



## **Ganoderma Root Rot Mortality: Managing the Growing Threat to the Tree behind Traditional Agroforestry in Indian Arid Region**

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**Abstract:** Last couple of decades have witnessed large-scale mortality of Indian mesquite (*Prosopis cineraria* (L.) Druce) or Khejri in specific areas of the Indian arid region. It is caused by *Ganoderma lucidum*, a root rot-causing soil-borne fungi. The disease is more common in sandy soils where trees experience greater moisture and temperature stress during the summers which predisposes them to the fungal infection. The infection spreads from diseased to healthy trees primarily through root-to-root contacts. Movement of injured lateral roots of *P. cineraria* from infected tree to healthy trees during mechanical ploughing is a common way of infection dissemination. In later stages of infection, the trees weaken and are then often attacked by an insect, *Acanthophorus serraticornis*, which aggravate the root rot incidence and accelerate the tree mortality. Isolating infected trees from healthy ones by digging a mechanical trench around has been advocated in past as a prophylactic measure. But the scattered distribution of trees in the fields limits adoption of this approach on a large scale and hence alternate approaches need to be developed to minimize the tree mortality. In this paper, we have discussed about symptoms, pathogen, predisposing factors and management strategies of *Ganoderma* induced tree mortality and also some ongoing studies.

**Key words:** *Prosopis cineraria*, *Ganoderma*, root rot, Trichoderma.

Indian arid zone occupies about 12% of the geographical area of the country i.e. about 31.8 m ha in seven states of the country. But, nearly 61% of the arid area falls in Rajasthan state alone. This area is typically characterized by erratic annual rainfall (100-350 mm), extremes of temperature (-2°- 48°C), long day sunshine, high wind speed (35-40 km h<sup>-1</sup>) and thus very high evaporative demand. Nearly 41 to 85% of ground water in the region is saline (8-60 ppt) (Bhati, 1995, 1997; Bhati and Faroda, 2001). The principal rain-fed crops include pearl millet, clusterbean, moth bean, cowpea, sesame and sorghum while in irrigated pockets of the region, wheat, mustard, cumin, blond psyllium, onion, garlic and carrot are cultivated. But after the introduction of canal and spread of ground water irrigation, cotton, ground nut, castor and many fruit plants are also being grown in large area (Sharma and Singh, 2014).

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Indian mesquite (*Prosopis cineraria* (L.) Druce), a nitrogen fixing trees has remained a part of production system in the region and has provided additional income and alternate means of livelihood. It is an important component of the prevailing agro-forestry system in agricultural fields. Farmers have religiously maintained it in their fields as it improves the growth of companion annual crops and provide fodder, timber and vegetable. Other tree species of importance in the region are *Tecomella undulata*, *Acacia senegal*, *Acacia nilotica*, *Hardwickia binata*, *Salvadora persica*, *Azadirachta indica* etc. Many of these trees and some shrubs are prone to the attack of the *Ganoderma lucidum* (Leyss.) Karst., which is becoming a continuous threat for standing trees (Lodha *et al.*, 1986; 1994). The genus *Ganoderma* includes several wood decaying fungi on living trees as well as on dead trunks and stumps in tropical and also in temperate countries (Mawar *et al.*, 2020). Several studies have been carried out on *Ganoderma* diseases, focusing on economic damage, severity of the disease and host range in many regions such as America, Asia, the Middle East and Europe (Fernando, 2008; Jazuli *et al.*, 2022). Generally, *Ganoderma* spp. cause extensive heart rot in standing trees by growing in the central, non-living woody tissues.

*Ganoderma* induced rapid decline in the population of *P. cineraria* in agricultural lands in last couple of decades in arid region causing considerable concern amongst farmers. Finding viable and effective disease control system of this disease is very challenging as it requires

an integration of methodologies and strategies, given that early detection is still very difficult. In this article, present status of this disease and its control measures are reviewed for reducing *Ganoderma* induced mortality in *P. cineraria* and some ongoing research efforts have also been discussed.

### Symptoms

The disease symptoms may take several years to manifest, and the presence of the pathogen's fruiting bodies becomes visible only after the fungus has become well established and when more than half of the tree trunk has been damaged. At this stage, the growers have very few options for saving the tree. In case of *P. cineraria*, initially the leaves of one or more twigs of the tree lose their usual green colour, do not look healthy and eventually turn yellow and drop. Affected trees appear overall sick and varying degrees of dieback initiates in the canopy, leading to complete drying of one or more branches. During the later stages of infection, the fungus generates fruiting bodies (sporophores), which might emerge before or after the above-ground symptoms become evident. These sporophores can form at the base of the trunk and their appearance serves as a key diagnostic characteristic of the disease (Fig. 1). They initially appear as small, white buttons of fungal tissues that develop rapidly into bracket-shaped mature sporophores, mostly dark brown in colour. The disease severity is assessed using the Disease Scoring Index (DSI) developed by Ilias (2000) and Abdullah *et al.*

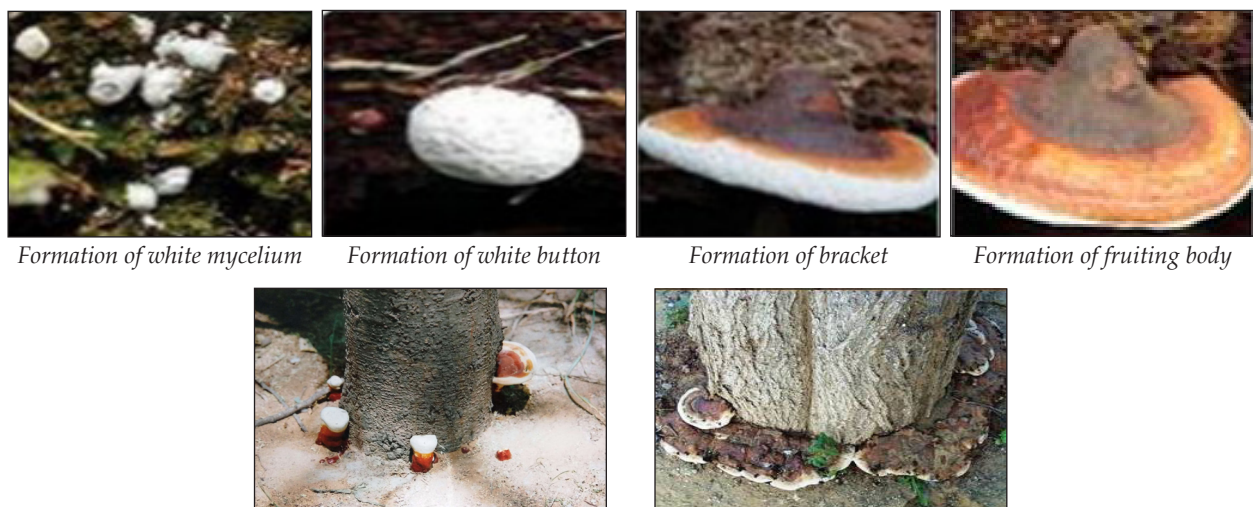


Fig. 1. Appearance and formation of fruiting bodies of *Ganoderma* on infected khejri trees

Table 1. Scale used for scoring disease severity

Disease classes	Range	Severity of infection
0	0	Apparently Healthy plants
1	<25	Drooping of leaves with pale look one or two twigs shows pale looking symptoms Initial development of pinheads of <i>Ganoderma</i> spp.
2	26-50	Increased intensity of pale looking leaves with drying of more than two twigs, Appearance of <i>Ganoderma</i> on the tree trunk but no remarkable damage observed in plants.
3	51-75	Partially top dying and all leaves are pale looking
4	>75	Fully top dying of plants and plants completely dried. All leaves shed away.

Formula used to calculate disease scoring index is :  $DSI (\%) = \frac{\sum (A \times B) \times 100}{\sum B \times 4}$

where: A - Disease classes (0, 1, 2, 3 and 4); B - Number of plants showing that disease classes per treatment

(2003), which assigns scores ranging from 0 to 4 to categorize extent of disease in different classes (Table 1).

### Pathogen

The genus *Ganoderma* includes several wood decaying fungi occurring on dead trunks, decaying hardwood, decaying stumps and occasionally on standing trees or trunks. It has been recorded mostly in tropical and temperate countries as a parasite on trees and a saprophyte on dead stumps (Pilotti, 2005; Dai *et al.*, 2007). In forest ecosystems, *Ganoderma* has an ecological role in the breakdown of the lignified woody plants. Generally, *Ganoderma* spp. causes extensive heart rot in standing trees by growing in the central, non-living woody tissues and decomposing lignin and cellulose (Adaskaveg *et al.*, 1990). Plants of 19 families, 36 genera and 48 species have been reported to be affected by *Ganoderma* spp. (Naidu *et al.*, 1986) and its host range has increased considerably over the years (Bilgrami *et al.*, 1991). Worldwide, more than 144 and in India, nearly 62 different tree species are affected by it (Kumari and Harsh, 2004; Sankaran *et al.*, 2005). *Ganoderma* produces various extra-cellular enzymes such as laccase, manganese peroxidase and lignin peroxidase, which are involved in the degradation of lignin and

their natural lignocellulosic materials. These enzymes oxidize phenolic compounds by creating phenoxy radicals, while nonphenolic compounds are oxidized via cation radicals. The basic mechanism of the fungal infection of the woody material is the lignolytic and cellulolytic degradation of lignin and other polysaccharides. Mawar *et al.* (2022) have reported a new strain of *G. tsugae* which more effectively decays wood because of their higher enzyme activity as compared to *G. lucidum*.

### Genesis

The problem of *Ganoderma* root rot mortality was not a serious concern until the late 1950s and surveys have brought out that sporadic incidences were observed later. Basidiocarps of the pathogen on the collar region which are called "bhambhod" which was given a religious context. However, the problem became more serious from 1970s onward after introduction of *Accacia tortilis* (Forsk) Hayne in the region primarily to control wind erosion (Anonymous, 1980). Profuse development of lateral roots of *Acacia tortilis* deplete soil moisture and weaken the roots of *P. cineraria* trees growing in vicinity and make them vulnerable to the *Ganoderma* infection (Lodha *et al.*, 1986; Lodha and Harsh, 2009). This disease spreads through root-to-root contact. But,



Fig. 2. Some of the symptoms appeared on *P. cineraria* trees affected by *Ganoderma* root rot disease

most of the growers remained ignorant about this. Later, with the increased mechanization in agricultural fields, like tractor operation at various stages of the crop cultivation, the infected root bits, stuck with plough/tillers spread farther in agricultural fields and thus more trees were infected. In general, disease pressure increases with temperature (Ryan *et al.*, 2008). This is because of the formation of chlamydospores by *Ganoderma* during adverse conditions which are more resistant to adverse environmental conditions than basidiocarps and could disseminate disease even in a scattered population of trees.

#### *Predisposing factors*

*Ganoderma*, is considered a weak parasite but many factors like concurrent high temperature and moisture stress, contact with infected roots and mechanical injury to the roots predispose the host to its infection. It is not essential that all the factors cumulatively make the host vulnerable to infection, but even more than one factor may be adequate.

(a) *Concurrent heat and soil moisture stress*: The most important predisposing factor for the occurrence of this disease is concurrent heat and soil moisture stress. The Indian arid region experiences high soil temperatures of 50-55°C during the summer months (April-June) when upper layer of sandy soils become completely dry (Lodha, 1995). Under such a condition, lateral roots lose their vigour which make them vulnerable to *Ganoderma* infection. However, for infection, the availability of inoculum is a pre-requisite. As discussed in a preceding paragraphs mechanism of its spread is still not known to most farmers. Therefore, farmers sometime bring infected tissues in contact of healthy trees while cleaning the above and below ground parts of dead/diseased trees. At the research farm of the ICAR-Central Arid Zone Research Institute, Jodhpur, *Ganoderma* was found to have infected an exotic shrub, Jojoba (*Simmondsia chinensis*), whose plantation in one pocket was in close proximity of an *A. tortilis* tree, heavily infected with *Ganoderma*. Pathogenicity of *Ganoderma* on healthy plants of jojoba was studied in laboratory by three different methods. Initially surface sterilized healthy segments of jojoba roots were put on 7-day old cultures of the pathogen growing on malt extract agar and left to incubate for

15 days. Subsequently, roots of two year-old jojoba plants grown in couple of earthen pots were exposed by clearing surrounding soil. In the first method, two root bits infested with pathogen were tied with sterilized cotton string to one exposed root. In the second method, colonized root bits were kept at a distance of 8-10 mm from the exposed roots and in third hyphal mats (15 days old) of *Ganoderma* mycelium harvested from malt extract agar were placed approximately 8 mm from the exposed roots. Jojoba roots, once exposed but un-inoculated, served as controls. Plants were irrigated at 4-, 6-, 8- and 10-day intervals to simulate different levels of moisture stress. Characteristic signs of root rot became evident approximately 5 months after applying the first method of inoculation on plants that were subsequently irrigated every 10 days. These plants eventually died within a period of 30 days. *Ganoderma* was isolated up to a distance of 7 cm from the inoculated sites. Similarly, plants subjected to the same inoculation procedure but receiving irrigation every 8 days displayed these symptoms after 6-7 months of inoculation. Notably, no root rot symptoms emerged in plants that were either irrigated every 4-6 days or inoculated using the latter two methods. This study clearly established the link between occurrence of the symptoms and soil moisture stress (Bhaskaran and Ramanathan, 1984). Such kind of behaviour is not limited to *Ganoderma* alone. Loss of root vigour following moisture stress also promoted *Fusarium equiseti* infection on Jujube (*Ziziphus mauritiana*) (Lodha, 1983). Apart from loss of root vigour, certain physiological parameters are also known to influence development of *Ganoderma* root rot. To investigate the underlying physical factors contributing to the susceptibility of *P. cineraria* to disease, a pot experiment was conducted. This experiment evaluated the impact of *Ganoderma* inoculation on seedlings exposed to varying levels of soil moisture stress (mild and severe). The study assessed growth, plant water potential and mortality rates. The experiment encompassed four treatments: (i) mild stress with 0.5 L of water every 3 days, (ii) severe stress with 0.5 L of water every 6 days, (iii) 1 L of water every 3 days with 50% root excision, and (iv) control with 1 L of water every 3 days. Water potential in seedlings increased under higher water stress conditions (Table 2). After 6 weeks, water potential differences became

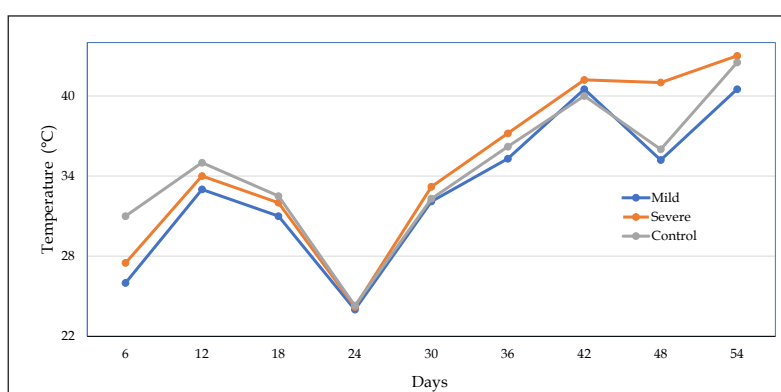


Fig. 3. Temperature fluctuation during the experimentation.

Table 2. Water potential (-bars) in *P. cineraria* seedlings at regular interval

Treatment	After 3 weeks	After 6 weeks
0.5 L water/3 days	24.3	22.5
0.5 L water/6 days	30.0	30.5
1 L water/3 days (50% roots excised)	27.6	23.5
1 L water/6 days	26.6	22.7

insignificant among the treatments 1, 3 and 4, except for treatment 2, where it was maximum. Soil temperatures remained stable after an initial increase. Temperature variations became pronounced among treatments after the 42<sup>nd</sup> day, with the highest levels in the treatment 2 (Fig. 3). Population counts of total fungi, bacteria and actinomycetes were higher in the control group compared to other treatments (Table 3). Water-stressed treatments exhibited lower counts of total microbes compared to other treatments. These results bring out a complex interplay between moisture stress, temperature and microbial populations in relation to disease susceptibility of *P. cineraria*.

Table 3. Total microbial population in the initial soil samples

Treatment	Total Fungi $\times 10^3$	Total Bacteria $\times 10^5$	Total Actinomycetes $\times 10^5$
0.5 L water/3 days (Mild)	16.0	6.3	3.0
0.5 L water/6 days (Severe)	13.3	3.0	2.6
1 L water/3 days (50% roots exercised)	18.6	8.3	3.3
1 L water/6 days (control)	21.3	10.6	5.0

Drought stress promotes diseases through several diverse mechanisms. It has the potential to modify the plant's physiology, rendering it more susceptible to infections. Additionally, it can curtail the plant's capacity to synthesize protective compounds or to outpace disease development. Intense drought stress can lead to physical harm to plant tissues due to desiccation, rendering these tissues vulnerable to invasion by pathogens that would typically pose less threat. Furthermore, drought can render plants more enticing to insects, some of which act as carriers for specific diseases. Studies have shown that electrolyte leakage increased with disease intensity and relative water content (RWC) was lower in diseased compared to healthy ones (Karthikeyan and Bhaskaran, 1998).

(b) *Root to root contact*: Experiments have shown that *Ganoderma* mycelium survives in the soil as a saprophyte but mycelium cannot move freely in rhizosphere due to microbial antagonism (Rees *et al.*, 2007). Therefore, for infection in a vulnerable tree to occur, contact between the diseased root bits or stump and the host root is a basic requirement. In the case of jojoba plantation, as discussed earlier, Disease manifested exclusively when the roots were in direct proximity to infected parts of the root, underscoring that the propagation of the root rot within the field is a consequence of root contact between healthy and diseased plants. Bakshi *et al.* (1976) has also made the similar observations. In earlier paragraphs we have discussed about *Ganoderma* infection in jojoba shrub growing near infected *Acacia tortilis* tree in CAZRI campus. Digging trenches at these sites broke the contact between infected *A. tortilis* roots and roots of jojoba plants and stopped the infection. Shallow root system of

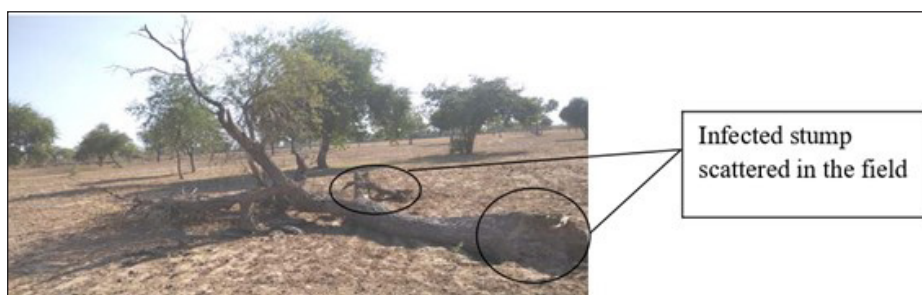


Fig. 4. Source of Inoculum of *Ganoderma* infection.

both *A. tortilis* and jojoba promoted infection of *Ganoderma*. Upon exposing the decomposing roots of *A. tortilis* to a depth of 40-50 cm, multiple instances of contact with infected jojoba roots were evident (Lodha *et al.*, 1994). Root-to-root contact as a source of disease spread has also been reported in *A. catechu* (Cutch tree) (Bakshi *et al.*, 1976), *Cocos nucifera* (L.) (coconut) (Bhaskaran and Ramanathan, 1984) and *Areca catechu* L. (Arecanut) (Kumar and Nambiar, 1990) and *Elaeis guineensis* (Oil palms) (Flood *et al.*, 2000; Worrall, 2004).

Studies conducted on *P. cineraria* showed that soil moisture stress is the most predisposing factor for making the tree vulnerable to infection. However, in past couple of decades *P. cineraria* trees even in arid climate have also started developing lateral roots because of the availability of moisture at the upper soil layer due to increased rainfall and irrigation in field with either underground water or canal water. A survey carried out in Neem Ka thana (Sikar) showed that for old *P. cineraria* trees (>25 years) (Fig. 4) stumps of *Ganoderma* infected *P. cineraria* left in the field and the infected material piled on the ground were the major infection source was through root contact (Mawar *et al.*, 2021a).

(c) *Mechanical injury*: Injury to the host root is considered an important factor for infection, which can be caused by a tractor, sickle, spade or any such means during agricultural operations. Such injuries expose host tissues and these sites make the way for mycelium from infected stumps to enter the injured portion. During a survey of several districts of arid region, a few of the *Ganoderma* affected trees were also found to be infected with an insect, *Acanthophorus serraticomis*. This insect has made tunnels in one or more roots of the *P. cineraria* tree, causing an insect-disease complex. This insect not only caused mechanical injury but also made *P. cineraria* trees more vulnerable to

*Ganoderma* infection (Ahmed *et al.*, 2004). Many other studies were conducted to assess the role of mechanical injury in *Ganoderma* infection (Ahmed *et al.*, 2004) and it can be conclusively said that mechanical injury has only a limited impact on *Ganoderma* infection.

#### *Penetration mechanism of pathogen*

The basic mechanism of the fungal infection of the woody material is the lignolytic and cellulolytic degradation of lignin and other polysaccharides. *Ganoderma* spp. is more effective in causing wood decay because of its higher enzyme activity. Enzymes also play a key role in fungal pathogenesis (Almeida *et al.*, 2015). The penetration of reaction zones by this fungus involves the breakdown of tyloses and polyphenolic deposits situated within the lumens of axial parenchyma and fiber-tracheids. The degradation of cell lumens occurs prior to the deterioration of the secondary wall, which eventually results in localized cavity formation as hyphae tunnel through the walls of fiber-tracheids. After the majority of tyloses and polyphenolic deposits have degraded, typically taking about 14 weeks, the fungus transitions to its recognizable white-rot mode, leading to substantial degradation of axial parenchyma along with the enlargement of simple pits and the creation of boreholes. The secondary cell walls of fiber-tracheids show erosion, starting around hyphae present in cell lumens and their internal layers display a staining reaction with safranin and astra blue, indicating delignification. By this stage, white-rot has progressed in the formerly sound sapwood beyond the reaction zone, causing some separation of neighboring fiber tracheids due to the delignification of middle lamellae. Additionally, selective delignification occasionally originates from the middle lamellae of ray parenchyma cells (Schwarze and Baum, 2000)

### Management strategies

At present, no satisfactory control for *Ganoderma* induced diseases under field conditions is available and efforts made in the past to manage this disease resulted only in partial control (Lodha and Harsh, 2009). The use of fungicides has not been effective in controlling *Ganoderma* and genetic resistance has not been reported for the disease in any of the vulnerable tree species. Isolating diseased trees from healthy ones by digging mechanical trenches reduces disease incidence (Bhakshi *et al.*, 1976), but is not feasible on large scale due to the scattered population of *P. cineraria* trees in agricultural fields. Amending soil with biocontrol agents (BCAs) supplemented with suitable substrate has been suggested as an easy, practical and long-term management strategy (Bhaskaran, 2000; Neeraja *et al.*, 2018). Bivi *et al.* (2010) to reduce instances of basal stem rot in natural habitats where another pathogenic species, *G. boninense*, coexisted. This discovery prompted the consideration that the disease might be managed through biological methods. Numerous Beneficial Microorganisms (BCAs), including fungal species like *Trichoderma* (Sariah *et al.*, 2005; Susanto *et al.*, 2005), *Burkholderia* (Sapak *et al.*, 2008), *Bacillus* (Suryanto *et al.*, 2012) and *Pseudomonas* (Bivi *et al.*, 2010) have demonstrated effectiveness in curbing *Ganoderma* colonization and infections, both in nursery and field environments, for oil palms and other species. BCAs present an appealing alternative for tackling diseases caused by *Ganoderma*, all while avoiding adverse environmental repercussions. This is attributed to BCAs' ability to inhabit the rhizosphere without leaving harmful residues, in contrast to fungicides (Dubey *et al.*, 2007). Enriching soils with BCAs, along with appropriate nutrient supplementation, has emerged as a pragmatic, long-term strategy for diminishing mortality due to *Ganoderma*-induced root rot (Bhadra *et al.*, 2016). The problem with this management strategy is that *Trichoderma* may not establish itself in the soil due to a lack of substrate and that a number of BCAs supplemented with substrate would be necessary to ensure their prolonged survival in arid sandy soils. If both the biocontrol agents and some more isolates from the same habitat, where *Ganoderma* exists, are combined together, chances of synergism leading to better control can be envisaged. In

studies conducted at ICAR-CAZRI, Jodhpur, it was frequently observed that a large population of actinomycetes and *Bacillus* spp. exists even in fairly dry soils (Lodha *et al.*, 1990). Also, in arid regions, soil temperature often reaches 50°C or more during the summer months (Lodha, 1995). Therefore, it is necessary to introduce native heat tolerant strains that can withstand high soil temperature. In a survey conducted in arid and semi-arid regions in 2015-16, effective bio-control agents were isolated from the rhizosphere soil of *Ganoderma* infected trees. The isolated BCAs were *Trichoderma longibrachiatum* (Accession no. NAIMCC-F-04134), *T. harzianum* (Accession No. MCC 1723) *Aspergillus nidulans*, *Streptomyces mexicanus* (Accession No. AF441168) and bacterium *Bacillus tequilensis* (Accession no. AYT001000043) (Mawar *et al.*, 2021a and b).

Laboratory investigations unveiled that native strain of bioagents such as *Trichoderma longibrachiatum*, *T. harzianum*, and *Aspergillus nidulans* displayed significant suppression of *G. lucidum* mycelial growth (Mawar *et al.*, 2021a). Experiments were conducted to establish the compatibility of these bioagents with varying concentrations of insecticides, viz., phorate (500 ppm, 1000 ppm and 2000 ppm) and chlorpyrifos (500 ppm, 1000 ppm and 2000 ppm), under conditions of both wet and dry soil. Significant variations in the survival of all three bioagents were observed in both conditions. Assessments of the interaction between insecticides and BCAs indicated that *T. longibrachiatum*, *T. harzianum* and *A. nidulans* can be synergistically utilized with phorate or chlorpyrifos (both organophosphates) at diverse concentrations. This could be used for partially infected trees or as a preventive measure for healthy trees (Mawar *et al.*, 2021a). Additionally, Mawar (2019) and Mawar and Mathur (2022) also found that for field application of the BCAs onion residue and *P. julifera* compost are suitable substrate.

The field application of BCAs should be followed by other measures (Srivastava and Verma, 2008) viz. (a) uprooting and burning of infected tree (b) digging isolation trenches in the case of row plantations (c) avoiding monoculture and planting resistant strains to break the continuity of fungal spread and (d) removal of old stumps at the time of new plantation. If keeping stumps is necessary for coppice plantations, the open surface

should be pasted with Bordeaux mixture or Chaubhatia paste. Similar studies were carried out by Srinivasulu and Raghava Rao (2009), who reported that the application of *Trichoderma* spp. caused lysis of the mycelium of *G. lucidum*. Furthermore, they have found that the application of *T. harzianum*/*T. viride*/*T. hamatum* pasted over bleeding patches and the soil application of the bioagents @ 50 g in 5 kg neem cake have reduced the perimeter of the *Ganoderma* wilt patches on coconut trees. A study was also conducted by Neeraja *et al.* (2018) in the east Godavari District of Andhra Pradesh to standardize the dosage, frequency and method of application of effective biocontrol agents by soil application of talc-based formulations of *T. reesei* and *Pseudomonas fluorescens* along with Neem cake, which reduced the disease index from 28.44 to 4.23 within a period of three years and also increased the nut yield under field conditions.

## Conclusion

Use of biological control agents provides a better substitute for addressing *Ganoderma*-induced diseases, presenting a solution that doesn't entail any detrimental repercussions on the environment. This is due to the fact that biological agents establish a presence in the rhizosphere and avoid leaving behind toxic residues, unlike fungicides (Dubey *et al.*, 2007). The impact of BCAs has been attributed to various mechanisms, as proposed by Chen *et al.* (2000). Amending soil with bioagents supplemented with suitable nutrient sources has been suggested as easy, practical and long-term management strategy to minimize *Ganoderma*-induced root rot mortality (Lodha and Harsh, 2009). Biocontrol agents need to be pesticide-resistant or tolerant for use in such programmes for simultaneous control of associated insects. Field studies investigating fungicidal control have yielded inconclusive results (Idris *et al.*, 2002), largely as *Ganoderma* has various resistant resting stages, such as melanised mycelium, basidiospores, and pseudosclerotia, that are less responsive to fungicides (Susanto *et al.*, 2005). Notably, Bivi *et al.* (2010) observed diminished basal stem rot incidence in specific natural stands where another pathogenic species, *G. boninense*, coexisted. This observation led to the hypothesis that biological approaches might effectively curb the disease. Several potential biological

control agents (BCAs), such as *Trichoderma* species (Sariah *et al.*, 2005; Susanto *et al.*, 2005), *Burkholderia* (Sapak *et al.*, 2008), *Bacillus* (Suryanto *et al.*, 2012) and *Pseudomonas* (Bivi *et al.*, 2010) have demonstrated effectiveness in controlling *G. boninense* colonization and infection in nursery and field settings, not only in oil palms but also in other tree species (Neeraja *et al.*, 2018). Leveraging BCAs presents an appealing strategy for mitigating *Ganoderma*-induced diseases, free from any detrimental environmental impact. This stems from BCAs' ability to establish a presence in the rhizosphere without leaving toxic residues, a notable contrast to fungicides (Dubey *et al.*, 2007). Hence, it becomes imperative to promptly address the outlined factors by devising strategies using cutting-edge technologies, high-throughput field device systems, biochemical assays, novel compounds, cultural techniques and the application of a "Highly Efficient Microbial Consortium." This approach provides a powerful means to combat *Ganoderma* with its wide-ranging antifungal abilities, ensuring affordability, efficacy and ecological soundness in disease control practices.

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## Declarations

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