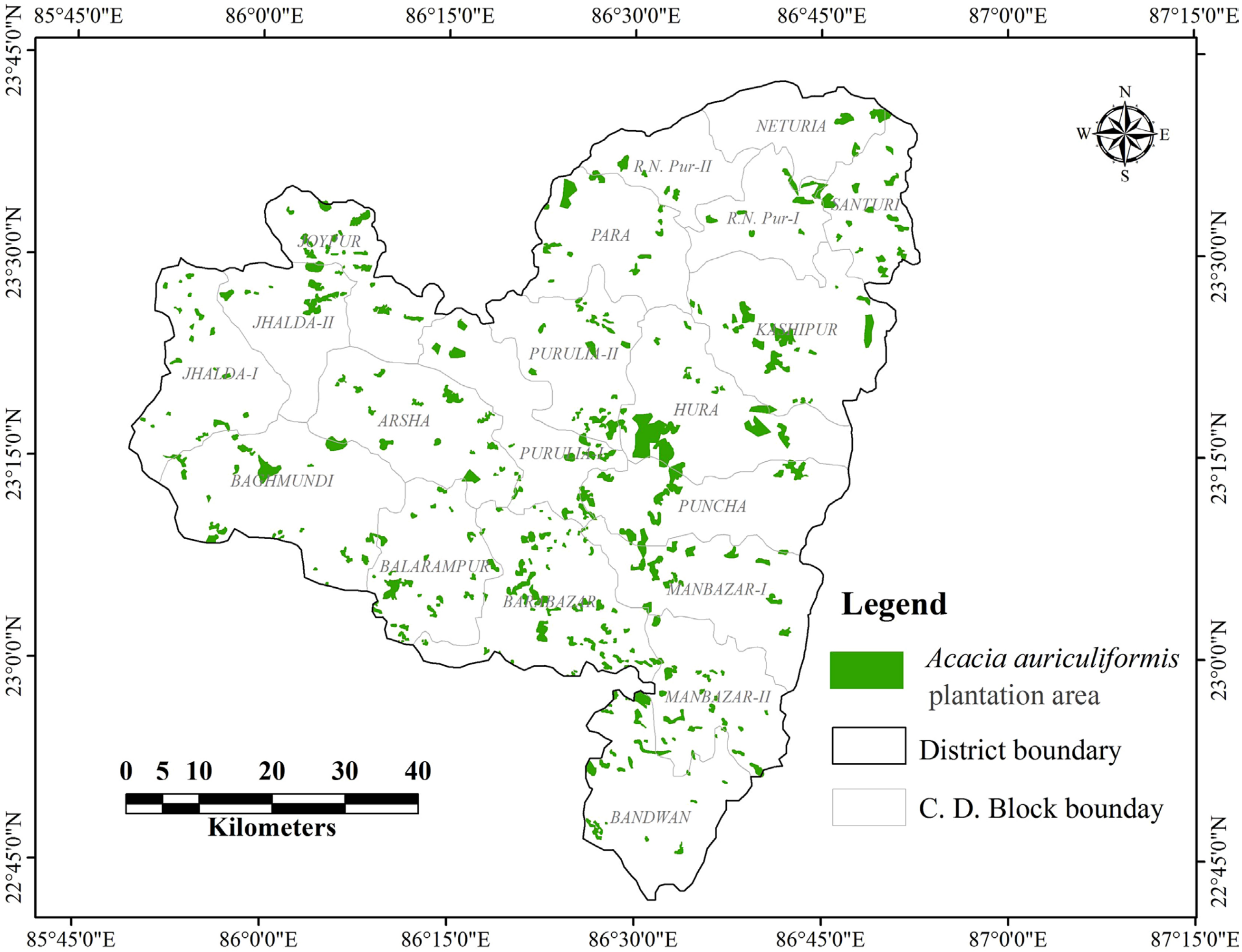

FIGURE 27.3 Spatial distribution of *Acacia auriculiformis* plantation in Purulia district using SOI topographical sheet, new edition in 2010 with the help of Arc-GIS 10.4 software assigning UTM, WGS 1984, 45°N zone projection system.

TABLE 27.1 *Acacia auriculiformis* plantation area and total plantation area of Purulia district during 2004–05 to 2014–15.

Year	Plantation area (ha)	*A. auriculiformis* plantation area (ha)	PS	GR
2004–05	514	381	74.12451362	13.39421613
2005–06	375	260	69.33333333	−31.75853018
2006–07	451	346	76.71840355	33.07692308
2007–08	745	620	83.22147651	79.19075145
2008–09	843	657	77.93594306	5.967741935
2009–10	802	569	70.94763092	−13.39421613
2010–11	971	815	83.93408857	43.23374341
2011–12	1098	746	67.9417122	−8.466257669
2012–13	897	705	78.59531773	−5.495978552
2013–14	1024	768	75.00	8.936170213
2014–15	1105	873	79.00452489	13.671875

Data source of plantation area and *A. auriculiformis* plantation area is Forest Department of Purulia, 2017. The present authors have computed PS and GR. PS—Percentage share of *A. auriculiformis* plantation area to plantation area, that is, PS = *A. auriculiformis* plantation area/plantation area × 100; GR—growth rate of *A. auriculiformis* plantation area, that is, GR = (present−past)/past × 100.

TABLE 27.2 Design of field sampling in Purulia district of West Bengal, India.

Sample sites	Geographical location		Soil weight (g)		Types of sample sites					
					Acacia auriculiformis planting Sites				Scrub and grassland sites	Native forest sites
	Latitude (N)	Longitude (E)	Ts	Ss	AG <5	AG 6–10	AG 11–15	AG >15		
1	22°57′22.476″	86°38′51.368″	371	346			√			
2	23°01′52.773″	86°41′33.841″	320	334					√	
3	23°07′52.073″	86°37′21.563″	311	309						√
4	23°04′58.115″	86°30′06.583″	327	353				√		
5	23°00′02.364″	86°26′24.135″	380	311						√
6	22°58′13.109″	86°34′18.301″	357	329					√	
7	22°54′48.643″	86°30′54.435″	314	367	√					
8	22°48′14.342″	86°31′56.891″	375	340			√			
9	22°46′17.605″	86°28′08.645″	305	304		√				
10	22°51′03.517″	86°37′10.034″	317	347				√		
11	23°00′46.845″	86°23′30.119″	388	357	√					
12	23°05′14.227″	86°23′42.137″	330	349			√			
13	23°06′38.342″	86°18′01.664″	342	320		√				
14	23°03′37.221″	86°12′00.389″	315	326					√	
15	23°10′07.309″	86°20′39.941″	365	367				√		
16	23°08′24.174″	86°29′58.420″	314	340						√
17	23°07′51.145″	86°35′04.169″	309	304			√			
18	23°06′57.701″	86°40′29.036″	327	347	√					
19	23°05′02.327″	86°43′49.187″	325	350						√
20	23°10′24.152″	86°43′39.512″	364	382				√		
21	23°09′51.361″	86°37′50.401″	340	342		√				
22	23°12′48.126″	86°40′01.353″	365	373					√	
23	23°14′00.991″	86°44′00.416″	318	360						√
24	23°17′25.256″	86°44′10.039″	355	330			√			
25	23°18′00.953″	86°37′39.114″	320	342						√
26	23°24′48.655″	86°32′19.540″	334	305	√					
27	23°16′39.607″	86°29′31.733″	350	314				√		
28	23°20′42.943″	86°33′39.206″	382	317		√				
29	23°13′22.258″	86°25′58.307″	342	330	√					
30	23°14′26.722″	86°19′49.858″	373	357						√
31	23°18′28.074″	86°22′56.381″	360	375					√	
32	23°22′14.154″	86°24′47.954″	324	380	√					
33	23°25′55.163″	86°28′01.280″	303	388						√
34	23°18′47.439″	86°17′03.911″	329	320				√		
35	23°21′09.167″	86°16′02.229″	357	313		√				
36	23°23′09.234″	86°11′05.357″	349	367					√	
37	23°19′13.458″	86°11′42.407″	320	351			√			
38	23°14′50.621″	86°11′08.856″	326	344						√
39	23°09′04.375″	86°11′54.502″	310	360						√
40	23°06′24.307″	86°08′05.148″	330	394	√					
41	23°11′40.825″	86°07′51.453″	364	411			√			

(*Continued*)

TABLE 27.2 Design of field sampling in Purulia district of West Bengal, India. (*Cont.*)

Sample sites	Geographical location		Soil weight (g)		Types of sample sites					
					Acacia auriculiformis planting Sites				Scrub and grassland sites	Native forest sites
	Latitude (N)	Longitude (E)	Ts	Ss	AG <5	AG 6–10	AG 11–15	AG >15		
42	23°12′01.004″	86°04′00.579″	345	356				√		
43	23°11′54.908″	85°58′57.388″	351	308					√	
44	23°15′19.642″	85°56′02.173″	322	354						√
45	23°15′56.027″	85°59′57.834″	318	396		√				
46	23°17′00.683″	86°05′51.081″	366	302	√					
47	23°18′17.514″	86°00′03.558″	326	374				√		
48	23°18′38.696″	85°52′58.331″	387	354						√
49	23°23′29.097″	85°56′01.922″	316	405		√				
50	23°21′56.341″	86°01′07.989″	389	327			√			
51	23°20′42.139″	86°05′17.505″	335	338						√
52	23°23′21.877″	86°04′44.112″	305	340	√					
53	23°26′39.972″	86°02′50.542″	322	362			√			
54	23°28′33.156″	86°23′11.934″	370	384						√
55	23°28′39.093″	86°31′52.739″	346	320				√		
56	23°31′01.972″	86°28′00.383″	334	348			√			
57	23°37′00.521″	86°33′56.149″	309	350		√				
58	23°31′48.227″	86°36′04.306″	353	355					√	
59	23°29′40.607″	86°39′52.911″	311	349	√					
60	23°36′08.192″	86°47′01.101″	329	324			√			
61	23°33′03.541″	86°49′54.834″	367	316				√		
62	23°24′44.077″	86°47′39.553″	340	346						√
63	23°20′48.233″	86°46′04.417″	304	305		√				
64	23°20′39.068″	86°40′11.105″	347	385					√	

Ts, Topsoil; *Ss*, subsoil; *AG*, age of *A. auriculiformis* species; √, selected sites for sampling.

with the help of standard procedures followed (Kasongo, Van Ranst, Verdoodt, Kanyankagote, & Baert, 2009). The samples were analyzed for the distribution of particle proportions by pipette method as well as estimation of organic carbon content (C_{org}) by Walkley and Black method, pH (water and KCl extracts 1:2.5), and total nitrogen content (N_{tot}) by macro-Kjeldahl method. Whereas exchangeable base cations (1_M NH_4OAc at pH 7) and cations exchange capacity (CEC_7) were ascertained on combined soil samples as prescribed by Van Ranst, Verloo, Demeyer, & Pauwels (1999). Uehara and Gillman (1980) method has been applied to determine field pH, pH_0, and charge properties of litter samples, and Gillman and Sumpter (1986) improved this method following for pH_0 ascertained, the soil component was Ca^{2+} impregnated and paddled to equilibrium with 0.002 $_M$ $CaCl_2$. The pH is standing to various values in the range from 4.0 to 7.0. In stable condition, the pH assessed and labeled as $pH_{0.002}$ (ratio of soil from solution 1:2.5), where the similar soil sample counterweighted with a 2_M $CaCl_2$ solution and labeled as $pH_{0.05}$. As the pH reacts with the determination of changes in negative and positive charges, the soil is again filled with Ca^{2+} and equilibrated with 0.002_M CaCl2.

Structural proportion of pH (H_2O), pH (KCl), C_{org} (%), N_{tot} (%), and C/N represents in different sites along with successive age of *A. auriculiformis* species.

2.5 Statistical analyses

Major variations in the chemical properties of the soil have been recorded in the *A. auriculiformis* plantation sites of different ages, scrub grassland sites, and native forest sites, identifying by the one-way ANOVA analysis. The variances between the treatments mean values at $P < .05$ significant find out by least significant difference (LSD) test. Pearson's correlation coefficients (PCC = r^2+_) have been calculated to ascertain the correlations between the specific soil characteristics.

3 Results and discussion

3.1 Chemical characteristics of soil

The mean chemical properties of topsoil and subsoil in *A. auriculiformis* plantation areas are shown in Tables 27.3A and B represent the average chemical properties of topsoil and subsoil in scrub grassland sites and native forest sites. Table 27.3A shows that the pH (H_2O) and pH (KCl) of topsoil and subsoil significantly decrease according to different successive ages of plantation field (Fig. 27.4A). Within 10 years, *A. auriculiformis* trees influence a clear acidification of the topsoil of the study area. The average topsoil pH(H_2O) of the 15-year-old *A. auriculiformis* forest is about 5.26, whereas it is about 6.40 under scrub grasslands and about 6.15 under the native forests (Fig. 27.4D).

The main reasons for the soil acidification with decrease in soil pH are organic acids generating from litter and corrosion products of the root or litter extractives (Kasongo et al., 2009). In addition to neutralizing the effects of enhanced N mineralization by nitrification, this study is influenced by the low-solubility macromolecular elements formed by the acidity reduction processes generated beneath the acacia forest. For example, it is seen here that the amount of C_{org} of organic matter in the acacia forest has decreased significantly from 2.92% to 1.94% during the early 6 years of the plantation.

The chronological sequence of *A. auriculiformis* species also highlights an important and uninterrupted decline in C_{org} and N_{tot} content over a period of 15 years (Fig. 27.4B and C). As estimated, the availability of organic components is mostly influenced in the topsoil, as a result about 252% decreases of the C_{org} content following 15 years of *A. auriculiformis* plantation. A major fluctuation in the C_{org} matters of together the topsoil (2.92%) and subsoil (1.31%) is existent during 5 years. During 6–10 years old *A. auriculiformis* fields, the C_{org} matters double to achieve moderately high heights in the topsoil (around 1.94%), while more than 15 years oldest *A. auriculiformis* fields are characterized by low C_{org} matters (1.16% and 0.77% in the topsoil and subsoil, respectively).

TABLE 27.3(A) Average pH (H_2O), pH (KCL), C_{org} (%), N_{tot} (%), and C/N ratio of topsoil and subsoil under the *Acacia auriculiformis* plantation sites of cumulative age.

Soil situation	Age of the plant species	*A. auriculiformis* plantation sites				
		pH(H_2O)	pH(KCL)	C_{org} (%)	N_{tot} (%)	C/N
Topsoil (0–20 cm)	AG <5	6.13c	6.01b	2.92d	0.280d	10a
	AG 6–10	5.77b	5.62ab	1.94c	0.186c	10a
	AG 10–15	5.51ab	5.34ab	1.87b	0.080b	11b
	AG >15	5.26a	5.19a	1.16a	0.045a	15c
	Average	5.67a	5.54ab	1.97c	0.148c	12b
Subsoil (20–40 cm)	AG <5	5.94b	5.87b	1.31c	0.100b	13a
	AG 6-10	5.82ab	5.60ab	1.00b	0.080b	13a
	AG 10-15	5.59ab	5.38a	0.97b	0.080b	12a
	AG >15	5.22a	5.14a	0.77a	0.040a	19b
	Average	5.64ab	5.49a	1.01b	0.075b	14a

TABLE 27.3(B) Average pH(H_2O), pH(KCL), C_{org} (%), N_{tot} (%), and C/N ratio of topsoil and subsoil under the scrub grassland sites and Native forest sites.

Soil situation	Scrub grassland sites					Native forest sites				
	pH (H_2O)	pH (KCL)	C_{org} (%)	N_{tot} (%)	C/N	pH(H_2O)	pH(KCL)	C_{org} (%)	N_{tot} (%)	C/N
Topsoil (0–20 cm)	6.39c	6.22c	3.02e	0.341e	9a	6.15c	6.31c	4.15e	0.414e	10a
Subsoil (20–40 cm)	6.24c	6.17c	2.97d	0.284d	11a	6.02c	6.12c	3.78e	0.311e	11a

pH (H_2O) and pH(KCL)—pH of water and KCl extracts 1:2.5; C_{org}—organic carbon content; N_{tot}—total nitrogen content. All the values followed by different letters are statistically significantly different ($P < .05$).

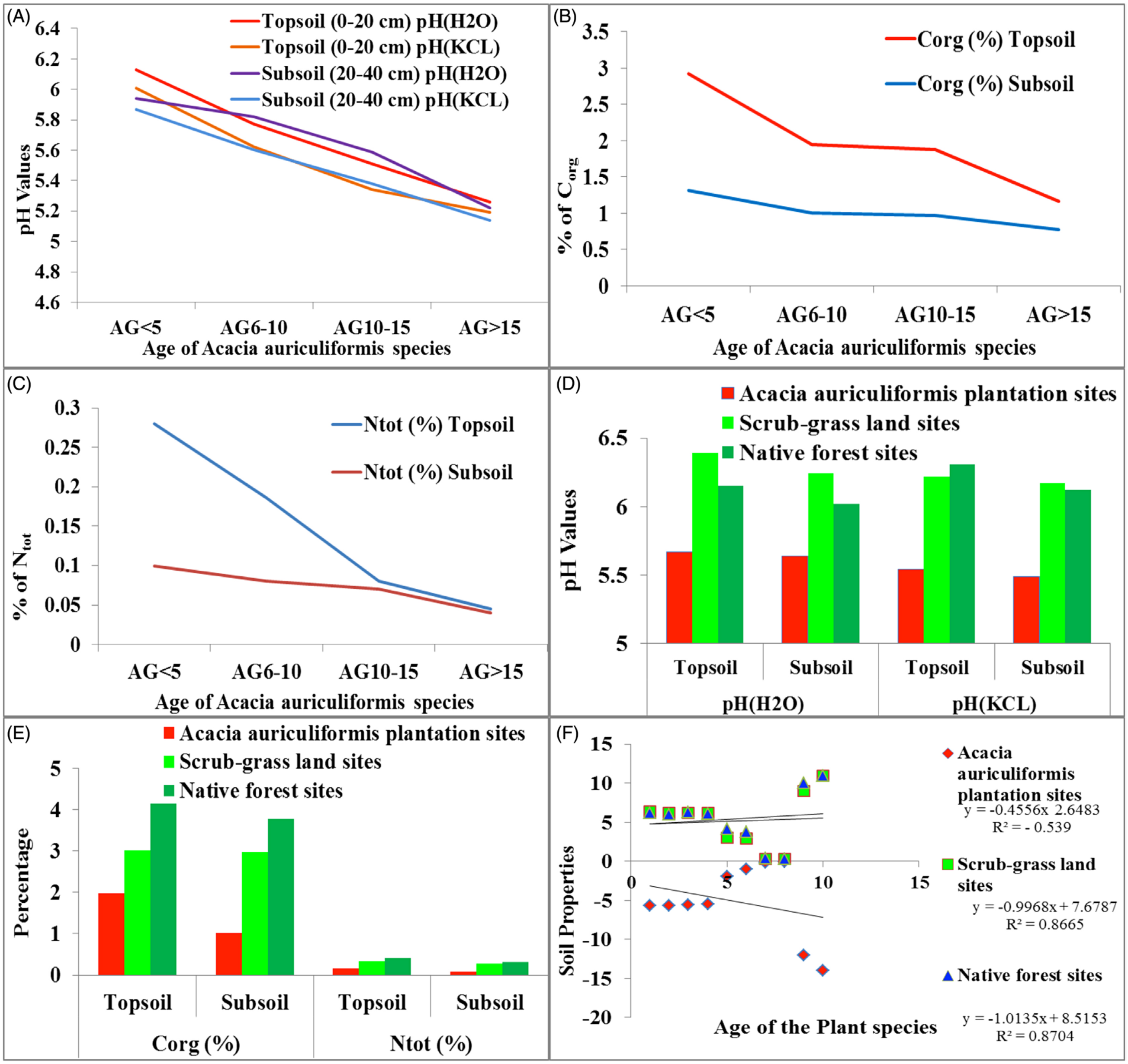

FIGURE 27.4 Graphical representation of various soil properties of different sites. (A) pH (H_2O) and pH (KCL) status of topsoil and subsoil in different ages of *Acacia auriculiformis* sites; (B) decreasing C_{org} in topsoil and subsoil of different ages of *A. auriculiformis* sites; (C) decreasing N_{tot} in topsoil and subsoil of different ages of *A. auriculiformis* sites; (D) comparison of pH values between different sites; (E) comparison of C_{org} and N_{tot} content between different sites; (F) correlation between ages of different plantation sites and chemical properties of soil.

The amounts of C_{org} and N_{tot} content in the scrub grassland sites and native forest sites are significantly higher than *A. auriculiformis* sites (Fig. 27.4E). The average C_{org} content of *A. auriculiformis* sites of topsoil and subsoil are 1.97% and 1.01%, respectively, where scrub grassland sites are 3.02% and native forest sites are 4.15%. On the other hand, the N_{tot} content of topsoil in scrub grassland sites are 0.341% and native forest sites are 4.15%, which are specifically better than the *A. auriculiformis* sites. The pH values of native forest sites and scrub grassland sites are characterized as neutral (Fig. 27.4D).

In all soil samples, the pH (H_2O) values are higher than the pH(KCl) signifying a clear adverse charge. Besides, the C_{org} matters is very ominously ($P < .01$) absolutely interrelated with the cation exchange capacity (Pearson product moment correlation values are *A. auriculiformis* sites, $r^2 = -0.539$; scrub grassland sites $r^2 = 0.8665$; native forest sites $r^2 = 0.8704$; (Fig. 27.4F), which aids from the supplementary supply of pH-dominated charged colloidal measurable.

3.2 The effects of density and canopy of *Acacia auriculiformis* species on soil C and N

Increasing density of *A. auriculiformis* species is associated with the soil nitrogen (N) and carbon (C) (Belsky, Mwonga, Amundson, Duxbury, & Ali, 1993; Ludwig, de Kroon, Berendse, & Prins, 2004; Hagos & Smit, 2005; Sitters et al., 2013) (Fig. 27.4; Tables 27.3A and B). The abundance of *A. auriculiformis* is the root cause of decreases in C_{org} and N_{tot} contents, which is also the cause of variances in soil nutrients. Primarily, the topsoil underneath in tree canopies of acacia is depriving the C_{org} and N_{tot} in all sites, which would expect given that all sites were of different ages. On the other hand, the relationship among the soil C and N and tree thickness outside the canopy of *A. auriculiformis* is significantly positive; it reflects the reality that the distance to the adjacent tree decreases with increasing density. Second, general decreases in C_{org} and N_{tot} along the density incline of acacia forest, and the soil C_{org} and N_{tot} values indicate decreasing ratio of soil C and N generating from the trees.

Binkley (2005) suggested that N-enhancement by N-fixing plants could cause fluctuations in the slow-moving soil-microbial community of organic matter; this process can account for the addition of C along the density gradient of the tree. In the scrubs and native forestlands, the N enhancement processes stabilized in this effect, but *A. auriculiformis* species become oppositely effects on microbial community. Therefore, the present authors have strongly standardized that the density and canopy of scrubs and native forest is better than the *A. auriculiformis*.

3.3 Effect of *Acacia auriculiformis* in Purulia

The widespread invasion of *A. auriculiformis* in different parts of the world has caused an overall conflict of focus on the positive and negative effects of the species (Kull & Rangan, 2008; Richardson & Rejmanek, 2011; Wilson et al., 2011; Tassin et al., 2012; Ismael & Metali, 2014; Aguiar, Barbosa, Barbosa, & Mourao, 2014; Souza, Chaves, Barbosa, & Clement, 2018). The multipurpose use of this species is socially and economically very much important (ISC, 2020). In spite of several described benefits of *A. auriculiformis* in forestry, agroforestry, and agricultural systems, there is growing evidence for the causes of its detrimental properties, as this species can have penetrating negative effects on biodiversity, soil health, and human well-being (Richardson & Rejmanek, 2011; Attias, Ferreira Siqueira, & de Godoy, 2013; Koutika & Richardson, 2019). However, *A. auriculiformis* have restrictions for enhancing forest productivity, restoring C and N, and soil fertility and controlling the degraded land restoration (Koutika & Richardson, 2019). The authors did not endorsed *A. auriculiformis* for reclamation of degraded land in Purulia, because of its restricted performance with reference to most of the variables that have been measured. In the same way, Parrotta and Knowles (1999) suggested that the defective capability of fast growing species (such as acacia and eucalyptus species) does not support in the successional processes of Brazil (Koutika & Richardson, 2019).

Initiatives have been taken for the cultivation of *A. auriculiformis* species to reclaim wastelands and fallow lands in Purulia, but these initiatives are not reducing the wastelands rather accelerates the same. This species becomes harmful for the environment of Purulia due to destroyed ecosystem facilities, habitat variation, monoculture formation, reform of successional arrangements, infrastructure damage, reduced natural biodiversity, damage of native species, and risk to endangered species. A huge plantation of fast-growing Australian acacia species on the wastelands of Purulia has omitted internal breeding of bird species (Chowdhury, 2019). *A. auriculiformis* plantation in Purulia is greatly reducing the number of native plant species (Mallick, 2018). Such findings show that extensive plantation of Australian *A. auriculiformis* is harmful in outside their native range, such as Purulia.

3.3.1 Negative effects on soil

Variations in the capable variability of microorganisms existing in soil (rhizobia and mycorrhizal fungi) inhibiting the growth of native flora species, while restoring wastelands and degraded lands in Purulia district with Australian *A. auriculiformis*. The other *Australian acacia* species of the district are *Akashmoni* and *Australian babul* (ISC, 2020), recognized optimistic plant-soil responses, which are significant materials for its additional annexation (Gaertner et al., 2014), indicated a tough antagonistic capability comparative to the native plant species. Australian *A. auriculiformis* has deleterious effects soil nutrients absorptions by neighboring plants (Liu et al., 2017; Meira-Neto et al., 2018). In early incursion stage, *A. auriculiformis* is capable to absorb the nitrogen in both soil and leaf, enhance canopy layers, and facilitate an extensive range of light difference that is helped by the nitrogen received and shifted to neighboring plants (Meira-Neto et al., 2018).

Planting of *A. auriculiformis* and native mixed tree species [like *Butea frondosa* (Palash), *Bassia latifolia* (Mohul), and *Shorea robusta* (Sal)] in the wastelands and degraded forestlands of Purulia district, soil N, C, and P accessibility declined in the topsoil of pure acacia sites compared to native mixed forest at the completion of the first 10-year cycle. In Purulia, native tree accumulated greater amounts of P and N via litter, although the opposite picture can be seen in *A. auriculiformis* (Santos, Balieiro, Fontes, & Chaer, 2017) (Fig. 27.5). In subtropical Purulia, the NFS

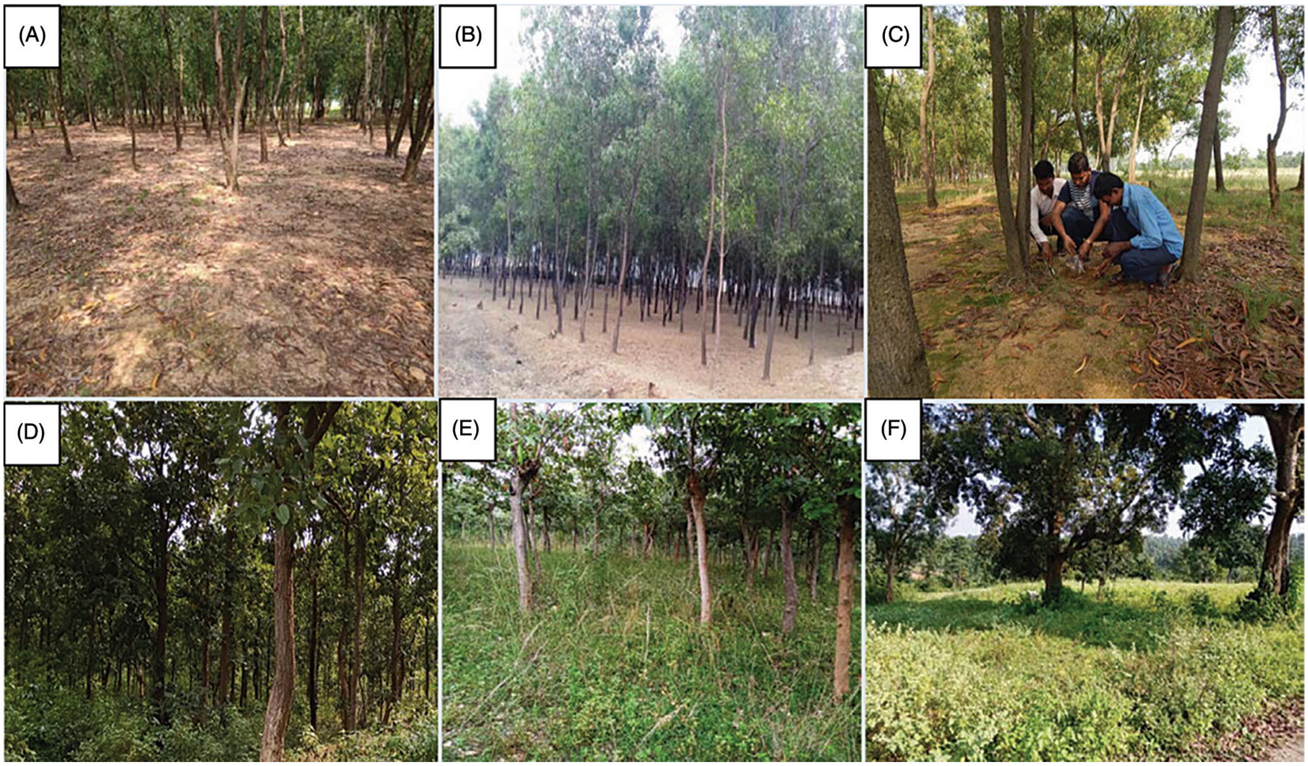

FIGURE 27.5 Field photographs exhibiting different kinds of canopy cover. (A) More than 10-year-old acacia forest of Kulabahal mouza under the Racab reserve forest, (B) *Acacia auriculiformis* plantation in Kantadih mouza of Balarampur forest range, and (C) collection of soil sample during from 10 to 15-year-old acacia forest in Simni mouza of Kotshila forest range. A–C represent alien species with no undergrowth under the canopy layer. (D) Sal forest of Ajodhya protected forest, (E) Arjun plantation in Seja mouza of Hura forest range, and (F) high scrub and undergrowth under the native Kusum tree in Kalimati mouza of Baghmundi forest range. D–F are native species, showing high undergrowth and balanced plant ecology under the forest.

such as *Albizia lebbek* (Siris), *B. frondosa* (Palash), *Terminalia arjuna* (Arjun), and *Lagerstroemia parviflora* (Sidha) have higher P storage ability rather than non-NFS (Begum, Pramanick, Mukhopadhyay, & Majumdar, 2020). These studies may reveal the potential risk of fluctuating from N limitation to soil P restraint in long term involved in reducing forest productivity. It is to be mentioned that *A. lebbek*, *B. frondosa*, *L. parviflora* plantations will be mostly benefited for the subtropical climate and nutrient-poor soil of Purulia (Fig. 27.6B), wherein N is the utmost inadequate nutrient and P accessibility is attenuate by forcible exploitation because of the huge quantities of Al and Fe oxide

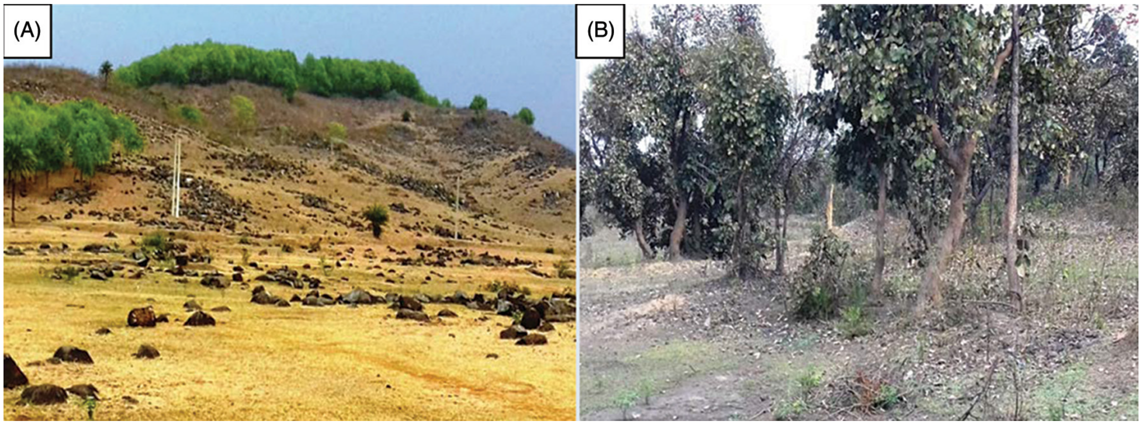

FIGURE 27.6 Different forest ecosystem of Purulia district. (A) *Acacia auriculiformis* Plantation on Maguria Pahar (hill) in Hura C. D. Block. This type of plantation promotes soil erosion and increases rocky field. (B) *Butea frondosa* (*Palash*) in Shyamalota mouza of Hura C.D. Block is an indigenous species of the study area. Palash is beneficial as it promotes undergrowth, increases soil moisture, soil organic matter. In Purulia, lac is cultivated in Palash tree, but the hard reality is that this tree is gradually being replaced by *A. auriculiformis*.

in maximum of subtropical soils. *A. auriculiformis* species help to increase the erosion rather than conservation (Fig. 27.6A) of soil in the study area due to reducing water availability of soil layers and absence of undergrowth.

3.3.2 Negative effects on biodiversity

In Purulia, the diversity and density of macroinvertebrates in the topsoil of native forests deliberate as moderate to lower (Begum, Pramanick, Mukhopadhyay, & Majumdar, 2020), and changes in other forms of land use in this ecosystem can drastically change their population. The macroinvertebrates of soil is an impressible indicator of natural systems and management, and it has a greater copiousness and multiplicity in the agroforestry methods compared to the other types of agricultural land use. Forestry and agroforestry plantations are mostly established in wastelands and degraded forestland of Purulia district that are extremely vulnerable to invasions of exotic trees. Australian *A. auriculiformis* can easily invade the degraded native forests that are suffering from water shortage and drought condition (Osunkoya, Othman, & Kahar, 2005). Attack of *A. auriculiformis* is supplementary with the modifications of biodiversity (ISC, 2020).

The spread of the *A. auriculiformis* trees on the native plants is identified as a specific threat to some infrequent species and their homes in Purulia. This species has invaded degraded forestlands, wasted areas, forestlands, and scrub in Purulia district and changed plant communities by shifting native plants. However, *A. auriculiformis* planting is taking place extensively across the district resulting in declining of soil moisture and rapid rise in temperature, which significantly effects on soil macrofauna community. This species is causing serious damage to lac insects and lac cultivation in the district. Lac insects require certain specific plant species (Modak & Basu, 2011) like *B. frondosa* (Palash), *Schleichera trijuga* (Kusum), and *Zizyphus xylopyra* (Kul) to survive. This species has an extensive range of effects on ecosystems, which is increasing with time and instability and habitually transforming into ecological activities, in that way changing and decreasing the delivery of ecosystem services.

3.3.3 Negative effects on water availability

In various parched and water inadequate parts of the tropics, initiating exotic NFS such as Australian *A. auriculiformis* may change patterns the seasonal water use (Rascher et al., 2011; Siddiq & Cao, 2016). The introduction of fast growing species *A. auriculiformis* and eucalyptus consumes abundant water rather than other native trees and forests. The roots of the *A. auriculiformis* tree can absorb water from far below the soil layer and have a higher rate of transpiration than other native trees. As a result, in the *A. auriculiformis* fields of the district, both the topsoil and subsoil layers exposed to this water crisis, which complicates the survival of the native species. Therefore, the 10-year-old fields of this species do not have any types of undergrowth (Fig. 27.5A–C). The *A. auriculiformis* species reduces the amount of moisture in the lower air, so the number of microscopic fauna species and different birds in these fields is much lower.

4 Risk assessment and remediation

Species such as the Australian *A. auriculiformis* have been extensively planted outside their native range for decades, which have become aggressive and have the negative impact on the environment. Attacks and related impacts naturally manifest only several decades after planting this species in large scale (Richardson, Le Roux, & Wilson, 2015; Koutika & Richardson, 2019). Outside of the native environment, this species has a definite detrimental effect on ecosystem and biodiversity (Wilson et al., 2011; Low, 2012; Attias et al., 2013; Sampaio & Schmidt, 2013; Aguiar et al., 2014; Richardson et al., 2015; Nambiar, Harwood, & Mendham, 2018).

From the experience of long history of planting *A. auriculiformis* in Purulia district, three key issues will need careful attention while considering *A. auriculiformis* invasive and management issues: (1) the role of habitation time and offensive debate, (2) harmful chemical effects of the environment, and (3) biological control.

Proper management of plantation can control invasions of *A. auriculiformis* into subtropical forests of Purulia and observing of soil seed stores, but no such evidence is found there. However, it is possible to maintain the nutrition balance and sustainability of the environment through appropriate remediation in the areas affected by *A. auriculiformis*.

- The principal remediation would be to develop practices to limit the damage of most important nutrient properties from the agroforestry scheme. The branches and bark of *A. auriculiformis* contain significant amount of nutrients, particularly Ca, C, and N (Louppe, Ouattara, & Oliver, 1998; Mendham, O'connell, Grove, & Rance, 2003; Nambiar & Harwood, 2014). Therefore, those parts have to be left in the cutting sites for process of decomposition, which will provide nutrients to the soil.
- A second remediation is the residue obtained after charcoal burning will have to be returned to the *A. auriculiformis* fields. This practice has been observed in some of the degraded fields after cutting the acacia trees, which are now being promoted to recover the physical and chemical properties and improve the efficiency of tropical soils. For the positive role on the physical and chemical properties of the soil, it is necessary to use charcoal in acacia fields (Glaser, Lehmann, & Zech, 2002), which is also increased the water holding capacity of soil (Glaser et al., 2002; Glaser & Birk, 2012).

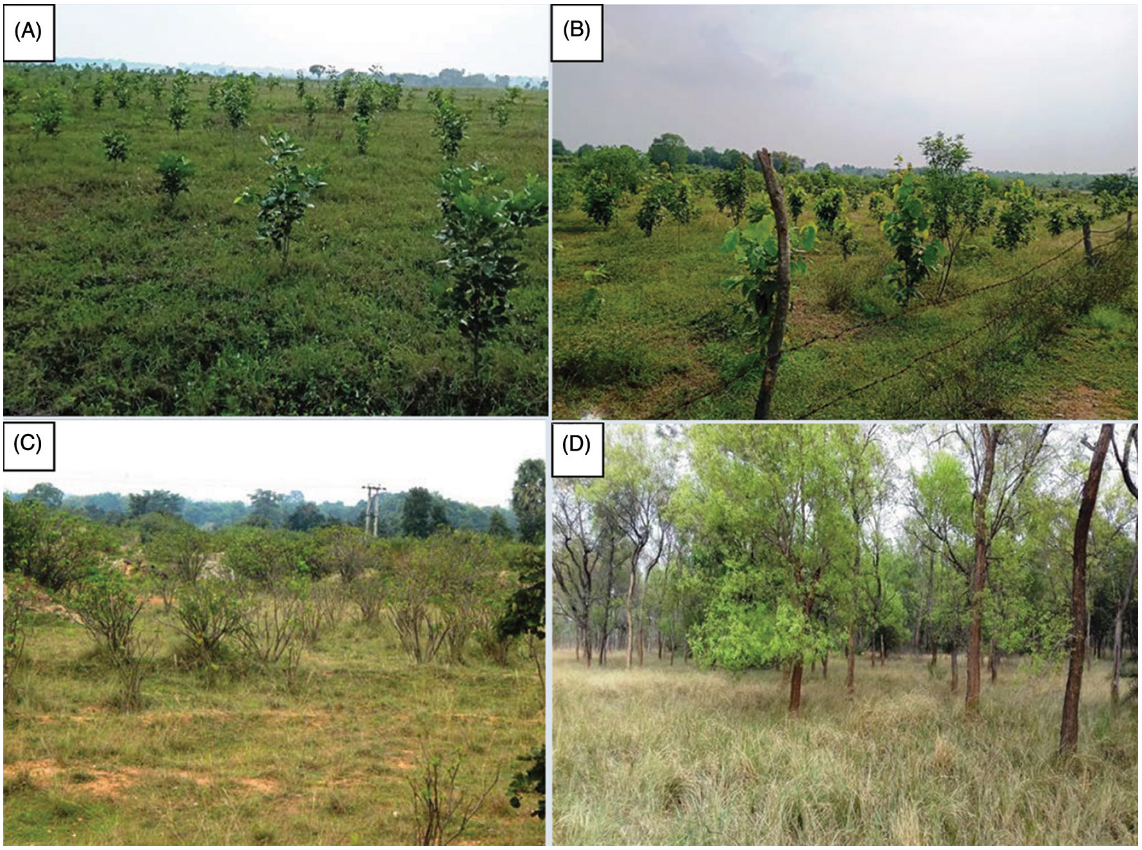

FIGURE 27.7 Forestry of native species. (A) *Carissa spinarum* (*Karamcha*) plantation in Dumdumi mouza of Purulia-I C.D. Block, (B) *Shorea robusta* (*Sal*) plantation in Chepua mouza of Manbazar-I C.D. Block, (C) Jatropha plantation in vast wasteland of Kulabahal mouza of Purulia-II C.D. Block for the reduction of wasteland and improvement of soil properties, (D) *Dalbergia sissoo* (*Shisham*) trees with undergrowth in Durmut mouza of Raghunathpur-I C.D. Block, which is gradually becoming rare in Purulia. These trees can be grown up in less amount of water.

- The restoration of minor biomass parts (leaves, twigs, and small branches) for the tree growing and production during the second tree rotation.
- In the second rotation of planting, instead of the *A. auriculiformis*, native species such as *Dalbergia sissoo* (Shisham), *B. frondosa* (Palash), *S. trijuga* (Kusum), *Z. xylopyra* (Kul), *B. latifolia* (Mohul), *S. robusta* (Sal), and *Carissa spinarum* (Karamcha) should be planted (Fig. 27.7), which can survive with less water. These native plants can increase biodiversity and conserve soil nutrients.
- Initiatives are needs for the genetic improvement of the *A. auriculiformis* trees that can genetically modify the seeds so that they provide nutrients to the soil and does not destroy native plants.

5 Conclusion

A valuable fast-growing species, *A. auriculiformis* has obvious benefits in economic and social perspectives for fuel wood, charcoal, timber, and ornamental purposes, but the species has the major negative effects on biodiversity and ecosystem functioning when it becomes more than 10 years old. In Purulia, with the increasing age, the *Acacia* species becomes increasingly detrimental to soil health. However, it is possible to bring back the soil nutrients in the acacia field through use of charcoal ash. As a result, the balance between soil physical, chemical, and biological components will be maintained and water-holding capacity will be increased. Finally, the authors have suggested that the most important way to protect the soil health and reclaim the wasteland in Purulia district is afforestation and reforestation of native plant species.

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References

Aguiar, A., Barbosa, R. I., Barbosa, J. B. F., & Mourao, M. J. (2014). Invasion of *Acacia mangium* in Amazonian savannas following planting of forestry. *Plant Ecology & Diversity*, *7*(1–2), 359–369. https://doi.org/10.1080/17550874.2013.771714.

Albaugh, J. M., Dye, P. J., & King, J. S. (2013). Eucalyptus and water use in South Africa. *International Journal of Forestry Research,* (852540), 2013 (1–11). https://doi.org/10.1155/2013/852540.

Anju, S. V., & Koppad, A. G. (2013). Influence of in situ soil moisture conservation measures on growth and productivity of *Acacia auriculiformis*. *Karnataka Journal of Agricultural Sciences*, *26*(1), 170–171. http://14.139.155.167/test5/index.php/kjas/article/viewFile/6785/7005.

Attias, N., Ferreira Siqueira, M., & de Godoy, B. H. (2013). Acacias Australianas no Brasil: Historico, Formas de Uso e Potencial de Invasao. *Biodiversidade Brasileira*, *3*(2), 74–96. https://www.icmbio.gov.br/revistaeletronica/index.php/BioBR/article/view/321.

Awang, K., & Taylor, D. (1993). *Acacia mangium*, growing and utilization. In *MPTS monograph series no. 3.* Bangkok, Thailand: FAO and Winrock international. https://agris.fao.org/agris-search/search.do?recordID=XF2015006354.

Begum, M., Pramanick, N., Mukhopadhyay, A., & Majumdar, S. D. (2020). Chapter 13: Scenarios of the tropical dry forest of Purulia district West Bengal: A CA-MARKOV model approach. In: Handbook of research on the conservation and restoration of tropical dry forests. IGI GLOBAL (pp. 254–267). Available from https://DOI:10.4018/978-1-7998-0014-9.

Belsky, A. J., Mwonga, S. M., Amundson, R. G., Duxbury, J. M., & Ali, A. R. (1993). Comparative effects of isolated trees on their under canopy environments in high-rainfall and low-rainfall savannas. *Journal of Applied Ecology*, *30*, 143–155. https://DOI:10.2307/2404278.

Berhe, D. H., & Retta, A. N. (2015). Soil improvement by trees and crop production under tropical agroforestry systems: A review. *Merit Research Journal of Agricultural Science and Soil Sciences*, *3*(2), 18–28. https://www.academia.edu/11450996/Soil_ Improvement_by_Trees_and_Crop_Production_under_Tropical_Agroforestry_Systems_A_Review.

Bernhard-Reversat, F. (1993). Dynamics of litter and organic matter at the soil-litter interface of fast-growing tree plantations on sandy ferrallitic soils (Congo). *Acta Ecologica*, *14*(2), 179–195. https://ci.nii.ac.jp/naid/20001339893.

Bhattacharya, B. K., Ray, P., Chakraborty, B. R., Sengupta, S., Sen, N. N., Sengupta, K. S., et al. (1985). In *West Bengal District Gazetteers, Purulia, Government of West Bengal.* West Bengal District Gazetteers, Calcutta: Narendra Nath Sen, State Editor. 2005. Available from www.wbpublibnet.gov.in.

Binkley, D. (1992). Mixtures nitrogen-fixing and non-nitrogen-fixing tree species. In M. G. R. Cannell, D. C. Malcolm, & P. A. Robertson (Eds.), *The ecology of mixed-species stands of trees* (pp. 99–124). Oxford: Blackwell.

Binkley, D. (2005). How nitrogen-fixing trees change soil carbon. In D. Binkley, & O. Menyailo (Eds.), *Tree species effects on soil: Implications for global change* (pp. 155–164). Dordrecht: Springer. https://link.springer.com/chapter/10.1007/1-4020-3447-4_8.

Bouillet, J. P., Laclau, J. P., Gonçalves, J. L. M., Voigtlaender, M., Gava, J. L., Leite, F. P., et al. (2013). *Eucalyptus* and *Acacia* tree growth over entire rotation in single- and mixed-species plantations across five sites in Brazil and Congo. *Forest Ecology Management*, *301*, 89–101. https://DOI:10.1016/j.foreco.2012.09.019.

Chowdhury, S. (2019). Causes of migratory birds' populations decline in Purulia district, West Bengal, India. *International Journal of Scientific Research in Multidisciplinary Studies*, *5*(8), 159–164. Available online at: www.isroset.org.

Coetzee, M. P. A., Wingfield, B. D., Golani, G. D., Tjahjono, B., Gafur, A., & Wingfield, M. J. (2011). A single dominant *Ganoderma* species is responsible for root rot of *Acacia mangium* and *Eucalyptus* in Sumatra. *Southern Forests: A Journal of Forest Science*, *73*(3–4), 175–180. https://doi.org/10.2989/20702620.2011.639488.

Das, K., Deb, S., & Arunachalam, A. (2011). Effect of earthworm and plant residues for soil enrichment under agroforestry systems for north-east India. *Indian Journal of Soil Conservation*, *39*(1), 73–79. https://www.indianjournals.com/ijor.aspx?target=ijor:ijsc&volume=39&issue=1&article=013.

Datta, S. K., & Chakraborty, T. (2017). *District statistical handbook, Purulia, bureau of applied economics & statistics, department of planning, statistics & programme monitoring*. Government of West Bengal. http://www.purulia.gov.in/distAdmin/departments/baes/baes.html.

Dubliez, E., Freycon, V., Marien, J. M., Peltier, R., & Harmand, J. M. (2018). Long term impact of *Acacia auriculiformis* woodlots growing in rotation with cassava and maize on the carbon and nutrient contents of savannah sandy soils in the humid tropics (Democratic Republic of Congo). *Agroforestry Systems*, *93*, 1167–1178. https://doi.org/10.1007/s10457-018-0222-x.

Dunn, J. A., & Dey, A. K. (1942). The geology and petrology of eastern Singhbhum and surrounding areas. In *Memoirs of the Geological Survey of India* (pp. 281–456). (Vol. LXIX). Calcutta: Govt. of India Press. 2.

Dunn, J. A. (1929). The geology of North Singhbhum, including parts of Ranchi and Manbhum districts. In *Memoirs of the Geological Survey of India* (Vol. 54). Calcutta: Govt. of India Press. http://www.worldcat.org/oclc/752645393.

EDDMapS. (2016). *Early detection and distribution mapping system*. Georgia, USA: University of Georgia-Center for Invasive Species and Ecosystem Health. http://www.eddmaps.org/.

Eyles, A., Beadle, C., Barry, K., Francis, A., Glen, M., & Mohammed, C. (2008). Management of fungal root-rot pathogens in tropical *Acacia mangium* plantations. *Forest Pathology*, *38*, 332–355. https://doi.org/10.1111/j.1439-0329.2008.00549.x.

FAO. (2015). In *Healthy soils are the basis for healthy food production* (pp. 4). Rome, Italy: FAO.

Forrester, D. I., Pares, A., O'Hara, C., Khanna, P. K., & Bauhus, J. (2013). Soil organic carbon is increased in mixed-species plantations of *Eucalyptus* and nitrogen-fixing *Acacia*. *Ecosystems*, *16*, 123–132. https://DOI:10.1007/s10021-012-9600-9.

Forrester, D. I., Theiveyanathan, S., Collopy, J. J., & Marcar, N. E. (2010). Enhanced water use efficiency in a mixed *Eucalyptus globulus* and *Acacia mearnsii* plantation. *Forest Ecology and Management*, *259*(9), 1761–1770. https://doi.org/10.1016/j.foreco.2009.07.036.

Franco, A. A., & de Faria, S. M. (1997). The contribution of N2-fixing tree legumes to land reclamation and sustainability in the tropics. *Soil Biology and Biochemistry*, *29*, 897–903. https://DOI:10.1016/S0038-0717(96)00229-5.

Franco, A. A., Campello, A. F. C., Dias, L. E., & de Farla, S. M. (1994). Revegetation of acidic residues from bauxite mining using nodulated and mycorrhizal legume trees. In: *Proceedings nitrogen-fixing tree* (pp. 313–320). Turrialba.

Fuentes-Ramirez, A., Pauchard, A., Cavieres, L. A., & Garcia, R. A. (2011). Survival and growth of *Acacia dealbata* vs. native trees across an invasion front in south-Central Chile. *Forest Ecology and Management*, *261*, 1003–1009.

Gaertner, M., Biggs, R., Te Beest, M., Hui, C., Molofsky, J., & Richardson, D. M. (2014). Invasive plants as drivers of regime shifts: Identifying high priority invaders that alter feedback relationships. *Diversity and Distributions*, *20*, 733–744. https://doi.org/10.1111/ddi.12182.

Ghosh, S. (2012). Geomorphic land evaluation for sustainable use of land resources in Purulia district, West Bengal. *Journal of Landscape Systems and Ecological Studies*, *35*(1), 263–274.

Gillman, G., & Sumpter, E. (1986). Modification to the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soil Research*, *24*, 61–66. https://doi.org/10.1071/SR9860061.

Glaser, B., & Birk, J. J. (2012). State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). *Geochimica et Cosmochimica Acta*, *82*, 39–51. https://DOI:10.1016/j.gca.2010.11.029.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal a review. *Biology and Fertility of Soils*, *35*(4), 219–230. https://link.springer.com/article/10.1007/s00374-002-0466-4.

Guleria, V., Vashisht, A., Gupta, A., Salven, T., Thakur, C., & Kumar, P. (2014). Carbon stocks and soil properties under nitrogen-fixing trees on degraded site in subtropical Himalayan region. *Indian Journal of Soil Conservation*, *42*(3), 293–297. https://www.researchgate.net/publication/326785504.

Guo, L. B., Sims, R. E. H., & Horne, D. J. (2002). Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand I: Biomass and nutrient accumulation. *Bioresource Technology*, *85*(3), 273–283. https://doi.org/10.1016/S0960-8524(02)00118-9.

Gupta, R. K. (1993). *Multipurpose trees for agroforestry and wasteland utilization*. New York, USA: International Science Publisher. https://books.google.co.in/books/about/Multipurpose_trees_for_agroforestry_and.html?id=QvPwAAAAMAAJ&redir_esc=y.

Hagos, M. G., & Smit, G. N. (2005). Soil enrichment by *Acacia mellifera* subsp. *detinens* on nutrient poor sandy soil in a semi-arid southern African savanna. *Journal of Arid Environ*, *61*, 47–59. https://doi.org/10.1016/j.jaridenv.2004.08.003.

Hai, P. H., Duong, L. A., Toan, N. Q., & Ha, T. T. T. (2015). Genetic variation in growth, stem straightness, pilodyn and dynamic modulus of elasticity in second-generation progeny tests of *Acacia mangium* at three sites in Vietnam. *New Forest*, *46*, 577–591. https://doi.org/10.1007/s11056-015-9484-6.

Hartemink, A. E. (2006). Assessing soil fertility decline in the tropics using soil chemical data. *Advances in Agronomy*, *89*, 179–225. https://agris.fao.org/agris-search/search.do?recordID=US201301096573.

Huttel, C., & Loumeto, J. L. (2001). Chapter 1: Effect of exotic tree plantations and site management on plant diversity. In: *Effect of exotic tree plantations on plant diversity and biological soil fertility in the Congo Savanna: With special reference to eucalypts* (pp. 9–18). http://www.fao.org/forestry/42677-0641c6b278b5916899e198a24444dc455.pdf.

Isaac, S. R., & Nair, M. A. (2006). Litter dynamics of six multipurpose trees in a homegarden in Southern Kerala, India. *Agroforestry Systems*, *67*, 203–213. https://link.springer.com/article/10.1007%2Fs10457-005-1107-3.

ISC, Invasive Species Compendium. (2020). *Detailed coverage of invasive species threatening livelihoods and the environment worldwide*. Wallingford, Oxon, UK: CAB International. Available from cabi.org/isc/datasheet/2157.

Ismael, N. A. N., & Metali, F. (2014). Allelopathic effects of invasive *Acacia mangium* on germination and growth of local paddy varieties. *Journal of Agronomy*, *13*(4), 158–168. https://doi.org/10.3923/ja.2014.158.168.

Jobbagy, E. G., & Jackson, R. B. (2001). The distribution of soil nutrients with depth: Global patterns and the imprint of plants. *Biogeochemistry*, *53*, 51–77. https://link.springer.com/article/10.1023/A:1010760720215.

Kasongo, R. K., Van Ranst, E., Verdoodt, A., Kanyankagote, P., & Baert, G. (2009). Impact of *Acacia auriculiformis* on the chemical fertility of sandy soils on the Batéké plateau, D. R. Congo. *Soil Use and Management*, *25*, 21–27. Available from https://doi:10.1111/j.1475-2743.2008.00188.x.

Kaye, J. P., Resh, S. C., Kaye, M. W., & Chimner, R. A. (2000). Nutrient and carbon dynamics in a replacement series of *Eucalyptus* and *Albizia* trees. *Ecology*, *81*, 3267–3273. https://DOI:10.2307/177491.

Khanna, P. (1998). Nutrient cycling under mixed-species tree systems in Southeast Asia. *Agroforestry Systems*, *38*, 99–120. https://link.springer.com/article/10.1023/A:1005952410569.

Kidanu, S., Mamo, T., & Stoosnijder, L. (2005). Biomass production of *Eucalyptus* boundary and their effect on crop productivity on Ethiopian highland Vertisols. *Agroforestry Systems*, *63*, 281–290. https://link.springer.com/article/10.1007/s10457-005-5169-z.

Koutika, L. S., & Richardson, D. M. (2019). Acacia mangium Willd: Benefits and threats associated with its increasing use around the world. *Forest Ecosystems.* January 2019, 2-9. Available from https://doi.org/10.1186/s40663-019-0159-1.

Kull, C. A., & Rangan, H. (2008). Acacia exchanges: Wattles, thorn trees, and the study of plant movements. *Geoforum*, *39*, 1258–1272. https://doi.org/10.1016/j.geoforum.2007.09.009.

Kushalapa, K. A. (1991). Performance of *Acacia auriculiformis* in India. *ACIAR Proceedings Series*, *35*, 189–193. Available from https://www.cabdirect.org/cabdirect/abstract/19920657735.

Lee, K. L., Ong, K. H., King, P. J. H., Chubo, J. K., & Su, D. S. A. (2015). Stand productivity, carbon content, and soil nutrients in different stand ages of *Acacia mangium* in Sarawak, Malaysia. *Turkish Journal of Agriculture and Forestry*, *39*, 154–161. https://doi.org/10.3906/tar-1404-20.

Lisanework, N., & Michelsen, A. (1993). Allelopathy in agroforestry systems: The effects of leaf extracts of *Cupressus lusitanica* and three *Eucalyptus* spp. on four Ethiopian crops. *Agroforestry Systems*, *21*(1), 63–74. https://link.springer.com/article/10.1007/BF00704926.

Liu, J., Li, Y., Xu, Y., Liu, S., Huang, W., Fang, X., et al. (2017). Phosphorus uptake in four tree species under nitrogen addition in subtropical China. *Environmental Science and Pollution Research*, *24*, 20005–20014. https://doi.org/10.1007/s11356-017-9633-x.

Louppe, D., Ouattara, N., & Oliver, R. (1998). Maintien de la fertilité dans trois jachères arborées. Bilan minéral (Korhogo, nord Côte d'Ivoire). *Agriculture et développement*, *18*, 47–54. https://agritrop.cirad.fr/390387/1/document_390387.pdf.

Low, T. (2012). Australian acacias: Weeds or useful trees? *Biological Invasions*, *14*, 2217–2227. https://doi.org/10.1007/s10530-012-0243-8.

Ludwig, F., de Kroon, H., Berendse, F., & Prins, H. H. T. (2004). The influence of savanna trees on nutrient, water and light availability and the understory vegetation. *Plant Ecology*, *170*, 93–105. https://DOI:10.1023/B:VEGE.0000019023.29636.92.

Mahato, M. K., & Jana, N. C. (2019). Impact of landform on agricultural land use pattern: A case study of Salda river basin in Purulia district, West Bengal. *Journal of Geography Environment and Earth Science*

International, *21*(3), 1–19. https://DOI:10.9734/JGEESI/2019/v21i330125.

Mallick, P. H. (2018). Trend of changes in annual forest cover of South West Bengal, India. *International Journal of Zoology and Animal Biology*, 1(5). Available from https://DOI:10.23880/izab-16000130.

Mandal, D., Dhyani, B. L., Kumar, A., Singh, C., Bihari, B., Muruganandam, M., et al. (2013). Impact of different land use systems on soil quality in northwest Himalayan region. *Indian Journal of Soil Conservation*, *41*(2), 200–205. Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home.

Meira-Neto, J. A. A., da Silva, M. C. N. A., Tolentino, G. S., Gastauer, M., Buttschardt, T., Ulm, F., et al. (2018). Early *Acacia* invasion in a sandy ecosystem enables shading mediated by soil, leaf nitrogen and facilitation. *Biological Invasions*, *20*, 1567–1575. https://doi.org/10.1007/s10530-017-1647-2.

Mendham, D. S., O'connell, A. M., Grove, T. S., & Rance, S. J. (2003). Residue management effects on soil carbon and nutrient contents and growth of second rotation eucalypts. *Forest Ecology and Management*, *181*(3), 357–372. https://doi.org/10.1016/S0378-1127(03)00007-0.

Midgley, S. J., & Turnbull, J. W. (2003). Domestication and use of Australian acacias: Case studies of five important species. *Australian Systematic Botany*, *16*(1), 89–102. https://DOI:10.1071/SB01038.

Modak, B. K., & Basu, S. (2011). Role of lac culture in the conservation of biological diversity: Fieldwork findings from Purulia district in West Bengal. *Journal of Environment and Sociobiology*, *8*(1), 109–114. Available from https://www.researchgate.net/publication/309548996.

Nair, P. K. R. (2007). The coming of age of agroforestry. *Journal of the Science of Food and Agriculture*, *87*, 1613–1619. https://DOI:10.1002/jsfa.2897.

Nair, P. K. R. (2014). Grand challenges in agro ecology and land use systems. *Frontiers in Environmental Science*, *2*, 1–4. https://DOI:10.3389/fenvs.2014.00001.

Nambiar, E. K. S., & Harwood, C. E. (2014). Productivity of acacia and eucalypt plantations in Southeast Asia. 1. Bio-physical determinants of production: Opportunities and challenges. *International Forestry Review*, *16*(2), 225–248. https://DOI:10.1505/146554814811724757.

Nambiar, E. K. S., Harwood, C. E., & Mendham, D. S. (2018). Paths to sustainable wood supply to the pulp and paper industry in Indonesia after diseases have forced a change of species from acacia to eucalypts. *Australian Forestry*, *3*, 119. https://doi.org/10.1080/00049158.2018.1482798.

NBSS and LUP (2010). *Forest Soils of Purulia district, West Bengal, Report No. 794*, 10. Available from https://www.nbsslup.in/kolkata.html.

Oelofse, M., Birch-Thomsen, T., Magid, J., de Neergaard, A., van Deventer, R., Bruun, S., et al. (2016). The impact of black wattle encroachment of indigenous grasslands on soil carbon, Eastern Cape, South Africa. *Biological Invasions*, *18*, 445–456. https://doi.org/10.1007/s10530-015-1017-x.

Osunkoya, O. O., Othman, F. E., & Kahar, R. S. (2005). Growth and competition between seedlings of an invasive plantation tree, *Acacia mangium*, and those of a native Borneo heath-forest species, *Melastoma beccarianum*. *Ecological Research*, *20*, 205–214. https://doi.org/10.1007/s11284-004-0027-4.

Otsamo, A., Adjers, G., Hadi, T. S., Kuusipalo, J., & Vuokko, R. (1997). Evaluation of reforestation potential of 83 tree species planted on *Imperata cylindrica* dominated grassland, a case study from South Kalimantan, Indonesia. *New Forests*, *14*, 127–143. https://link.springer.com/article/10.1023/A:1006566321033.

Pandey, D. N. (2007). Multifunctional agroforestry systems in India. *Current Science*, *92*(4), 455–463. http://www.kiran.nic.in/pdf/agri-info/jhum%20cultivation/Multifunctional.pdf.

Parrotta, J. A., & Knowles, O. H. (1999). Restoration of tropical moist forests on bauxitemined lands in the Brazilian Amazon. *Restoration Ecology*, *7*(2), 103–116.

Paul, K. I., Polglase, P. J., Nyakuengama, J. G., & Khanna, P. K. (2002). Change in soil carbon following afforestation. *Forest Ecology and Management*, *168*(3), 241–257. https://doi.org/10.1016/S0378-1127(02)00304-3.

Paula, R. R., Bouillet, J. P., Trivelin, P. C. O., Zeller, B., de Moraes Gonçalves, J. L., Nouvellon, Y., et al. (2015). Evidence of short-term belowground transfer of nitrogen from *Acacia mangium* to *Eucalyptus grandis* trees in a tropical planted forest. *Soil Biology and Biochemistry*, *91*, 99–108. https://doi.org/10.1016/j.soilbio.2015.08.017.

Permadi, D. B., Burtona, M., Pandita, R., Walker, I., & Race, D. (2017). Which small holders are willing to adopt *Acacia mangium* under long-term contracts? Evidence from a choice experiment study in Indonesia. *Land Use Policy*, *65*, 211–223. https://doi.org/10.1016/j.landusepol.2017.04.015.

PROTA. (2016). *PROTA4U web database*. Wageningen, the Netherlands: Plant Resources of Tropical Africa. http://www.prota4u.org/search.asp.

Rascher, K. G., Grobe-Stoltenberg, A., Maguas, C., & Werner, C. (2011). Understory invasion by *Acacia longifolia* alters the water balance and carbon gain of a Mediterranean pine. *Ecosystems*, *14*, 904–919. https://doi.org/10.1007/s10021-011-9453-7.

Ray, S. (1982). Some aspects of geoecological adjustment in the upper Kangsabati basin, West Bengal. *Indian Journal of Landscape Systems, Calcutta*, *5*(1–2), 25–27. https://shodhganga.inflibnet.ac.in.

Resh, S. C., Binkley, D., & Parrotta, J. A. (2002). Greater soil carbon sequestration under nitrogen-fixing trees compared with *Eucalyptus* species. *Ecosystems*, *5*, 217–231. https://link.springer.com/article/10.1007/s10021-001-0067-3.

Richardson, D. M., Le Roux, J. J., & Wilson, J. R. U. (2015). Australian acacias as invasive species: Lessons to be learnt from regions with long planting histories. *South Forests*, *77*(1), 31–39. https://doi.org/10.2989/20702620.2014.999305.

Richardson, D. M., & Rejmanek, M. (2011). Trees and shrubs as invasive alien species—A global review. *Diversity and Distributions*, *17*, 788–809. https://doi.org/10.1111/j.1472-4642.2011.00782.x.

Rodriguez-Echeverria, S., Afonso, C., Correia, M., Lorenzo, P., & Roiloa, S. R. (2013). The effect of soil legacy on competition and invasion by *Acacia dealbata* link. *Plant Ecology*, *214*, 1139–1146. https://doi.org/10.1007/s11258-013-0238-2.

Sampaio, A. B., & Schmidt, I. B. (2013). Especies Exoticas Invasoras em Unidades de Conservacao Federais do Brasil. *Biodiversidade Brasileira*, *3*(2), 32–49. https://www.icmbio.gov.br/revistaeletronica/index.php/BioBR/article/view/351.

Santos, F. M., Balieiro, F. C., Fontes, M. A., & Chaer, G. M. (2017). Understanding the enhanced litter decomposition of mixed-species plantations of *Eucalyptus* and *Acacia mangium*. *Plant and Soil*, *423*, 141–155. https://doi.org/10.1007/s11104-017-3491-7.

Sarvade, S., Gautam, D. S., Upadhyay, V. B., Sahu, R. K., Shrivastava, A. K., Kaushal, R., et al. (2019). Agroforestry and soil health: An overview. In *Agroforestry for climate resilience and rural livelihood* (pp. 275–297). Scientific Publisher. Available from https://www.researchgate.net/publication/330223844.

Sarvade, S., & Singh, R. (2014). Role of agroforestry in food security. *Popular Kheti*, *2*(2), 25–29. https://www.researchgate.net/publication/283354289.

Sarvade, S., Singh, R., Prasad, H., & Prasad, D. (2014). Agroforestry practices for improving soil nutrient status. *Popular Kheti*, *2*(1), 60–64. https://www.researchgate.net/publication/283473187.

Siddiq, Z., & Cao, K. F. (2016). Increased water use in dry season in eight dipterocarp species in a common plantation in the northern boundary of Asian tropics. *Ecohydrology*, *9*, 871–881. https://doi.org/10.1002/eco.1689.

Singh, R. P. (1969). Geomorphological evolution of Chotanagpur highlands. *National Geographical Society of India, Varanasi*, *5*, 4–29. https://search.library.wisc.edu/catalog/999615257002121.

Sitters, J., Edwards, P. J., & Venterink, H. O. (2013). Increases of soil C, N, and P pools along an *Acacia* tree density gradient and their effects on trees and grasses. *Ecosystems*, *16*, 347–357. https://link.springer.com/article/10.1007/s10021-012-9621-4.

Slavich, P. (2001). Soil health: A systems approach to soils. In: *Soil health: The foundation of sustainable agriculture, workshop proceedings* (pp. 1–7). Wollongbar. https://www.researchgate.net/publication/242220954.

Souza, A. O., Chaves, M. P. S. R., Barbosa, R. I., & Clement, C. R. (2018). Local ecological knowledge concerning the invasion of Amerindian lands in the northern Brazilian Amazon by *Acacia mangium* (*Willd.*). *Journal of Ethnobiology and Ethnomedicine*, *14*, 14–33. https://link.springer.com/article/10.1186/s13002-018-0231-x.

Tassin, J., Rangan, H., & Kull, C. A. (2012). Hybrid improved tree fallows: Harnessing invasive woody legumes for agroforestry. *Agroforestry Systems*, *84*, 417–428. https://doi.org/10.1007/s10457-012-9493-9.

Tornquista, C. G., Hons, F. M., Feagley, S. E., & Haggar, J. (1999). Agroforestry system effects on soil characteristics of the Sarapiqui region of Costa Rica. Agriculture. *Ecosystems and Environment*, *73*, 19–28. https://DOI:10.1016/s0167-8809(99)00004-3.

Uehara, G., & Gillman, G. (1980). Charge characteristics of soils with variable and permanent charge minerals. I. Theory. *Soil Science Society of America Journal*, *44*, 250–252. https://doi.org/10.2136/sssaj1980.03615995004400020008x.

Van Ranst, E., Verloo, M., Demeyer, A., & Pauwels, J. M. (1999). Manual for the soil chemistry and fertility laboratory. In *Analytical methods for soils and plants equipment and management of consumables* (pp. 243). Ghent, Belgium: Ghent University. https://biblio.ugent.be/publication/113771.

Voigtlaender, M., Laclau, J. P., Gonçalves, J. L. M., Piccolo, M. C., Moreira, M. Z., Nouvellon, Y., et al. (2012). Introducing *Acacia mangium* trees in *Eucalyptus grandis* plantations: Consequences for soil organic matter stocks and nitrogen mineralization. *Plant and Soil*, *352*, 99–111. https://link.springer.com/article/10.1007/s11104-011-0982-9.

Wilson, J. R. U., Gairifo, C., Gibson, M. R., Arianoutsou, M., Bakar, B. B., Baret, S., et al. (2011). Risk assessment, eradication, and biological control: Global efforts to limit Australian acacia invasions. *Diversity and Distributions*, *17*, 1030–1046. https://doi.org/10.1111/j.1472-4642.2011.00815.x.

Xiong, Y., Xia, H., Li, Z., Cai, X., & Fu, S. (2008). Impacts of litter and understory removal on soil properties in a subtropical *Acacia mangium* plantation in China. *Plant and Soil*, *304*, 179–188. https://DOI:10.1007/s11104-007-9536-6.

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ঔপনিবেশিক মানভূম: জমির হাতবদল, পরিবেশগত পরিবর্তন ও জনজীবনের ওপর তার প্রভাব

জয়ন্ত পান্ডে

আদিবাসী অধ্যুষিত মানভূম জেলায় ঔপনিবেশিক হস্তক্ষেপ গুরুত্বপূর্ণ আর্থ-সামাজিক পরিবর্তনের সূচনা করেছিল। সাধারণভাবে জল, জঙ্গল, জমি- এই তিনের ওপর নির্ভর করেই আদিবাসী জীবনযাত্রা আবর্তিত হত। ভারতবর্ষে ব্রিটিশ শাসনের প্রতিষ্ঠা অন্যান্য অঞ্চলের মতো মানভূমের আদিবাসীদের সহজ সরল জীবনযাত্রায় ছেদ ঘটায়। তাদের ধীরে ধীরে শোষণমূলক ঔপনিবেশবাদের আওতায় নিয়ে আসা হয়। আদিবাসীদের পুরোনো ভূমিব্যবস্থা বাতিল করে তাদের ওপর নতুন ভূমিরাজস্ব ব্যবস্থা আরোপ করা হয়; যা ভূমি সম্পর্কের ক্ষেত্রে গুরুত্বপূর্ণ বদল নিয়ে আসে। অন্যদিকে মানভূমের বিশাল প্রাকৃতিক সম্পদের ওপর ঔপনিবেশিক নিয়ন্ত্রণ স্থাপনের প্রয়াস, পরিবেশগত অবনমনের পথ প্রশস্ত করে। ভূমি সম্পর্কের ভোলবদল ও পরিবেশগত পরিবর্তন মানভূমের আদিবাসী জনজীবনকে গভীরভাবে প্রভাবিত করেছিল। তাদের স্বাভাবিক জীবনযাপনের চেনা ছন্দটাই নষ্ট হয়ে যায়।

উনিশ শতকের ত্রিশের দশকে জঙ্গলমহল জেলা থেকে মানভূম জেলা (বর্তমান পুরুলিয়া) তৈরী করা হয়।[১] ভৌগোলিক দিক দিয়ে এই অঞ্চলটি ছোটনাগপুর মালভূমির অংশ। ঔপনিবেশিক জনসংখ্যাগত তথ্য অনুযায়ী মানভূম ছিল প্রধানত একটি আদিবাসী অধ্যুষিত এলাকা। সাঁওতাল, ওরাঁও. কোড়া, মুন্ডা, কোল, ভূমিজ প্রমুখ আদিবাসী সম্প্রদায়ভুক্ত মানুষ এই অঞ্চলে বসবাস করত। পাশাপাশি শবর, বীরহোড়, খেড়িয়ার মতো অরণ্যবাসী আদিম জনজাতিরও উল্লেখযোগ্য উপস্থিতি ছিল।[২] এলাকাটি ছিল একান্তভাবেই কৃষির ওপর নির্ভরশীল। প্রাক ঔপনিবেশিক সময়কালে আদিবাসীরা ব্যাপকভাবে জঙ্গল পরিষ্কার করে কৃষিযোগ্য জমি প্রস্তুত করেছিল। আদিবাসী কৃষকদের সঙ্গে স্থানীয় রাজাদের একটা সুন্দর বোঝাপড়ার সম্পর্ক গড়ে উঠেছিল। তাদের