Vol. 22(10), pp.257-264, October 2023
DOI: 10.5897/AJB2021.17377
Article Number: BA5027A71395
ISSN: 1684-5315

http://www.academicjournals.org/AJB

ACADEMIC JOURNALS
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African Journal of Biotechnology

Review

Introducing cotton farming by the use of transgenic cotton for phytoremediation of industrial wastes polluted soils in Southern Nigeria

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Received 29 June, 2021; Accepted 18 August, 2021

Industrialization in the Niger Delta region of southern Nigeria has resulted in excessive discharge of industrial wastes, especially oil spillage. Farming in this region has declined and cotton farming has not survived there due to this menace. Phytoremediation, which is an emerging green technology has been adopted for the revitalization of farming in polluted sites and has been integrated towards solving this challenge. Many indigenous plants of high phytoremediation strength within and outside Nigeria have been reported. The use of genetic engineering approaches for developing transgenic plants with higher phytoremediation potential have also been successful in certain plants. This review, therefore, focused on phytoremediation, its impact, success, potential plants, plant's phytoremediation mechanisms, and the technological advancement need through cotton genetic engineering. Cotton is the foremost commercially important fiber crop and its fiber is the backbone of the textile industry. It has significant impact in the economy but its phytoremediation strength is naturally poor; hence, prompting attention to the genetic modification of cotton for phytoremediation purposes and basing the future phytoremediation on the use of transgenic economic plants, especially cotton, are of significant importance.

Key words: Pollution, farming, cotton, phytoremediation, genetic engineering.

INTRODUCTION

Cotton is an important rare economic success story in sub Saharan Africa, a major source of foreign exchange earning in more than 15 countries of the continent and a crucial source of income for millions of rural people (Nnaemeka and Sun, 2021). It is considered as the foremost commercially important fiber crop and is deemed as the backbone of the textile industry (Chakravarthy et al., 2014). Therefore, issues surrounding cotton have become of serious concern to the world. In the past, there was decline in cotton farming as a result of pest infestation and other related factors. The revitalization of cotton for its fiber was a huge scientific exercise survived by the discovery of *Bacillus thuringiensis Bt*. by Shigetane in 1901. Berliner in 1915

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reported the existence of a crystal within the *Bt.* while Hannay et al. (1956) found that the main insecticidal activity against Lepidoptera (moth) insect was due to the parasporal crystal. In 1995, it became feasible to move the gene that encodes the toxic crystals into some plants in which cotton was among the genetically engineered plants by Monsanto (USA). (Monsanto 2002b). Cotton therefore, has been successfully genetically manipulated to resist insect attack. However, other issues regarding the quality of the cotton fiber have been approached because the price received for the cotton is dependent on the quality of each cotton bale, long, uniform, strong, fine mature cotton fiber provides better returns to growers and open more market opportunities for premium fabrics (Nnaemeka and Sun, 2021). Despite the already solved pest infestation challenge, in terms of fiber length and micronaire, Nigerian cotton was found at (Grade 5) compared to Australian cotton of (Grades 6 and 7), respectively in the international market. The limitation of Nigeria cotton fiber inspired interest in working on cotton plant (Upland cotton) at Plant Genomics Lab of Zhejiang Sci-Tech University (ZSTU) and we focused on combining traits of cottons towards genetically improving the fiber quality of the upland cotton (*Gossypium hirsutum* L.) which is the dominant species in Nigeria. Successes recorded from the research are expected to enhance the quality of the cotton fiber and improve effort towards integration of the genetic approaches used in cotton farming. However, following observations from excursion to some of the farming sites in Nigeria, we realized that the efforts made towards improvement of the cotton fiber quality have met another serious challenge (land pollution) that hinders cotton farming.

Generally, the current challenge farming is facing in the Southern Nigeria is due to spillage. High concentration of metal (loids) and organic pollutants in the contaminants are released into the soil, presenting a global threat to the surrounding environment and human health (Gordana et al., 2018). These contaminants are discharged from various processes which also include the printing and dying processes in the textile industry that contain high concentration of carcinogenic halides (Gao et al., 2019). Studies have disclosed the harmful effects of such chemicals to aquatic and terrestrial lives and also the climate. Led by Prof. Sun Yuqiang at ZSTU Plant Genomics lab, we used molecular biology approach to develop naturally colored cotton fibers yarn without or very less dying directly into cloth, matching the increasing great demand for green products, environmental protection and human health in modern society (Gao et al., 2019). Currently, only brown and green colored cotton is available in the actual production which seriously restricts the development of colored cotton industry and paves the way for continuous dyeing process that are constituting environmental havoc (Gao et al., 2019). Also in the nearby refinery industries, limited efforts have been made to curb discharge of similar obnoxious substances. Also, poor waste disposal from domestic activities resulted to the persistent decline in agricultural activities, especially in cotton farming which is of great economic importance. Although, heavy metal (loids) occurs naturally in the environment from pedogenetic of weathering of parent materials and also through anthropogenic sources, the most significant natural sources are weathering of minerals, erosion and volcanic activity, while the anthropogenic sources depend upon human activities such as spillage, mining, smelting, electroplating, use of pesticides and phosphate fertilizer discharge as well as biosolids (Ruchita et al., 2015). Government of Nigeria have so far initiated a clean-up program to clean the affected farm land but this effort have yielded minimal result and the decline in farming as a result of contamination from these activities is still increasing. Because Nigeria is the most populous and economy rich country in Africa as well as a major contributor to Africa economy, and cotton has significant impact on its economy growth (Nnaemeka and Sun, 2021), issues surrounding its economy, agriculture and environment are usually of serious concern. The quest for contribution to solving these challenges inspired this review. Here, an outlook of the depreciating farming activities in Southern Nigeria due to spillage is presented and the role of phytoremediation in revitalization of the farming situation is discussed. The paper highlights challenges facing agriculture and precisely cotton farming in Nigeria and even Africa and demonstrates how phytoremediation and genetic engineering approaches are the key to sustaining farming, maintaining healthy ecosystem and odor free environment. It also provides national and regional successes with a number of recommendations based upon previous known lessons and reform programs.

ENVIRONMENTAL AND ECOSYSTEM CHALLENGES DUE TO SPILLAGE

Spillage has been known as the process of spilling or act of releasing liquid. However, when these liquid is released from an unfriendly industrial or domestic processes into the environment in such a quantity capable of causing environmental hazard, it becomes dangerous to the existing lives in the ecosystem. UNDP (2006) reported that most of the ecological degradation in oil-producing communities of the Niger Delta may be due to oil spillage, which could be as a result of accident linked to human error, equipment failure and deliberate destruction of oil pipes and pipelines. Approximately 6% of these spills were on land (UNDP, 2006) and other waste water sources also have inimical quantity of heavy metals and other environmentally unfriendly substances (Ademoroti, 1996; Afiukwa, 2013). Spillage from any source can contribute to land pollution. It is difficult to quantify or even summarize the effects of such pollution, since oils themselves vary much (Nelson, 2005). Frequent crude oil spillage on agricultural soil, and the consequent fouling effect on all forms of life adversely affects the soils fertility such that most of the essential nutrients are no longer available for plant and crop utilization (Abii and Nwosu, 2009). However, plants germinate, develop and grow in soil medium where water, air and nutrient resources supply plants for healthy growth for productive and profitable agriculture (Essien and John, 2010); but in the case of land spillage, many researchers have reported its effects on plants growth. Udo and Fayemi (1995) reported that oil spillage accounted for 50% reduction in termination of *Zea mays* L. Ayesa et al. (2018) discussed extensively the poor growth of the seedlings of cash crop, *Dacryodes edulis* (African pear), hot pepper and tomato seeds, which are as a result of the suffocation of the plants due to exclusion of air by the oil that interfered with plants soil-water relationships. It has been estimated that oil concentration above 3% in the soil will reduce germination by suffocating seeds, thereby affecting their physiological activities (Amadi et al., 1996). Overall, spillage affected crop yield and farm income by extension of the social and economic livelihoods of farming communities (Odjuvwuederlie et al., 2006; Braide, 2000; Atubi and Onokala, 2006). Majority of agricultural and crop farming activities take place on the land including cotton farming; therefore, damages on the farmland due to spillage require close attention and revitalization technology. A conventional approach to solving this problem has been *ex-situ* but this is very expensive and damaging to the soil structure and ecology (Kramer et al., 2000); Salt and Kramer, 2000. Thus, an ecology and environment friendly approach (Phytoremediation) is reviewed.

SIGNIFICANCE OF PHYTOREMEDIATION

A shift to phytoremediation has become possible and necessary since it is environmentally and economically viable and very effective in the detoxification of contaminants (Yang et al., 2005). The main phytoremediation technologies are phytostabilization, phytoextraction, rhizodegradation and phytodegradation/ phytotransformation (Raskin et al., 1997; Salt et al., 1998; Nguyen et al., 2013; McCutcheon and Schnoor, 2003; Pilon-Smits and LeDuc, 2009). Phytoremediation is defined by UNEP (2012) as the use of living green plants for *in-situ* removal, degradation and containment of contaminants in soils, surface waters, and ground water. It offers a roadmap to increase the financial possibility of restoration programs, and to decrease disposal risks through the use of metal fortified plant biomass in energy and metal restoration with the burnt process. Phytoremediation is an emerging green technology that can be a promising solution to remediate hydrocarbon-polluted soils is not only in developed countries but also in developing countries like Nigeria, especially in the southern region. It is among the most potent and viable community-based management solutions for poor farmers. Based on phytoremediation versatility, it can also serve as useful link between researchers and farmers and will also recover the farming purpose of polluted soils. Phytoremediation application can be extended to anywhere pollution has affected the static water environment or an environment suffering from chronic danger due to pollution.

PLANTS PHYTOREMEDIATION MECHANISMS

Studies disclosed several species of plants have the ability to grow in contaminated soils and actually extract the pollutants through their roots system (Katherine, 1997). Heavy metals mostly exist in insoluble form in soil which is not bioavailable by releasing a variety of root exudates, which can change rhizosphere pH and increase heavy metal solubility (Dalvi and Bhaleroa, 2013); Gajic et al., 2018). There are series of processes involved in accumulation of heavy metals in plants, including heavy metal mobilization, root uptake, xylem loading, and root-to- shoot transport, cellular compartmentation and sequestration (Garba et al., 2011). Generally, there are two major ways plants can perform its function of phytoremediation: First is by bioaccumulating the pollutants in their tissues (Ndimele, 2003, 2010). The second is by converting the pollutants to less toxic components and then volatilizing them (Terry and Zayed, 1994; Brooks, 1998). Some of the end products are- alcohol, acids, carbondioxide and water, which are generally less toxic and less persistent in the environment than the parent compounds (Gordana et al., 2018). Transport of metal (loids) ions from roots to leaves is performed via membrane transporters, amino acids and/or organic acids (Jabeen et al., 2009). It is also known that fiber plants have many free hydroxyl groups at the molecular level that easily bond with oil or water (Bazargan et al., 2014), thus supporting the advancement of cotton for phytoremediation.

PHYTOREMEDIATION POTENTIAL PLANTS

Sunflower (*Helianthus annus* L.), an annual plant in the family Asteraceae has thus been identified as one of the target species that has great potential as a phytoextractor due to the fact that it produces large amounts of biomass, capable of hyper accumulating heavy metals in its harvestable parts (stems, leaves, and roots) and grows quickly (Francis, 2017; Nnamani and Nwosu, 2015)). In Nigeria, sunflower is one of the six common phytoremediation weeds (Wilberforce, 2015). Indian mustard (*Brassica jinxes* L.) is really useful to accumulate certain metals while producing high quantities of biomass in the process, and is the star of this group, as it can remove three times more Cd than others, reduce 28% of Pb, up to 48% of Sc and can also remove Zn, Hg and Cu (Jay, 2015). White willow (*Salic* species) can deal with Cd, Ni and Pb, and even in mixed heavy metals such as dismal fuel polluted sites (Jay, 2015). Poplar tree (*Populous deltoids*), due to it naturally well-designed root system which take up large quantities of water can degrade petroleum hydrocarbons like benzene, toluene and D-xylene according to Canadian database. Indian grass (*Sorghastrum nutans*) is one of the nine members of Gramineae family identified by Phytopet as capable of remediating petroleum hydrocarbon. *Glycine max* L. Merr*, Zea mays* L., *Sorghum bicolor* (L.) Moench and *Medicago sativa* L. have been shown too to have phytoremediation potential. The most efficient crop of Cd, Pb, Cu, Ni, Cr, and Zn was *B. carinata* (Oksana et al., 2016). *Selaginella jacquemontii, Rumex hastatus,* and *Plectran thusrugosus* showed multifold enrichment factors (EF) of Fe, Mn, Cr, Ni, and Co (Muhammad et al., 2013). *Arabidopsis halleri* and *Solanum nigrum* have also been utilized for phytoremediation of cadmium (Ruchita et al., 2015). Typically, revegetation uses a combination of woody species and grasses. Woody species have included autumn olive (*Elaegnus angustifolia*), Scotch pine (*Pinus sylvestris*), red pine (*Pinus resinosa*), white pine (*Pinus strobus*), blafi locust (*Robinia pseudoacacia*), Virginia pine (*Pinu svirginiana*) and short leaf (*Pine echinata*). Pines tend to acidify soils which may increase mobility of heavy metals like Cd and Zn if they are present (Bergkvist et al., 1989). Paper birch (*Betula papyrifera*) has been shown to accumulate twice as much Cu as many other trees (Lepp and Dickson, 1998). David (2018) also disclosed *Petunia grandifloraJuss.* Mix F1 and *Marigold-Nemo* Mix have phytoremediation potentials. *Potamogeton natans* and *Alisma plantago-aquatica* were found to accumulate even higher concentration of Zn, Cu, and Pb (Fritioff and Greger, 2003). Furthermore, some other potential Nigerian weeds such as: *Phyllanthus amarus* (Chancapiedra), *Chromoloena odorate* (Awolowos weed), *Strachytarpheta indica* (Gervao), *Bryophyllum pinnatum* (Life leaf) and *Murraya koenigii* (Curry leaf) have been found to absorb Pb, Zn, Cd, Cu and Ni from contaminated sites (Nnabuk and Ndo, 2007). Guinea grass (*Panicum maximum*) and water leaf (*Talinum triangulare*) have shown phytoremediation potential for further clean-up of crude oil contaminated soil in Nigeria (Isaac, 2008). Waziri et al. (2016) also reported that jatropha (*Jatropha curcas*), neem (*Azadirachta ndica*) and baoba (*Adansonia digitata*) also have phytoremediation potential for heavy metals in Nigeria. Several researches within and outside Nigeria also reported several phytoremediation plants within and outside Nigeria. A few metals, including Cu, Mn and Zn, are however essentials to plant metabolism in trace amount. It is only when metals are present in bioavailable forms at excessive levels that they have the potential to become toxic to plants (Reichman, 2002).

HISTORY AND SUCCESS REPORT OF PHYTOREMEDIATION

Soil phytoremediation has only been developed in the last 30 years. A prolific literature of phytoremediation in the soil has been developed in that time (Brooks, 1998a; McIntyre, 2003). Most plants that hyper accumulate metals have been identified for other areas than USA (Brooks, 1998). Like every other technology, phytoremediation can only be accepted if its success is demonstrated (Jean-Paul et al., 2002). Various chemical contaminants like suspended solids, dissolved oxygen, nitrogen, phosphorus and heavy metal etc. have minimized in India, China, Australia and Venezuela using phytoremediation plants (Roongtanakiat and Chairoj, 2001; Troung et al., 2008). Jean-Paul et al. (2002) also compared the success of phytoremediation in USA and Europe and several successes in many experimented sites were reported. The success of phytoremediation in USA paved way for the replication and advancement of the phytoremediation methods in other developing countries. These successes inspired integration of the approaches by Nigerian researchers towards actualizing similar results. However, minimal successes have been recorded in Nigeria using basically weeds and some other indigenous plants (Onyeike and Osuji, 2003). Cotton, thus, has not been integrated into this approach in Nigeria directly or by genetic modifications. Therefore, this limitation has formed the base of a further research.

PHYTOREMEDIATION BREAKTHROUGH WITH COTTON PLANT

Oil spillage in the Niger Delta region of Southern Nigeria has hindered cultivation of certain crops with less phytoremediation potential including cotton. Only 24 states in Nigeria are known for cotton farming (Nnaemeka and Sun, 2021) and none of the states is from the Niger Delta region. Success report of other plants for phytoremediation of polluted soils encouraged trial of economic plants for such purpose. Ramandeep et al. (2018) examined the bioaccumulation and translocation of heavy metals in different parts of cotton plant grown in an alkaline soil with very high sand contents which resulted in low retention of metals (As, Cr, Cu, Mn, Sr, and Zn). The bioaccumulation and translocation factors calculated for metal accumulation analysis in cotton plant parts were found above 1 (maximum 9.13 for Sr) indicating that cotton plant can become a significant system for phytoremediation. Cotton plant has a relatively large biomass, a profuse root system and capacity for heavy metal (Changfeng et al., 2020). Cotton as an economic fiber crop has a greater of becoming a promising candidate for phytoremediation because it could also minimize risk of human food chain contamination and ecological benefit. In this case, effort towards improvement of cotton for this future position is recommended.

GENETIC MODIFICATION OF COTTON FOR PHYTOREMEDIATION

Plant breeding has been pursued to increase the efficacy of phytoremediation (Ernest, 2014). Some plants that are metal tolerant may not provide effective ground cover or have unknown cultural needs (Vangronsveld and Cunningham, 1998). Research has also been conducted in using transgenic plants for removal of mercury (Henry, 2000). In the last decade, there has been an increase in research on improving the ability of plants to remove environmental pollution (phytoremediation). Phytoremediation can be substantially improved using genetic engineering technology. Recent research results, including over expression of genes whose protein products are involved in metal uptake, transport or sequestration, or act as a small enzyme involved in the degradation of hazardous organic, have opened up new possibilities in phytoremediation (Sam and Margarida, 2005). Genes from microbes, plants, and animals are being used successfully to enhance the ability of plants to tolerate, remove, and degrade pollutants (Sharon, 2008). Sharon also reported, over expression of mammalian genes encoding cytochrome P450s led to increased metabolism and removal of a variety of organic pollutants and herbicides. Gisbert et al. (2003) produced a tobacco plant that could remove more lead from soil than normal tobacco plant by inserting a gene from wheat plants that produces phytochelatin synthase into a shrub tobacco plant (*Nicotiana glauca*) to increase its absorption and tolerance of toxic metals particularly leaf. They found that the genetically modified plants absorbed about twice as much lead compared to non-modified plants. S-transferase has been introduced into higher plants, resulting in significant improvement of tolerance, removal and degradation of pollutants (Benoit and Sharon, 2009). Sharon (2008) has also recognized plant associated bacteria playing a significant role in phytoremediation leading to the development of genetically modified rhizospheric and endophytic bacteria. So far, several evidences have supported interest in adding such or similar genes from its parent organisms into cotton plant in order to improve cotton phytoremediation strength and pave way for future hope in cotton farming amidst pollution. Research involving cotton plant in this advance technology is insufficient. Transgenic plant technology for remediation of toxic metals and metaloids covers all the technical aspect of gene transfer from molecular methods to field performance using a wide range of plants and diverse abiotic stress factor (Majeti, 2019). In other words, the methods for the modification of cotton plant will also follow standard molecular methods.

CONCLUSION

Cotton is grown in around 105 countries with about 10 countries contributing highest quantity (Figure 1). Africa as a whole contributes less than 5% to the global demand for cotton and Nigeria which used to be Africa's leading cotton producer and 12th largest in the world now accounts for about 20.29% of Africa's cotton production by 2029. However as at 2020, Nigeria's share of Africa cotton production stood at 29.28% compared to Africa's projected cotton production share in 2029 which is expected to decline by about 7.60% (OECD-FAO Agricultural Outlook, 2020). These downtrends have been since 2010. With a total production capacity of 602,440 metric tons, Nigeria was Africa's leading cotton producer but declined to 51,000 metric tons in 2020. Also, export earnings from cotton plunged too significantly to about #866 million in the third quarter of 2020 from #1.71 billion in 2010. Efforts towards reviving the production and earnings have become paramount. Therefore, increasing the production capacity of cotton by introducing cotton farming in other areas of Nigeria beyond the Savanna belt region where they are currently grown formed the base of this review. To actualize this, employing genetic engineering approaches by developing genetically modified cottons capable of surviving and yielding in the Niger Delta region despite the polluted soils is recommended. Nevertheless, native plant species grown in particular areas over a long period of time without human intervention possess certain characteristics that make them the best adapted to local conditions, providing practical and ecologically valuable alternative for landscaping and eco restoration projects (Chidi et al., 2015; Dorner, 2002). Therefore, phytomanagement of degraded sites encourages selection of native species that in the long run form self-sustaining plant communities that do not require much maintenance (Gordana et al., 2018). In spite of the successes already recorded, dependence on the natural plants with phytoremediation potential may not meet the future demand for healthy environment as a result of increase in industrialization and urbanization from which wastes are discharged. Thus, advance in use of genetic approaches towards modifying naturally none or less phytoremediation potential plants with high cultivation and economic demand is necessary. This recommendation is possible because current trend of cotton breeding have been successful and these techniques have increased the productivity of cotton within the period of invention. With the advancement in cotton genomics, some important genomes and genomics banks have been constructed. Also, newer wild species have been discovered and many countries are conserving genetic resources within and between species, implying that this valuable germplasm can be exchanged among countries for increasing productivity (Iswarappa et al., 2020). There is huge scope for pre

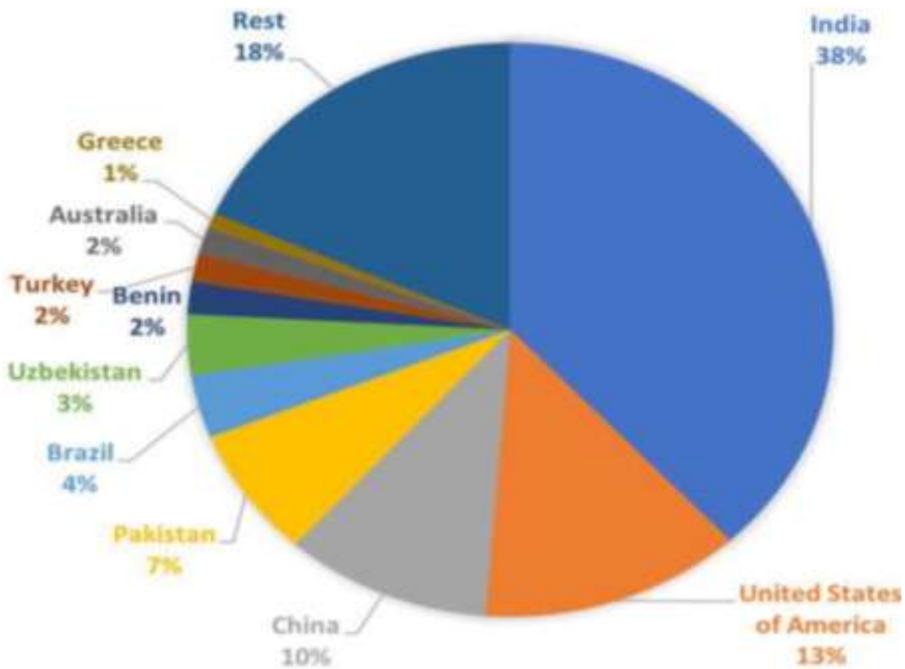

Figure 1. Highest cotton-producing countries.
Source: Ishwarappa et al. (2020).

Table 1. Countries with wide list of cotton germplasm.

Country	*G. hirsutum*	*G. barbadense*	*G. herbaceum*	*G. arboreum*
India	8851	536	565	2053
Uzbekistan	13,241	3019	1495	1185
United States of America	6302	1584	194	1729
China	7752	633	18	433
Russia	4503	1057	336	365
Brazil	1660	1509	19	219
France	2173	483	50	69
Australia	1573	99	39	211

Source: Ishwarappa et al. (2020).

breeding work in cotton to combat biotic and abiotic stresses. Some countries however, have maintained wide list of cotton germplasm (Table 1), supporting the possibilities of transforming cotton to combat abiotic stress due to pollution in Southern Nigeria.

Based on this, interest in the use of transgenic cotton as one of the most promising candidates for phytoremediation is recommended. In this regard, it becomes essential to select upland cotton (*G. hirsutum* L.) for transformation with genes known to influence phytoremediation in plants. The sole aim is to support initiation of research into development of transgenic cottons with high phytoremediation strength and results are expected to be integrated in the agriculture and environmental advancement strategies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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