



Forest fires induced alterations on soil physicochemical and microbiological properties

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Abstract

Forest fires represent ecological disturbance with its far-reaching consequences for terrestrial ecosystem. Present review examines the multifaceted impact of fires on soil properties to develop an intricate relationship between fire and the soil dynamics. Fires reduce available nutrient pool of soil through processes of immobilization, volatilization, salts leaching and severe erosion. Intense heat generated during a fire event alters soil's physical properties. Fire leads to reduction of soil organic matter and thus decreases moisture retention and increases erosion susceptibility. Fire induced changes in soil texture and structure affect the water infiltration rates, soil porosity and ultimately leads to increased runoff and decreased soil fertility. Fires lead to rapid metamorphosis of biological form of nutrients to its inorganic form. The combustion of organic matter releases nutrients such as nitrogen, phosphorus and potassium into the atmosphere. Elevated soil temperature during combustion alters soil pH towards acidity. Alterations in pH impart a significant effect on nutrient availability and microbial activities responsible for impacting plant growth. Mineralization rate generally found to be increased after the fire but reduced with time as it might have destroyed the organic matter from the soil. Furthermore, fire incidence increases the evaporation rates and exacerbates soil drying which leads to decreased microbial activity and nutrient cycling. Apart from the negative consequences, post fire leads to regeneration of the fire adapted species and improves the soil fertility as fire release appreciable amounts of nutrients. Fire causes drastic reduction in soil microbial biomass. However, soil bacterial communities are found more tolerant to heat as compared to fungi.

Keywords: Forest fire, soil properties, organic carbon, environmental hazards, soil biota

Introduction

Forest fires are a natural and recurring ecological phenomenon, but their frequency and intensity have increased in recent years due to factors such as climate change and human activities. Soil stands as a paramount natural resource integral to socio-ecological and natural systems (Alcaniz *et al.*, 2018) playing a pivotal role in nutrient cycles, mineral storage, carbon sequestration, and fostering plant growth. Recognized as non-renewable on a human timescale due to its rapid degradation and slow formation soil faces deterioration of biological, chemical and physical properties leading to temporary or permanent effects. Primary drivers of soil degradation in forests encompass deforestation, fires, erosion, and soil contamination (Silverio *et al.*, 2019) [44]. Fires, pervasive in tropical, temperate and boreal forest ecosystems are considered a global phenomenon with their evidence traced back to 360 million years old fossil records (Fernandez-Garcia *et al.*, 2019 a,b) [15, 16]. Fires exert influence on forest ecology by affecting nutrient turnover, hydrophobicity, species composition, regeneration and ecological biodiversity. Human-induced wildfires outnumber naturally occurring ones contributing significantly to soil degradation and nutrient losses through volatilization and erosion (Knorr *et al.*, 2016) [27].

These fires impact the biological and physico-chemical quality of soils, reducing nutrient pools through volatilization, oxidation, ash transfer and erosion (Pellegrini *et al.*, 2018) [33]. Studies report a drastic decline in microbial biomass carbon after forest fires, and reductions in nitrogen, phosphorus, and magnesium due to volatilization and oxidation processes. High-intensity fires alter soil physical properties, rendering it vulnerable to nutrient depletion through erosion. The severity and frequency of fires

significantly affect soil quality indicators, with intense, slow-moving fires causing more damage than fast-moving ones (Perez-Izquierdo *et al.*, 2021) [34]. Elevated temperatures during fires, particularly exceeding 850 °C on soil surfaces with dry, heavy fuel loads, may have destructive effects on soil properties (DeBano, 2000) [11]. Certain nutrients, including potassium, calcium and magnesium may be unaffected or increased, while sulfur and nitrogen typically decline due to fire. Temperature-specific regulation of nutrient volatilization within the soil is observed, in organic matter, N beginning to volatilize at 200 °C and calcium requiring 1484 °C to vaporize (Johnston and Barati, 2013) [25].

Global warming and extreme droughts escalate the risk of forest fires. Predictions suggest increased fire duration, intensity and frequency in forested regions, especially in the tropics due to higher temperatures. This elevated fire risk not only affects forest flora but also has significant impacts on soil physical, chemical and biological properties. Although fires influence forest soils in complex ways, comprehensive studies comparing their effects to those on vegetation are lacking. Fires on forest soils influence diverse processes, including organic matter loss, nutrient availability and dynamics, and vegetation revival post-fire. Understanding changes in soil properties following fires is crucial for developing sustainable and adaptable management practices for soils and forests (Zhang and Biswas, 2017) [50].

Overview of wildfires and prescribed fires

Wildfires

The term "wildfire" is employed to define fires that occur outside urban areas. The Australasian Fire Authorities Council (AFAC, 2010) characterized wildfires as

unintentional vegetation fires, encompassing forest fires and shrub fires. In the United States, a wildfire is described as "any non-structure fire that occurs in the wildland" (National Wildfire Coordinating Group, 2011) [32]. In Australia, the term "bushfires" denotes any vegetation fire (AFAC, 2010). The European Commission (2010) uses the term "forest fire" to refer to any wildfire or bushfire in Europe. Over the past decade, significant wildfires have occurred with devastating effects in different regions. For instance, in Canada between 1970 and 2017, approximately 5.6 million acres of vegetation were annually degraded from 8000 wildfire incidents (Tymstra *et al.*, 2020) [45]. Current climate change predictions, coupled with more frequent and prolonged droughts are expected to worsen the incidence of wildfires in various agro-ecologies (Caon *et al.*, 2014) [9].

Bushfire, forest fire or wildfire, regardless of the name is a major disturbance affecting forest ecosystems. Its impact on soil properties is influenced by its intensity, frequency, and duration (Bento-Goncalves *et al.*, 2012) [7]. Fire intensity which correlates with the heat output per area burned per time, can be classified as low intensity (<100 °C), medium intensity (up to 250 °C), and high intensity (>350 °C) (Caon *et al.*, 2014) [9]. However, the severity of wildfires depends largely on the fuel load in the ecosystem, soil type and moisture content, and fire intensity. Researchers have extensively documented the impact of wildfires on soil properties (Ibanez *et al.*, 2022 [22]; Jhariya and Singh, 2021) [24]. In grassland vegetation, Liu *et al.* (2018) observed an increase in soil nutrients following a low-intensity wildfire. However, moderate to high-intensity wildfires have generally been associated with reduced physical and biological properties. For example, Heydari *et al.* (2017) [19] reported adverse effects of wildfires on water content, water repellence, bulk density, and stable aggregates, while Fernandez-Garcia *et al.* (2019a, b) [15, 16] and Moya *et al.* (2019) observed decreased microbial biomass and enzymatic processes resulting from wildfires. Thus, evaluating the impact of wildfires is crucial as it leads to changes in soil physical, chemical and biological properties in the short- and long-term.

Prescribed fires

Prescribed fires, also known as prescribed burning, are controlled and low-intensity fires strategically employed to achieve specific management goals (Francos and Ubeda, 2021 [18]; Shubham *et al.*, 2023) [42, 43]. This scientific tool is utilized to manage fuel loads, primarily organic material in forested areas, aiming to prevent or mitigate potential wildfires (Bento-Goncalves *et al.*, 2012) [7]. In addition to reducing large fuel accumulations, prescribed burning serves various purposes, such as regenerating certain species, clearing land in slash-and-burn agriculture (Dicen *et al.* 2020) [13], and serving as a training exercise for firefighters (Shaltout and Ismail, 2020) [39]. Furthermore, prescribed fires play a role in influencing soil properties and ecological processes, controlling forest diseases and insect pests, and shaping plant and animal biodiversity in diverse vegetative ecosystems. Given the low severity of prescribed fires, their effects on soil properties are generally positive (Alcaniz *et al.*, 2018) [4].

Several researchers have documented the positive impacts of prescribed burning. Study by Akburak *et al.* (2018) [3] indicated an increase in base cations following prescribed burning, attributed to the accumulation of ash on the soil

surface. Similarly, Francos *et al.* (2019) [17] observed an elevation in soil pH in burnt soils after prescribed fires. Furthermore, electrical conductivity showed an increase in burnt soils after low-intensity prescribed fires due to the release of soluble inorganic ions and the formation of black carbon. Despite the benefits of prescribed burning, its application could pose risks to the soil ecosystem if temperatures surpass the permissible threshold for low-intensity fires (Francos and Ubeda, 2021) [18].

Factors influencing the severity of forest fires

Indigenous populations introduce fire into forests for various purposes, including facilitating the collection of non-timber forest products (Saha, 2002) [38], while instances of intentional and accidental fires also contribute to fire occurrence (Kodandapani *et al.*, 2008) [28]. Notably dry deciduous woodland areas experience significant instances of burning (Krishna *et al.*, 2012) [29]. Factors such as the high resin content in subtropical pine regions and dry conditions in tropical areas as highlighted by (Chandra *et al.*, 2005) [10], play crucial roles in the propagation of fires in India. The intensity of the fire along with other factors, determines its characteristics, including size, severity, soil heating, season of the burn, duration of residency and the time elapsed since the last fire. The direct impact of fire on the reduction of biomass and carbon stored in seasonally dry tropical forests has implications for both biomass and carbon accumulation (Kauffman *et al.*, 2003) [26].

Climate change, driven by factors such as greenhouse gas emissions, has led to rising temperatures, prolonged droughts, and altered precipitation patterns, creating conditions conducive to forest fires (Abatzoglou *et al.*, 2016) [1]. The type and amount of vegetation (fuel) in a forest significantly impact fire behavior. Accumulated dead biomass, such as fallen trees, leaves, and undergrowth, can serve as fuel (Reinhardt *et al.*, 2008) [37]. Human induced activities, including arson, campfires, and deforestation, can ignite and spread forest fires. The terrain, slope, and wind patterns in a region significantly affect fire behavior, speed, and direction. Steep slopes and canyons can channelize fires. Prolonged droughts reduce soil moisture and the availability of water for plants, making forests more susceptible to ignition and fire spread (Williams *et al.*, 2019) [48]. Fire management practices, including controlled burns, and wildfire suppression techniques influence the frequency and intensity of forest fires (Bowman *et al.*, 2011) [8]. Unhealthy forests, marked by stressed and dying trees, are more susceptible to fires, as the dead trees act as fuel. The proximity of human communities to forested areas, known as the wildland-urban interface, increases the risk of forest fires impacting homes and infrastructure (Radeloff *et al.*, 2018) [36]. Some ecosystems are adapted to regular, low-intensity fires, which play a role in maintaining biodiversity.

Effect of forest fire on soil physiochemical properties

Soil texture and bulk density

Soil texture, denoting the distribution of particles in the soil, reflects the relative proportions of inorganic elements <2 mm in mineral soil. Forest fires typically have minimal effects on soil texture as sand, silt, and clay exhibit high-temperature thresholds, with clay being more susceptible due to a lower threshold (400–800 °C for clay compared to 1414 °C for sand and silt). Studies in a pine forest on sandy clay loam and under oak forest revealed changes in particle

distribution, with a decrease in clay content and an increase in silt and sand particles after wildfires (Inbar *et al.*, 2014^[23]; Heydari *et al.*, 2017)^[19]. The collapse of clay particles during fires leads to the aggregation of finer particles, forming larger sand and silt particles. Despite shifts in particle distribution, many studies did not report significant changes in overall soil texture (Moya *et al.*, 2019).

Forest fires negatively impact soil bulk density, influencing soil porosity (Heydari *et al.*, 2017)^[19]. While some studies report lower soil bulk density after fires, others find no significant effect. Increased soil bulk density following wildfires has been observed in various regions, such as oak forests in Iran (Heydari *et al.*, 2017)^[19], prescribed and wildfires in Australia and Mexico, and tropical dry deciduous forests in India (Verma *et al.*, 2019)^[47]. The rise in soil bulk density is attributed to the collapse of soil aggregation and the destruction of organic matter during fires (Alcaniz *et al.*, 2018)^[4]. This destruction leads to increased bulk density, as reported by Heydari *et al.*, (2017)^[19] and Verma *et al.*, (2019)^[47], they highlighted the impact on soil structure, pores, and organic matter. The relationship between soil bulk density and porosity is inverse, with increased bulk density leading to reduced porosity and consequential effects on hydrological properties (Lucas-Borja *et al.*, 2020)^[30]. However, conflicting findings, such as lower soil bulk densities after prescribed fires in Nevada, USA, and a decrease in bulk density after a high-intensity wildfire in Mount Kenya (Downing *et al.*, 2017)^[14], suggest the need for further research to comprehensively understand the mechanisms underlying the impact of fires on bulk density.

Soil water repellency

Soil water repellency (SWR) is a significant soil physical property influenced by fire (Agbeshie *et al.*, 2022)^[2]. SWR diminishes water infiltration and promotes runoff, leading to increased soil erosion. Forest fires can induce, intensify, or alleviate SWR (Hosseini *et al.*, 2017)^[20]. Research in a Mediterranean karst forest in Croatia by (Weninger *et al.*, 2019) demonstrated an increase in SWR after a wildfire. In Australia, (Granged *et al.*, 2011) observed heightened SWR in a Eucalyptus Forest soil following a prescribed fire at 142 °C. Conversely, Varela *et al.* (2015)^[46] reported reduced SWR after a moderate-intensity wildfire in a *P. pinaster* forest in northwest Spain. Inbar *et al.* (2014)^[23] found decreased SWR in soils with a water-drop penetration time < 5 s following a low-moderate severity wildfire in *P. halepensis* and *P. brutia* forest soils. The increase in SWR is attributed to the formation of a hydrophobic layer on mineral particles during the combustion of organic matter. Hydrophobic compounds move downward during the fire, condensing on cooler particles and forming a hydrophobic coat. However, (Zavala *et al.*, 2010)^[49] noted that water repellency generally increases as soil temperatures approach 200 °C and is destroyed at temperatures above 300 °C. Lower SWR on surface soils can result from factors such as soil texture, where water repellency decreases more in fine-textured soils than in coarse-textured ones (Inbar *et al.*, 2014)^[23]. Other factors include organic matter coupled with moisture content, where low organic matter and high-water content increase SWR after fires. Additionally, the depth of the soil profile influences SWR, with deeper profiles showing increased water repellency due to the condensation of hydrophobic organic coating on cooler mineral particles

(Varela *et al.*, 2015)^[46]. Surface temperatures during burning also play a role, as high surface temperatures can completely break down soil hydrophobicity (Plaza-Alvarez *et al.*, 2018)^[35]. Infiltration and erosion processes are closely tied to SWR, with an increase in water repellence contributing to overland flow and a decrease in water infiltrability. Studies by Hosseini *et al.* (2017)^[20] observed that increased runoff and sediment loss were associated with elevated water repellency in a *P. pinaster* forest in North-Central Portugal after a wildfire. Similarly, Inbar *et al.* (2014)^[23] reported increased soil loss on burnt plots under *P. halepensis* and *P. brutia* after a wildfire, attributing it to the breakdown of soil aggregates and increased water repellency resulting in augmented runoff.

Soil available nitrogen, potassium and phosphorus

Nitrogen (N) is identified as the most limiting nutrient in both cropping and forest ecosystems. It exists in the soil matrix as available or mineral N (such as NH_4^+ and NO_3^-) and organic N (Zhang and Biswas, 2017)^[50]. Forest fires lead to N depletion via volatilization, especially when soil temperatures exceed 200 °C. Losses of N after a fire may also result from erosion and leaching, but the effects of forest fires on soil N present contradictory results. Some studies indicate a decrease in total N following forest fires. For example, Franco *et al.*, (2019) reported significant decreases in total N in the topsoil of different forest types. In contrast, other studies found no differences or even increases in total N after a fire (Akburak *et al.*, 2018^[3]; Hosseini *et al.*, 2017^[20]; Liu *et al.*, 2018). The increase in total N after a fire is often attributed to the addition of ashes rich in nitrogen, especially after low-intensity fires, and a higher rate of mineralization of organic litter (Alcaniz *et al.*, 2018^[4]; Ferrer *et al.*, 2021; Wan *et al.*, 2021).

Forest fires generally lead to increased soil temperatures and higher pH, impacting inorganic nitrogen (NH_4^+ and NO_3^-) dynamics via mineralization and nitrification processes. After a forest fire, nitrogen not completely volatilized is mineralized to NH_4^+ -N and can further be nitrified to NO_3^- -N under favorable conditions. Typically, there is an increase in available nitrogen following a fire. Several studies reported significant increases in NH_4^+ -N and NO_3^- -N after fires (Wang *et al.*, 2014; Adkins *et al.*, 2019; Hinojosa *et al.*, 2021; Heydari *et al.*, 2017)^[19]. The increase in NH_4^+ -N and NO_3^- -N is associated with higher ash deposition, increased N mineralization, and nitrification influenced by temperature, pH, and microbial activities.

In summary, the impact of forest fires on soil nitrogen is complex and context-dependent, influenced by factors such as fire intensity, vegetation type, and soil properties. The effects may include both losses and gains in total nitrogen and changes in the availability of NH_4^+ -N and NO_3^- -N, with the final outcome being shaped by the interplay of various environmental factors. The study indicates that forest fires have a positive impact on soil nitrogen content across all selected land uses. Maximum nitrogen contents of 191.52, 193.54, 437.58, and 323.98 kg/ha were observed in March for all land uses. The duration of the fire exhibited promising results in enhancing nitrogen levels in the soil. However, immediately after the initiation of the fire, available nitrogen was found to be lower compared to pre-fire levels. Similar observations were reported by (Hyodo *et al.*, 2013)^[21].

In terms of soil available potassium, its concentration increased with the duration of the fire, reaching maximum levels in March in agricultural and control sites. Conversely, in forest and grassland areas, the concentrations of soil available potassium were found to decrease with the duration of the fire. This decrease might be attributed to factors such as lower soil temperature, low soil moisture, and zero tillage, which could reduce potassium concentration. Among different land uses, the maximum concentration of potassium was recorded in agricultural-based land use, specifically 453.61 kg/ha. This higher concentration in agricultural areas could be attributed to the application of inorganic fertilizers and manures to crops, leading to an increase in soil potassium (Shubham *et al.*, 2021) ^[41]. The figures visually demonstrate that nitrogen and potassium concentrations improved over time, suggesting a positive relationship between fire and nutrient transformation (Shubham *et al.*, 2023) ^[42, 43]. This highlights the dynamic and complex interactions between forest fires and soil nutrient dynamics with the potential for both positive and negative impacts depending on various factors. In post-burned soils, there is a notable increase in phosphate and potassium levels. The process involves the mineralization of organic phosphorus in the organic matter after forest fires, leading to the creation of accessible orthophosphate, which plants can absorb (Zhang and Biswas, 2017) ^[50]. Additionally, various studies have shown that exchangeable cations, such as Ca^{2+} , Mg^{2+} , K^+ , and Na^+ tend to increase after forest fires (Alexakis *et al.*, 2021) ^[5]. This increase is attributed to the burning of plants and organic matter, which transforms into ash in the soil, consequently enhancing the soil's phosphorus content (DeBano and Conrad, 1978) ^[12].

Effect of forest fire on microbiological properties of soils

The heating of soils caused by wildfires or prescribed burns induces fluctuations in soil biological properties, encompassing microorganisms, biota activities, and communities, as well as soil invertebrates. Fire impacts biological properties either directly through the combustion-induced death or denaturation of soil biota or indirectly through post-fire plant recovery or alterations in soil organic matter (Jonathan *et al.*, 2016; Ibanez *et al.*, 2021). Alcaniz *et al.*, (2018) ^[4], in their review of prescribed burning on soil attributes, highlighted that temperatures ranging from 50 to 120 °C are required to eliminate most soil biological matter. According to Santin and Doerr, 2016, temperatures between 50–150 °C lead to the destruction of fine roots, bacteria, fungi, and seeds within the soil. The impact of forest fires on soil biological properties has been documented by several researchers.

For instance, Fernandez-Garcia *et al.*, (2019 a,b) ^[15, 16] reported that, in Spain, under *P. pinaster* in a *Haplic Umbrisol*, the highest microbial biomass carbon (MBC) was observed in unburnt soil compared to a burnt soil following a wildfire. Akburak *et al.* (2018) ^[3] studied the effects of low-intensity prescribed fire on soil microbes under *Q. frainetto* forest and recorded a decline in MBC in burnt soils compared to unburnt soils. Similarly, Moya *et al.* (2019) ^[31] observed decreased MBC in burnt soils after high-severity wildfires in *P. ponderosa* (USA) and *P. halepensis* forests (Spain), respectively. The reduction in MBC could be attributed to the loss of microbial biomass by fire, a decrease in nutrient availability, and the release of

compounds limiting fungal growth (Akburak *et al.*, 2018 ^[3]; Fernandez-Garcia *et al.*, 2019^{a,b}) ^[15, 16]. However, some researchers reported an increase in microbial biomass in burnt soils following fire, possibly due to the addition of mineral ash and the abundance of labile C (Fultz *et al.*, 2016).

In the Anatolia region of Turkey, Erkovan *et al.* (2016) documented changes in the microbial community after forest fires. They observed a shift from a fungal-dominant community to a bacterial one. This shift was also noted by Fultz *et al.*, (2016) in a burnt grassland soil in Texas, USA. Similar findings were reported by Oliver *et al.*, (2015), who observed modifications in microbial communities from fungal-dominated to bacterial-dominated ones. These shifts in microbial communities could be attributed to increased pH and the availability of nutrients (base cations) following fire (Pressler *et al.*, 2019; Wang *et al.*, 2020).

In addition to microbial community modifications, fire impacts enzymatic activities in burnt soils. Fultz *et al.* (2016) and Moya *et al.*, (2019) ^[31] reported decreased β -glucosidase activity in burnt forest soils, associating the decline with fire incidence and the abundance of nutrients from ash depositions. Fernandez-Garcia *et al.*, (2019 a,b) ^[15, 16] and Moya *et al.* (2019) ^[31] observed decreased acid phosphatase after forest fires, potentially due to damage or a decline in microbial biomass activity. The decrease in acid phosphatase could also be attributed to higher available phosphorous added to the soil following fire, diminishing acid phosphatase activity (Xue *et al.*, 2014).

In context to microbial biomass, research by Shubham *et al.*, 2022 ^[40] showed that following a fire incident, the soil microbial biomass content initially decreased, evident in reduced biomass content in September. However, as the duration of the fire extended, the microbial biomass content showed a subsequent increase, reaching a maximum of 175 $\mu\text{g/g}$ in forest land, 153 $\mu\text{g/g}$ in agricultural based landsite and varying values in other land uses. This increase in microbial biomass in forest land may be attributed to the regeneration of new flora after the fire, coupled with the incorporation and decomposition of litter, which enhances the nutrient pool in the soil. The increased nutrient availability serves as an energy source for the microbial population. Fire, acting as a mineralization agent, likely elevated the available nutrient content, easily accessible by soil microbes. Similar observations have been reported previously by Schoch and Binkley, (1986). The higher microbial biomass in agricultural land could be explained by the addition of previous crop straw, potentially enhancing microbial functional diversity. The initial reduction in microbial biomass immediately after the fire might be a consequence of elevated soil temperatures, which could have decreased microbial activities and reduced labile carbon content in the soil.

Conclusion

Forest fires have complex and multifaceted effects on soil properties and nutrient dynamics. While there are often immediate negative consequences, the long-term impacts can include both positive and negative changes in soil health and fertility. Understanding these effects is crucial for land and forest management practices and for predicting how ecosystems may respond to future fire events. Forest fires have a significant impact on various soil properties. These impacts include changes in soil texture, bulk density, water

repellency, and biological properties, which can influence the overall health and quality of the soil. Forest fires play a complex role in soil nutrient dynamics. While there may be initial losses of nutrients, such as nitrogen, due to volatilization and other processes, the long-term effects can lead to increased availability of certain nutrients like phosphorus and potassium. The exact nature of these effects can vary based on factors such as fire intensity, duration, and soil characteristics. Forest fires can alter microbial communities within the soil. There is often a shift from fungal-dominated to bacterial-dominated communities, which can have implications for nutrient cycling and soil health. Microbial biomass and enzymatic activities may decrease initially after a fire but can recover over time, especially in response to nutrient inputs. Soil water repellency can be increased by forest fires, leading to reduced water infiltration, increased runoff, and soil erosion. This can have significant ecological and hydrological consequences, including increased sediment loss. The effects of forest fires on soil properties and nutrient dynamics can change over time. Initial impacts may be negative, but with time, some soil properties may recover or even improve. This temporal aspect should be considered when assessing the long-term ecological impacts of forest fires. Prescribed burns can be used as a management tool to achieve specific objectives. These controlled burns can have positive effects on soil properties, such as reducing fuel load and improving soil health. Properly managed prescribed burns can mitigate the risks associated with uncontrolled wildfires.

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Conflict of interest statement

The authors wish to confirm that there are no known conflicts of interest associated with this publication. We confirm that we have given due consideration to the protection of intellectual property associated with this work. We confirm that the review paper has been read and approved by all named authors.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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