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Efficacy of biofertilizers in abiotic stress management of fruit crops : A review

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Abstract

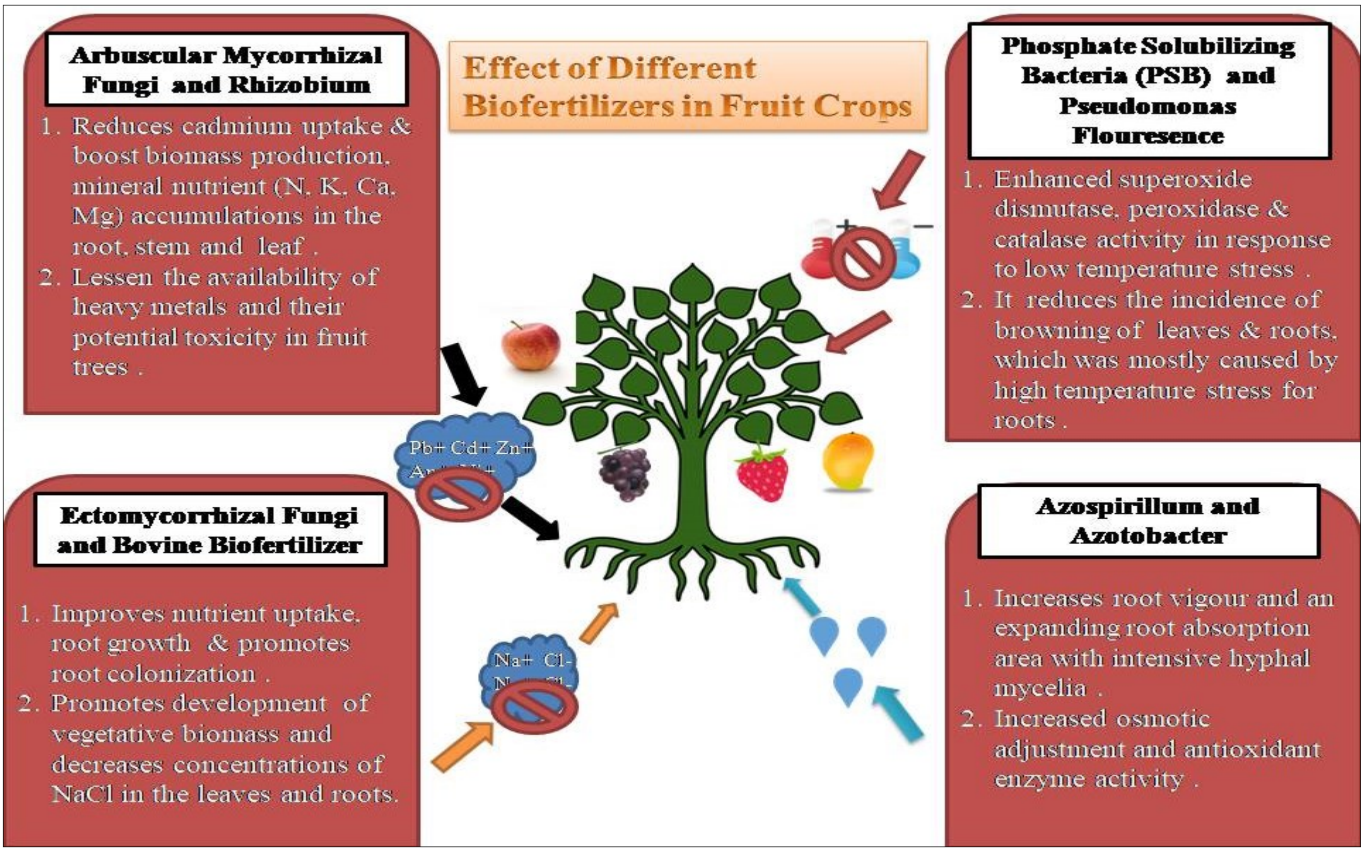
Biofertilizers are gaining widespread acceptance in agriculture due to their numerous advantages over chemical fertilizers. These environmentally friendly alternatives play a crucial role in enhancing soil health and fertility through various mechanisms. Biofertilizers consist of diverse microorganisms that can effectively promote plant growth and development, even under abiotic stress conditions. As a result, the utilization of biofertilizers is steadily increasing, especially with the escalating costs of chemical fertilizers and their adverse effects on soil health and crop yields. Certain microorganisms, such as *Azotobacter*, *Azospirillum*, Arbuscular Mycorrhizal Fungi (AMF) *Gigaspora rosea*, *Pseudomonas*, and *Funneliformis geosporus*, hold substantial potential for commercial use as biofertilizers to improve the growth and development of fruit crops. In-depth research has demonstrated that biofertilizers can significantly augment the biomass and productivity of various fruit crops. Their application in fruit crop production is particularly beneficial as they not only enhance growth but also confer improved resistance to abiotic stress factors like high temperatures, drought, salinity, and metal toxicity. This comprehensive review highlights the substantial promise of biofertilizers in mitigating abiotic stress and fostering sustainable practices in fruit crop cultivation.

Keywords

Bio-fertilizers; Arbuscular Mycorrhizal Fungi; Abiotic; Stress; Drought; Salinity

Introduction

Fruit crops encounter various challenging conditions throughout their life cycle, starting from seed germination to maturity. Abiotic stresses, such as drought, salinity, high temperatures, and metal toxicity, significantly impact global productivity. These stressors pose major obstacles to horticultural success, particularly in developing nations where farming is crucial for rural livelihoods. Drought and salt stress are prevalent issues that hinder agricultural productivity. Environmental stressors like drought, soil salinity, and extreme temperatures lead to substantial reductions in agricultural and horticultural yields globally, causing average losses of over 50% for major crops (1). To address these challenges, biofertilizers have emerged as a cost-effective and sustainable solution to reduce reliance on chemical fertilizers and enhance the quality of natural land resources while managing stress effectively (2). The use of nitrogen-fixing microorganisms, such as biofertilizers like *Azotobacter*, and phosphate-solubilizing bacteria (PSB) to enhance plant nutrition in agricultural crops, has been widely established (3). Biofertilizers containing beneficial microorganisms offer several advantages in the rhizosphere compared to synthetic chemicals. These advantages include enhancing nutrient fixation, producing plant growth stimulants, improving soil stability, providing biological control, facilitating biodegradation, promoting nutrient recycling, encouraging mycorrhiza symbiosis, and developing bioremediation methods for soils contaminated with toxic, foreign, and persistent substances (4). Therefore, the adoption of more sustainable approaches like biofertilization becomes imperative to mitigate environmental harm (5). Several biofertilizers have been successfully utilized to support plant growth and development in challenging environments, including mycorrhizal helpful bacteria (MHB), AMF, plant growth-promoting rhizobacteria (PGPR), and consortia of other beneficial microorganisms. With this background in mind, the present study was initiated to investigate the effects of biofertilizers under abiotic stress conditions such as drought, salinity, temperature, etc., in fruit crops.



Effect of Different Biofertilizers in Fruit Crops

Arbuscular Mycorrhizal Fungi and Rhizobium

1. Reduces cadmium uptake & boost biomass production, mineral nutrient (N, K, Ca, Mg) accumulations in the root, stem and leaf .
2. Lessen the availability of heavy metals and their potential toxicity in fruit trees .

Phosphate Solubilizing Bacteria (PSB) and Pseudomonas Flouresence

1. Enhanced superoxide dismutase, peroxidase & catalase activity in response to low temperature stress .
2. It reduces the incidence of browning of leaves & roots, which was mostly caused by high temperature stress for roots .

Ectomycorrhizal Fungi and Bovine Biofertilizer

1. Improves nutrient uptake, root growth & promotes root colonization .
2. Promotes development of vegetative biomass and decreases concentrations of NaCl in the leaves and roots.

Azospirillum and Azotobacter

1. Increases root vigour and an expanding root absorption area with intensive hyphal mycelia .
2. Increased osmotic adjustment and antioxidant enzyme activity .

Fig. 1: Effects of bio-fertilizers under abiotic stresses in fruit crops

Impact of Abiotic stress on fruit crops

Fruit crops are vulnerable to various abiotic stresses, such as high temperatures, excessive or insufficient moisture, salinity, metal toxicity, and others (6, 7, 8, 9). The consequences of global warming are expected to exacerbate the frequency, intensity, and duration of stress related to water scarcity, excess water, and elevated temperatures. Drought stress can have several detrimental effects on plants, including reduced vegetative growth, decreased net photosynthetic area, and increased transpiration rate, all of which can affect water use efficiency. Consequently, these factors can impact the overall production of dry matter in fruit crops (10). In addition to moisture stress, fruit crops also face challenges from other environmental factors like high temperatures, flooding, salinity, radiation stress, etc. For instance, salinity stress significantly affects banana plants, resulting in a reduction of pseudo stem thickness, delayed blooming, smaller fingers, and poor quality bunches (11, 12). Similarly, salinity stress in strawberries can lead to nutrient absorption imbalances, osmotic or ionic effects, leaf burning, and fruit deformities (13). The detrimental impacts of salinity on plants mainly arise from the reduction in soil osmotic potential, which induces water stress, and the specific effects of ions that cause salt stress. These factors can lead to nutritional imbalances or a combination of these mechanisms (Fig. 1).(Table. 1.)

Biofertilizers to mitigate abiotic stress

Bio-fertilizers, composed of naturally occurring living microorganisms, exhibit no adverse effects on plants, soil health, or the environment (14, 15). These microorganisms play a pivotal role in facilitating nitrogen and phosphorus nutrition in plants, either by their presence in the soil or through symbiotic associations with plants. Such associations directly or indirectly contribute to the nutrient supply for plants. Notably, bio-fertilizers have demonstrated their potential to augment the development and production of horticultural crops. Research findings suggest that the utilization of bio-fertilizers can significantly increase crop yields, with strawberry crops exhibiting improvements ranging from 15% to 30% (16). Additionally,

Table.1: Impact of several stress on fruit crops and its mitigation using biofertilizers

S.No	Name of crop	Type of stress	Impact of stress	Amendment and concentration	References
1	Avocado	Drought, Salinity	Decreases aerial and root length, Low chlorophyll content.	*Bacterial consortia* @ 108 CFU mL$^{-1.}$	(50)
2	Jack fruit	Drought	Rate of Survival % decreases.	MF - BIOVAM @ ± 2g.	(51)
3	Muskmelon	Drought	Reduces production efficiency.	*Pseudomonas*, *Azotobacter* and (108 CFU/ mL).	(52)
4	Passion fruit	Salinity	Limit the availability of water and nutrients, physiological.	Bovine biofertilizer diluted in water at 0, 33.3, 66.6 and 100 % in soil.	(53)
5	Banana	Drought, Salinity	Survival rate drops, limits growth leads to death of plant, imbalance of nutrient uptake.	*AMF sp* 35 - 50 cm^{-3} spores.	(54)
6	Plum	Drought Salinity	Reduced growth (root and shoot dry weight, total phosphate contents), stomatal imbalance.	*AMF* (250 g/plant), *Funneliformis mosseae* (FM) @10g.	(55,56)
7	Date Palm	Metal Toxicity	Inhibition of growth and photosynthesis, altered water balance and nutrient assimilation	algae-based bio fertilizers @0.5g/ plant	(57)
8	Papaya	Metal Stress	Decreasing the capability of roots to extract nutrients	MYKOVAM@5 g/plastic bag	(58)
9	Musk Melon	Metal Cadmium Stress	Low biomass accumulation, chlorosis	*B. fortis* IAGS 223 and ZnO-NPs (20 mg kg^{-1})	(59)
10	Trifoliate orange (*Poncirus trifoliata*)	Temperature Stress	Inhibits growth and leads to death	15 g inocula of *Glomus mosseae* (495 spores, hyphae and infected roots of *Sorghum vulgare*)	(60)

CFU: colony forming unit, **g/plant**: grams/plant

bio-fertilizers actively synthesize essential substances such as hormones, vitamins, and other growth-promoting elements, thereby fostering enhanced growth and overall development in strawberries (17). Moreover, biofertilizers, comprising beneficial microorganisms, have shown promising results in enabling horticultural crops to effectively combat abiotic stress through diverse mechanisms. Mycorrhizal symbiosis has been widely observed in nearly all fruit tree species grown in nurseries or cultivated in fields (18). Arbuscular mycorrhizal (AM) symbiosis, in particular, has been extensively studied and is known to promote plant growth, enhance nutrient uptake, improve fruit quality, and increase resilience to various abiotic challenges, including cold temperatures, dehydration, and salinity (19). Among the Azospirillium species, A. brasilense stands out due to its exceptional resistance to multiple abiotic stresses and is considered of great significance. These bacteria have been found to promote plant growth even in adverse conditions such as drought (20).

It has been observed that when *Citrus tangerine* seedlings were inoculated with AMF at a temperature of 25°C, a significant increase in root volume was noted (21). Furthermore, under a lower temperature condition of 15°C, seedlings treated with AMF exhibited considerable enhancement in root length, surface area, and volume, indicating substantial growth stimulation. PGPR possess the capability to produce ACC-deaminase within the rhizosphere of plants. They achieve this by metabolizing ethylene, which is a precursor known as 1-aminocyclopropane-1-carboxylic acid (ACC), converting it into α-ketobutyrate and ammonium. This process leads to decreased ethylene levels in plants (22), resulting in improved plant growth. Numerous studies have indicated that AMF contribute to the enhancement of root systems, leading to stronger, healthier plants with increased nutrient uptake (23). AMF also have the capacity to alleviate water stress levels (24). Approximately 80% of plant roots can establish mutualistic connections with AMF, which are microscopic organisms living in the rhizosphere. Additionally, AMF can increase the host plants' tolerance to the heavy metal cadmium (Cd) and facilitate the absorption of mineral elements by plants (19). Moreover, AMF possess the ability to immobilize Cadmium (Cd) by colonizing host plants. They achieve this by forming external hyphae and producing glomalin. Furthermore, they can enhance the physicochemical properties of the rhizosphere soil and enrich the composition of the microbial community. As a result, the accessibility of heavy metals is reduced, mitigating the negative effects of cadmium stress on plants.

Impact of biofertilizers on drought stress

During drought conditions, water availability is limited, leading to adverse effects on plant growth, metabolism, stomatal conductance, and tissue water content. However, plants possess a remarkable ability to sense variations in soil water content through their roots. When the soil becomes drier, root-sourced signals are transmitted to the leaves through the xylem, triggering responses that reduce water loss and slow down leaf growth (24). Drought-induced stress induces numerous morphological, physiological, and biochemical alterations in all plant organs. Berry crops, in particular, have shown significant impacts during drought, as indicated by various reviews. In the context of this research, three species of arbuscular mycorrhizal fungi (AMF) were studied: Glomus intraradices, Glomus mosseae, and Glomus etunicatum. These AMF species were either applied individually or as a mixed inoculum to micro-propagated strawberries transplanted in the field. The results revealed a remarkable increase of more than 10% in root length (25). In the case of high-bush blueberry plants subjected to drought stress, Funneliformis mosseae exhibited the most beneficial effects on plant growth. Plants inoculated with AMF demonstrated an enhanced ability to photosynthesize compared to non-inoculated plants under drought conditions. The observed growth improvement can be predominantly attributed to non-stomatal factors, specifically advancements in energy absorption by the chloroplasts and the photochemical capacity of photosystems in blueberry plants (26).

The study involved inoculating pomegranate plants with two strains of the AMF, *Rhizophagus intraradices*, and subjecting them to varying irrigation regimes. The results indicated that mycorrhizal plants exhibited enhanced antioxidant defenses, including superoxide dismutase, catalase, and ascorbate peroxidase, under both irrigation conditions (27). Similarly, in mango, the application of Azospirillum and Azotobacter significantly alleviated drought stress. However, with increasing drought severity, membrane stability and photosynthetic pigments declined, while electrolyte leakage, soluble sugars, total carbohydrates, and proline content increased in the mango cv. Owais (28). In citrus orchards facing drought stress, mycorrhizal inoculation, specifically with *Funneliformis mosseae* (formerly Glomus mosseae), significantly increased root concentrations of abscisic acid (ABA), indole-3-acetic acid (IAA), methyl jasmonate, and brassinosteroids (BRs) (29). Utilizing *F. mosseae* as a biofertilizer in citrus orchards holds the potential to enhance both sustainable agriculture and environmental conservation. When seedlings were treated with bio-fertilizers, particularly 100 g of mycorrhiza per pot, there was a noteworthy increase in leaf fresh Relative Water Content, enzyme activity, chlorophyll a and b, and a decrease in ion leakage (30). In pistachio, studies have demonstrated the beneficial outcomes of the interaction between plants and AMF on plant growth, nutrient levels, and the accumulation of osmoprotectants. These investigations were carried out on different rootstocks such as Abareghi, Bane Baghi, Sarakhs, and Badami-Rize-Zarand, all of which were subjected to drought stress conditions (31).

Impact of biofertilizers on salinity stress

Under salt stress conditions, the mycorrhizal citrus plant species *Citrus tangerina* Hort. ex-Tanaka exhibited heightened rates of stomatal conductance, net photosynthesis, and transpiration. These improvements were attributed to elevated values of photosynthetic rate (*Pn*), transpiration rate (*E*), and stomatal conductance in mycorrhizal seedlings (32). In salt stress experiments, researchers qualitatively and quantitatively examined the root H^+ effluxes of trifoliate orange (*Citrus trifoliata*) seedlings. Upon the introduction of *Funneliformis mosseae* (*Glomus mosseae*), the amount of H+ efflux from the roots to the rhizosphere increased. This phenomenon is attributed to the mutualistic relationship between mycorrhizal fungi and host plants, which promotes the enhanced release of hydrogen ions (H^+) from the roots into the immediate soil environment, leading to increased acidity in the rhizosphere. Consequently, the mycorrhizal roots' ability to acidify the surrounding area is augmented, resulting in a more acidic environment that enhances the salt tolerance of AMF (arbuscular mycorrhizal fungi) seedling rhizospheres (33). Date palms (*Phoenix dactylifera*) have shown the capacity to improve their resistance and adaptability to saline environments, particularly when subjected to various abiotic stressors in the presence of putrescine (34). Treatments with *Glomus fasciculatum*, an AMF species, have been observed to boost date palm productivity, reduce salt-induced oxidative damage, and enhance fruit quality in these conditions. Conversely, salt has been found to have adverse effects on the root colonization of grape (*Vitis* spp.) rootstocks (35).

Salinity stress can have detrimental effects on pomegranate (*Punica granatum*) growth, but the presence of AMF, specifically *Funneliformis mosseae*, has been shown to alleviate some of these negative impacts. When pomegranate plants were exposed to salinity stress, the application of AMF resulted in noteworthy improvements, including a 23% increase in shoot dry weight, a 9% increase in root colonization, a 53% increase in leaf area, and a 17.25% increase in root and shoot phosphorus (P) concentration (36). In contrast, increasing water salinity levels from 0.3 to 4.0 dS m-1 led to a decrease in the number of jackfruit (*Artocarpus heterophyllus*) seedlings. However, the negative effects of salinity stress were mitigated when biofertilizers were introduced to the growing medium. As a result, the jackfruit seedlings exhibited enhanced stem diameters and overall root length (37). The growth of papaya (*Carica papaya*) seedlings was adversely affected by escalating soil salinity and irrigation water salinity. Nevertheless, the negative impacts were partially alleviated in the presence of bovine biofertilizers (38). AMF has proven beneficial in facilitating nutrient uptake and seedling development in various plant species. For instance, melon (*Cucumis melo*) seedlings demonstrated increased tolerance to salinity levels of up to 150 mM when assisted by AMF. Furthermore, AMF played a crucial role in reducing both mechanical and metabolic damage caused by stress in melon seedlings (39).

Impact of biofertilizers on temperature stress

High temperatures have been shown to have detrimental effects on the physiological and physical characteristics of strawberry plants. However, when strawberry plants are associated with AMF, they exhibit improved traits such as increased leaf and root numbers, larger leaf area, and higher dry weights of leaves and roots. Notably, the species *Glomus aggregatum* demonstrated particularly higher dry weights for both leaves and roots. The symbiotic relationship between strawberry plants and AMF has been found to enhance overall strawberry growth. Additionally, AMF pre-infection significantly reduced the frequency and severity of leaf and root browning caused by recurrent high-temperature stress on the roots (42).

In the case of Azotobacter and Phosphate-Solubilizing Bacteria (PSB) isolates, their capacity to thrive at elevated temperatures of 30°C and 35°C has been observed. Conversely, the growth of papaya plants was negatively affected as temperatures increased from 35°C to 40°C. However, under stressful conditions, the PSB isolate demonstrated the ability to multiply and effectively solubilize phosphorus. This finding suggests that these isolates have a high tolerance to stress and can efficiently solubilize phosphates even under conditions of high temperatures (43).

Trifoliate orange (*Poncirus trifoliata*) seedlings exposed to high-temperature stress exhibit a significant increase in the activities of Superoxide Dismutase (SOD) and Catalase (CAT) enzymes, along with an elevation in soluble protein content, when inoculated with the arbuscular mycorrhizal fungus *Glomus mosseae*. Moreover, *Glomus mosseae* positively influences root morphological characteristics, thereby ameliorating the deleterious effects of high-temperature stress (44). The enhanced root morphology in mycorrhizal plants enables more efficient uptake of water and nutrients from the soil, ultimately alleviating temperature stress (45). By facilitating water and nutrient absorption, mycorrhizal associations are instrumental in mitigating the impact of high temperatures on plants. In contrast, blueberry (*Vaccinium corymbosum*) plants exposed to low temperatures experience a decline in soluble sugars, phosphate, and potassium leaf concentrations. However, the application of the arbuscular mycorrhizal fungus *Glomus mosseae* has demonstrated the potential to enhance blueberry plant resilience to low-temperature stress (46). Through improvements in antioxidant content, osmotic adjustment, and nutrient availability, *Glomus mosseae* enhances the tolerance of 'Britewell' blueberry plants to low-temperature stress.

Impact of biofertilizers on metal toxicity stress

In the cultivation of date palm (*Phoenix dactylifera L.*) on soil contaminated with heavy metals, the presence of rhizobia and arbuscular mycorrhizal fungi (AMF) isolates has been found to positively impact both the growth of date palm and the uptake of lead (Pb). Consequently, there is a noteworthy increase in the occurrence of AMF colonization in date palm, reaching a frequency of 86.67% (47). Even under low-temperature conditions, heavy metals exhibit reduced growth due to photosynthesis inhibition, chlorophyll biosynthesis, and mineral assimilation (48). In the case of *Cucumis melo* seedlings, the application of bio-fertilizer containing *Bacillus fortis* has shown remarkable improvements in the activity of catalase (CAT), peroxidase, and superoxide dismutase (SOD) enzymes, leading to enhanced growth and improved physiochemical features under both normal and cadmium-contaminated conditions (49).

Prospects and Conclusion

It is evident from various studies that the application of a batch of biofertilizers can significantly enhance the tolerance of different fruit crops to abiotic stresses, particularly when utilizing organisms such as *Azotobacter*, *Azospirillum*, *AMF*, *Glomus mosseae*, *Pseudomonas*, *Funneliformis geosporus*, among others, which have great commercial potential. Abiotic stresses like drought, salt, waterlogging, and high temperatures adversely affect fruit crops, but their negative effects can be alleviated through the use of biofertilizers. Biofertilizers play a crucial role in stimulating plant growth and root development, while also enhancing water and nutrient uptake through extraradical hyphae. Additionally, they contribute to the regulation of phytohormones and signaling substances, reinforce antioxidant defense systems, promote the accumulation of osmolytes, increase chlorophyll levels, and improve soil structure and fertility within the mycorrhizosphere of fruit crops that have been inoculated with microbial agents. It is worth noting that biofertilizer extracts, derived from a diverse range of beneficial microorganisms, have the capacity to increase abiotic stress tolerance, improve fruit quality, and enhance nutrient uptake from the soil. Consequently, the application of biofertilizer extracts is recommended not only as a means to enhance morphological and physiological aspects but also as a strategy to mitigate stressful conditions that can impede crop growth and development, with minimal environmental impact. The utilization of bio-fertilizers offers numerous advantages, including their organic and eco-friendly nature, which safeguards soil quality and health. Therefore, it is advisable for farmers to opt for bio-fertilizers over excessive use of chemical fertilizers, especially urea. Emphasizing the potential of bio-fertilizers in fruit crop development is crucial due to their cost-effectiveness and potential to increase the overall revenue for growers.

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Authors contributions

The primary authorship of the manuscript is attributed to GGR, who has been responsible for conducting the recent research and making significant findings. RR has provided essential guidance throughout the preparation of the manuscript and has granted final approval for the version intended for publication. KC, AK, TS, and TV actively contributed to the manuscript's editing process, incorporating novel information. All authors have thoroughly reviewed and given their endorsement to the final manuscript.

Compliance with ethical standards

Conflict of interest: **:** The authors declare that they have no competing interest.

Ethical issues: None

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