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Review Article

Sissoo, its Pathogenic Constraints and their Management in Nepal: A review

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Abstract

Sissoo (*Dalbergia sissoo*) is a deciduous tree, native to Nepal and the Indian subcontinent. The tree is traditionally used for making furniture, fodder and herbal medicine. It is also used as shelter-wood, and in conserving soil in degraded areas. This review focuses on the health management practices against pathogenic constraints in sissoo. Literature published till June 2020 was considered to understand the biology of the tree species and associated pathogens apart from understanding the management practices to treat the diseases. Despite the massive significance of this tree, available publications on the pathogenic risks and the strategies to cope with them are unnoticed so far. This article expects to bring together information on sissoo tree's biology, pathogen attacks and its management. Of various fungal diseases in sissoo, this article deals with only two of the fungal diseases, *Fusarium solani* and *Ganoderma lucidum*, which cause dieback and root rot in sissoo, respectively. The findings highlighted can further reinforce the current sissoo management and pathogen control strategies and improve its health to augment high quality timber.

Keywords

Dieback; *Fusarium*; *Ganoderma;* Root rot; Sissoo

Introduction

Sissoo (*Dalbergia sissoo*) is a multi-purpose tree species grown in the Indian subcontinent (Hossain and Martin, 2013). It is grown throughout the riverine forest of Nepal from the East to West (72 m to 1500 m altitude) (Parajuli *et al*., 1999). It grows up to 30 m in height and 80 cm in diameter at breast height (DBH) in a suitable geoclimatic condition (Naqvi *et al*., 2019) occupying well-drained areas near streams and rivers (Shah, Mukhtar and Khan, 2010).

The primary botanical characteristics of sissoo include pinnately compound leaves with alternate pinnation (Bhattacharya, Singh and Ramrakhyani, 2014). The leaflets are broadly ovate, leathery, acuminate, glabrescent and petiolate. Flowers (5-8 mm long) are scented and whitish to pink in colour. The fruits are in the form of pods, which are oblong, flat, thin and strap-like (4-8 cm long and 1 cm wide). Each fruiting pod contains 1-4 kidney-shaped thin, flat, and light brown seeds (Bhattacharya, Singh and Ramrakhyani, 2014). The tree has a long tap-root system and several surface roots producing suckers. Young shoots are downy and dropping while mature tree stems have light brown to dark grey bark up to 2.5 cm thickness, shed in narrow strips (Kumar and Khurana, 2016). The tree has a spreading oval crown supported by its large upper branches (Sultana *et al*., 2015).

Commercially, it is used for manufacturing furniture, cabinets, veneers, plywood and musical instruments (Sharma, Singal and Pokhriyal, 2000). Because of its superior quality, color, grain, finishing and durability of hardwood, sissoo is preferred for furniture trade (Bajwa, Javaid and Shah, 2003). As medicines, sissoo bark is used for its anthelmintic property, leaves as an expectorant (muco-active agent), and wood as an antipyretic (fever reducer) and abortifacient (abortion-causing agent) (Shah, Mukhtar and Khan, 2010). In Nepal and India, leaf extracts of sissoo are also used as medicine for gonorrhoea, syphilis, dysentery, sore throat and heart problems (Al-Quran, 2008). The extracts also possess antioxidant property (Yadav *et al*., 2008). Sissoo trees are also excellent nitrogen fixers, drought-tolerant and effective in recovering sodic land when they are planted in woodlots (Mishra, Sharma and Khan, 2002). However, the ecologically and economically significant sissoo trees, due to different site (salinization, drought, and nutrient depletion) and pathogenic stresses, face a severe problem of reduced productivity, especially in south Asian farmlands (Mishra, Sharma and Khan, 2002; Alauddin and Quiggen, 2008).

The records reveal the exposure of sissoo to several diseases in different environmental settings, causing severe damage to both plantations as well as naturally growing trees. The prevalent diseases mostly include root and foliage damage, caused by phanerogamic parasites and poor soil drainage (causing physiological disorders) (Yousuf, 2002). Several forest pathologists have reported diseases such as powdery mildew, leaf rust, leaf blight, collar rot, wilting, dieback and *Ganoderma* root rot (Bakshi, 1954; Zakaullah, 1999; Khan, 2000). Wilting (dropping of leaves and branches due to loss of turgidity in plant cells) and dieback (progressive death of twigs and branches from apex to base) diseases in sissoo are still common in recent decades (Shah, Mukhtar and Khan, 2010; Al-Quran, 2008; Ahmad, Khan and Siddiqui, 2013). Dieback disease is mostly caused by *Fusarium solani* (Rajput *et al*., 2012) and wilting is its major symptom (Bajwa, Javaid and Shah, 2003). However, wilting in sissoo can be caused by the infection from several pathogens other than *F. solani*. Further, *Ceratocystis fimbriata* is believed to be the principal pathogen of sissoo tree causing gummosis (pathological exudation of gum by a plant resulting from fungal or bacterial infection), wilting and chlorosis (yellowing of leaf tissue due to lack of chlorophyll)

(Poussio *et al*., 2010). Browne (1968) also reported the serious wilt of sissoo seedlings in nurseries in Pakistan caused by *Fusarium oxysporum*. Similarly, *Ganoderma* root rot is another common disease in sissoo (caused by *Ganoderma lucidum)*, which results in wilting of the plant.

The studies on pathogenic stresses of sissoo are significantly lesser in Nepal even though the vast plantation areas are rendered useless time and again (Thapa, 1990; Karki, 1992; Parajuli *et al*., 1999). However, we can refer to the research carried out in other countries of South Asian region having comparable growing conditions to seek a solution for it. Available literature from Nepal attributes to the vast monoculture practices, deficiency of good seeds, lack of well-equipped institutions and administration for the disease attacks in Terai region (lowland region in Southern Nepal and Northern India) plantation areas (Parajuli *et al*., 1999; Joshi and Baral, 2000). The main objective of this article is to review the globally available literature on sissoo trees, and management practices to develop a comprehensive health management plan addressing two principal fungal stresses (*G. lucidum* and *F. solani)*.

Methodology

Method includes reviewing the published and unpublished research articles from 1954 to 2020. Google scholar and ResearchGate were the primary databases used for obtaining the literature with keywords "*Dalbergia Sissoo*", "Sissoo", "Dieback and Wilting", "Sissoo root rot", "*Ganoderma lucidum"* and "Diseases and pathogens of Sissoo". Finally, 83 published and unpublished items were picked up for review and analysis.

Results and Discussion

Taxonomy of Sissoo

Table 1 provides details on the Taxonomic classification of sissoo.

Table 1**:** Taxonomic classification of sissoo

Kingdom	Plantae
Division	Magnoliophyta
Phylum	Tracheophyta
Class	Magnoliopsida
Order	Fabales
Family	Fabaceae
Genus	*Dalbergia*
Species	*sissoo*

Source: Vasudeva *et al*., 2009; Sultana *et al*., 2015

Distribution of Sissoo

The geographical distribution of sissoo is diverse and dispersed in different zones of tropical Asia, Australia and North America (Thothathri, 1987). It is magnificently grown in Nigeria, Sri Lanka, Kenya, Java, Mauritius, Palestine, South Africa and Northern Zimbabwe (Tewari, 1994). Furthermore, figure 1 shows the worldwide distribution of sissoo trees.

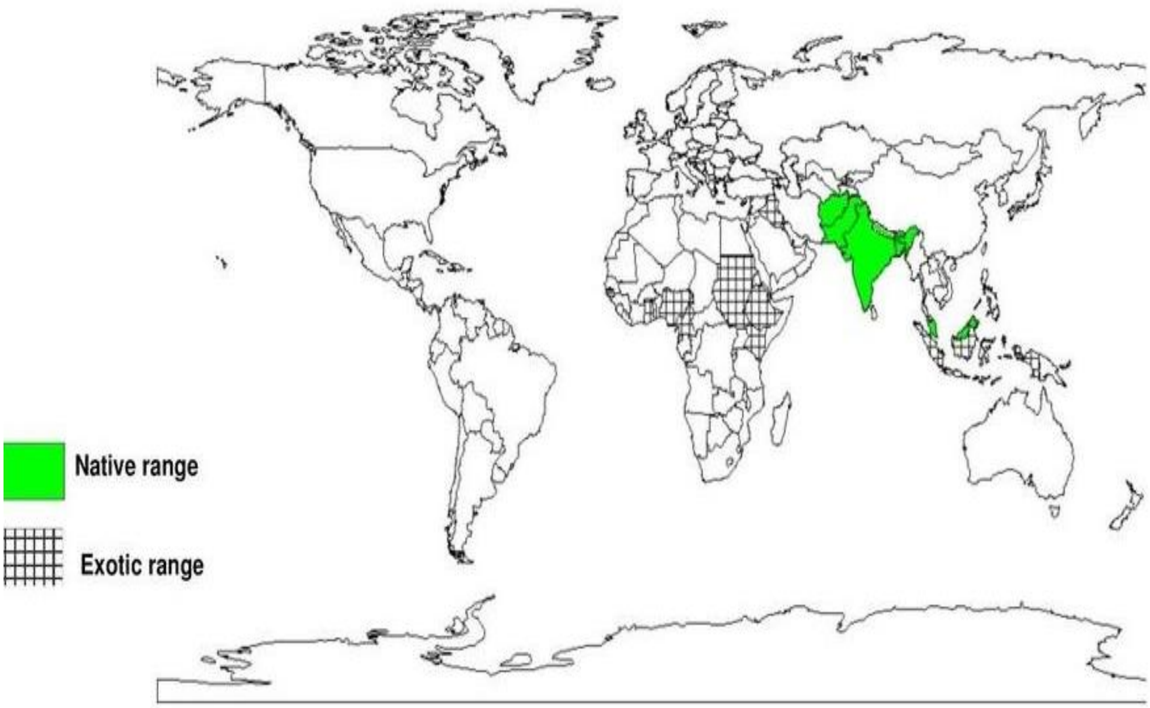

Figure 1: Native and exotic ranges of sissoo (Orwa *et al*., 2009)

Incidence of the Pathogens

The fungal pathogens in sissoo have been extracted from different parts of the plant such as leaves barks and roots. Khan *et al*. (2004) states that *Colletotrichum* species of leaf blight fungus infects stem and branches of sissoo, while *F. solani* infects root of the plant. Rehman *et al*. (2012) recorded the pathogens mostly infect roots rather than twigs and barks. The pathogens such as *Macrophomina phaseolina* (that attacks leaves and barks), *F. solani* (affects roots, barks and stem), *Fusarium oxysporum* (affects leaves and barks), *Fusarium moniliforme (*affects leaves and roots), *Rhizoctonia solani* (infects sissoo leaves and barks), and *Botrytis* species (affects roots of sissoo) were recorded from Swabi district of Pakistan. Comparing the incidences in barks, roots and leaves, *F. solani* causes higher rate of infection in roots (Parveen *et al*., 2019). Ahmad, Hanan and Gul (2015) reported *Botryodiplodia theobromae* as the chief causative agent of dieback disease in sissoo in Faisalabad of Pakistan. They further noted that *F. oxysporum, F. solani* and *B. theobromae* are concentrated in stem, leaves and the whole plant, respectively. Besides, there are four species of *Aspergillus* recorded, *A. flavus, A. fumigatus, A. japonicus* and *A. teerius* (found in seeds), which are responsible for ceasing the germination of the sissoo seeds (Javaid, Shafique and Bashir, 2010) (Table 2).

Table 2: Fungi isolated from different parts of sissoo

Fungi Isolated	Nature of disease	Plant parts affected
Botryodiplodia species	Soil-borne	Roots
Cladosporium species	Soil-borne	Seeds, Pods

Colletotrichum sissoo	Air borne	Leaves
Aspergillus species	Seed-borne	Seeds, Pods
Ganoderma species	Wood rot	Heart wood
Fusarium solani	Soil-Borne	Roots, Heart wood
Slternaria species	Seed-borne	Seeds, Pods
Phoma species	Leaf blight	Leaves
Maravalia achora	Leaf blight	Leaves
Phyllachora dalbergiae	Leaf spot	Leaves
Phyllactinia dalbergiae	Powdery mildew	Leaves
Uredo sissoo	Leaf rust	Leaves
Polyporus species	Wood rot	Heart Wood

Source: Manandhar and Shrestha, 2000; Naqvi *et al*., 2019

Decline and Dieback of Sissoo

Generally, a decline in sissoo is attributed to the decrease in development, maturation, power and vigour of the plant, whereas complete destruction of the tree crown is considered as dieback (Naqvi *et al*., 2019). Fungal pathogens including *Fusarium solani, Fusarium oxysporum, Phytohpthora cinnamomi, Curvularia lunata, Ganoderma lucidum* and *Rhizoctonia solani* are recognized as causative pathogens for rapid decline and death of sissoo (Ahmad, Khan and Siddiqui, 2013). Rajput *et al*. (2010) detected ten fungi from different parts of the sissoo tree; and by inoculation they observed that *F. solani* causes higher infections (75%) compared to other fungi. Similarly, Shakya and Lakhey (2007) also confirmed *F. solani* to be the causal agent for dieback of sissoo in a lab experiment on diseased host samples collected from different parts of Nepal.

Sissoo is under critical risk of dieback disease for last few decades in Pakistan (Ahmad, Khan and Siddiqui, 2013), India (Sharma, Singal and Pokhriyal, 2000), Bangladesh (Tantau *et al*., 2005) and Nepal (Thapa, 1990), and disease is affecting millions of sissoo trees in these countries (Vogel *et al*., 2011). This disease has been a serious threat to sissoo forest and timber production activities in India, Nepal, Pakistan, Bangladesh and Afghanistan since 1993 (Shukla, 2002). Wilting is the common symptom of decline and dieback (first observed in natural and plantation forest in Uttar Pradesh, India) (Bakhshi, 1954). Wilting takes place when the vessels of a tree get plugged by fungal (*F. solani*) hypha (Bajwa, Javaid and Shah, 2003; Bakhshi, 1954; Bakhsai and Singh, 1959). About 80% of sissoo trees in Punjab of Pakistan were reported to be suffering from wilting along the canal bank and roadside areas; however, the trees growing in the agricultural and well-managed lands were less disturbed by wilt and dieback disease (Bajwa and Javaid, 2007).

Both biotic and abiotic stress agents are responsible for the dieback disease hampering the natural physiological activities of plants (Basak, Baksha and Khair, 2003), among which insects and pathogens are biotic stress agents while extreme temperature, drought, and waterlogging conditions are abiotic stress agents (Naz *et al*., 2015). The sissoo tree weakened by *F. solani* finally dies due to further stresses from the environment and other biotic factors (Javaid, Bajwa and Anjum, 2004). Various secondary factors including insects (termites), fungi (phytophthora), livestock (causing girdling on the tree), human activities (pruning, herbicide spray drift, etc.), and climate change are responsible for the dieback of sissoo (Simpson, 1993; Bajwa, Javaid and Shah, 2003).

Besides, sissoo dieback is also found to be associated with the tree age (Ahmad *et al*., 2019), bacteria (Aktar *et al*., 2016; Valdez *et al*., 2013) and viruses (Vogel *et al*., 2011). Acharya and Subedi (2000) conducted a field survey from 28th March to 19th April 2000 to quantify the degree of damages caused by dieback in sissoo in the western region of Nepal where they recorded mortality of over-matured dieback-affected sissoo trees in a short period of time. Tantau *et al*. (2005) performed 16S rDNA sequence analysis[1] of trees suffering from dieback and found bacteria as a causative agent of dieback disease. They found *Pseudomonas* bacteria in the samples of severely affected sissoo tree. Recording presence of double stranded RNA and other viral particles in leaf samples of sissoo trees infected with dieback, Vogel *et al*. (2011) concluded that dieback is caused by viruses too.

Symptoms of Dieback in Sissoo

Some common symptoms of dieback disease of sissoo trees are dried leaves and branches, alteration in color and wilting of the crown, which finally leads to death of the tree (Tantau *et al*., 2005). Dieback infected trees also bear the reduced leaf size, lesioned stem (producing gum), change in leaf color (dark green to light green or yellow) and, finally, the entire tree gets defoliated leaving the branches leafless and desiccated from apex to base (Ahmad, Khan and Siddiqui, 2013). Pathogens causing dieback are mostly found in roots of sissoo but sometimes in trunk bases too (Tantau *et al*., 2005). Symptoms first appear in the crown of the tree and then move downwards, leading to a stag headed condition in the severe stage (Khan, 2000; Bajwa, Javaid and Shah, 2003).

Management of F. solani (fungus causing dieback in Sissoo)

Billions of sissoo trees have been rendered useless in different parts of South Asia until now due to the dieback and decline disease; still, the practical solution is unavailable (Naqvi *et al*., 2019). The mitigation approaches adopted for this disease are slightly different in various regions of South Asia with more focus on control measures rather than the preventive measures. However, the awareness generating seminars for the local people besides the technical interventions to control the disease are producing positive results in Pakistan (Javaid, 2008). For any type of disease control, information on the history of disease, frequency of epidemic, prevalent pathogens, resistant host varieties, locality factors, accessibility of labour, and cost would be beneficial before carrying out the intended management activity (Agrios, 2005).

Studies reveal that *F. solani* could be controlled both biologically and chemically. Studies show *Trichoderma* species to be effective against the growth of *F. solani* due to the production of both antibiotics and extracellular lytic enzymes working against the fungal development (Elad, Chet and Henis, 1982; Basak and Basak, 2011; Banerjee *et al*., 2020). *Trichoderma harzianum* releases chitinolytic enzymes that control the development of various pathogenic fungi (Lorito *et al*., 1993). Further, chitinolytic enzymes produce volatiles that suppress the growth of fungal species and cause vacuolation of its cell, followed by the breakdown of fungal hyphae (Brasier, 1975).

The biological control measures alone might not be the sole solution for this pathogen, where it demands the introduction of chemical inhibitors. In most of the cases in Nepal, studies show the frequent use of Bordeaux mixture (50% lime + 50% copper sulphate) paste (Karki *et al*., 2000;

[1] 16S rDNA sequence analysis is a broadly used technique for the identification of bacteria (Sun *et al*., 2008).

Parajuli *et al*., 1999). To overcome *F. solani* in India, different kinds of fungicides, namely Antracol, Copper Oxychloride, Ridomil Gold, Dithane M-45, Alliete and Topsin-M, were tested against *F. solani* in varying concentrations (Nene and Thapliyal, 1993). Dithane M-45 and Ridomil Gold were most effective against *F. solani* whereas Topsin-M and Alliete showed partial results. Antracol and Copper oxychloride were least efficient in retardation of fungal growth. Similarly, in another study, Ridomil Gold, Dithane M-45, Captan, Bayleton and Benomyl exhibited higher effectiveness against the mycelia growth of *F. solani* in-vitro. In contrast, Alliete showed minimal influence against this fungus, while Benomyl was useful in-vivo only (Rai and Mamatha, 2005). Further, Dennis and Webster (1971) suggested that Carbendazim and Captan have the inhibitory effect on the mycelial growth of *F. solani*. Moreover, Ahmad *et al*. (1996) reported Vitavax, Bavistin, Dithane M-45 and Benlate to be capable of retarding the growth of mycelia in *F. solani*. Injecting Methyl-2benzi Maidazol carbamate (MBC) (a precipitate) toxicant (derived from benomyl fungicide) is also believed to be effective against sissoo wilting due to its firmness and strength (McWain and Gregory, 1973). Although several chemicals have been tested against *F.* solani, Idrees *et al*. (2006) claimed no cure for it when the disease prevalence exceeds 25% in his experiment, which used Topsin-M, and Dithane along with other chemicals (M-45, Trimitox Forte, Score and Derosal) in Pakistan for the control of sissoo dieback disease. The results from the experiments infer the toughness to cease or overturn the advancement of the disease once the symptoms of dieback are onset (Javaid, Bajwa and Anjum, 2004).

Ganoderma Root Rot in Sissoo

Ganoderma root rot in sissoo is caused by the fungus *Ganoderma lucidium* (division Basidiomycota). *G. lucidum* attacks both natural and plantation sissoo forest spreading quickly on light-textured soil as compared to heavy textured; therefore, the trees are swiftly killed in such sites (Bakshi, 1974). Once the tree is infected with this fungus, it attacks the cambium of the tree and interferes with the nutrient and water supply, eventually leading the tree to death (Bhattarai *et al*., 2020).

Generally, *G. lucidum* infects broad and small-leaved trees in natural forest (Bakshi, Reddy and Singh, 1976) and sissoo is one of them. *G. lucidum* (Fr.) Karst. (Dadu chyau in Nepali) has been documented from different parts of Nepal on various substrates like rotten trunks (from Bakhri kharka, north of Pokhara) (Balfour-Browne, 1968), tree trunks (from Lele, Kathmandu) (Singh and Nisha, 1976), and trunk of *Rhododendron arboretum* and *Quercus* species (from Manichur, Kathmandu) (Adhikari, 1988). In early 1989, it was reported that *G. lucidum* was responsible for the mass-mortality (75% of total) of a ten-year-old sissoo plantation in Teekapur, Kailali District, Nepal (Thapa, 1990; Karki, 1992). The general means of *Ganoderma* spore introduction in hosts and its life cycle is presented in figure 2.

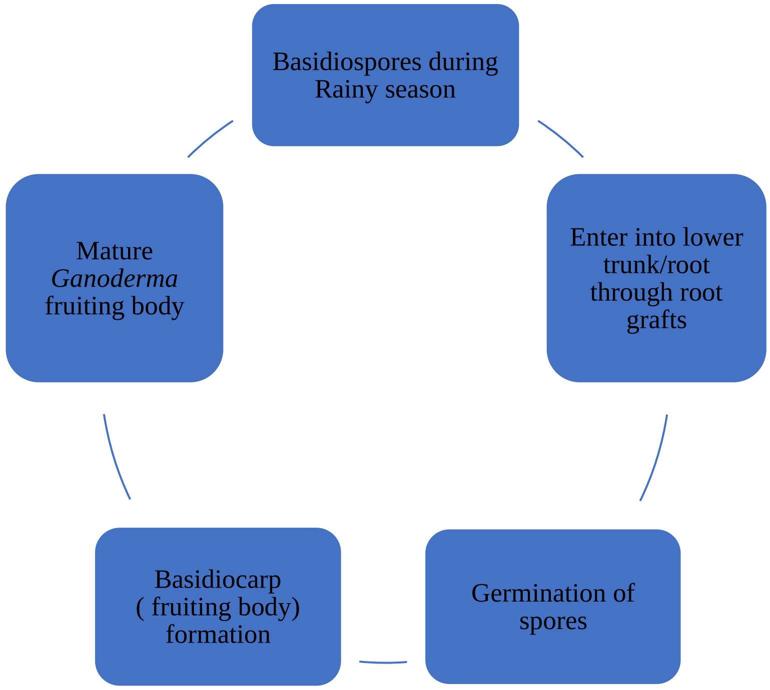

Figure 2: Life cycle of *G. lucidum* (adopted from Bhattarai *et al*., 2020).

Signs and Symptoms of G. lucidum

The initial visible sign of infection is the formation of fruiting bodies (description provided in Table 3 and Figure 3), either single or in clusters, on the lower trunk and exposed root areas (Verma, 2014; Bhattarai *et al*., 2020). However, the appearance of conks (shelf-like fruiting bodies around 14 inches or 35.6 cm wide) is the final sign after which the disease becomes irreversible (Missouri Botanical Garden, 2012). The basidiocarp (basidium (spore) bearing fruiting body) of *Ganoderma* is annual, hard, and brittle and appears in the rainy season (Bhattarai *et al*., 2020). It is originated on a brown stalk, laterally stipitate, and can be observed in the collar or basal region of the tree (Verma, 2014; Zhou *et al*., 2015). Its upper and lower surfaces are yellowish-brown and white, respectively, and produce a white mycelial mat in between bark and the wood of infected trees (Verma, 2014). In the sissoo tree, *G. lucidum* infects root through wounded surfaces, damages bark and causes white fibrous rot in the sapwood. This fungus spreads through root contact from tree-to-tree, and symptoms start to appear from the third year of plantations (Bakshi *et al*., 1972). Followed by the infection, the whole tree becomes leafless, branches start dying, and ultimately the tree dies within a few years. Infected trees exhibit a stag-headed condition in the beginning and finally, root and butt rot right before the death (Shah, Mukhtar and Khan, 2010; Bakshi, 1974). Yellowing of leaves, wilting, appearance of undesirable leaves, dead branches, and decay of sapwood are other symptoms of this fungal infection (Shah, Mukhtar and Khan, 2010).

Table 3: Description of *Ganoderma lucidum* fruiting body

Scientific name	*Ganoderma lucidum*
Common name	Reishi mushroom
Family	Ganodermataceae
Colour (mature fruiting body)	Red with white colour pores

Length (mature fruiting body)	6.4 cm
Width (mature fruiting body)	3.5 cm
Spore bearing surface under cap	Pores on hymenium
Spore diameter (average)	Length: 9.0 µm, Width: 5.53 µm
Spore shape	Single-walled, smooth and oblong or spherical
Pileus (fruiting body)	Whitish, dry and curved in the margin
Texture of the fruiting body	Woody
Flesh odour (fruiting body)	Disagreeable
Pores colour	White

Source: Aminuzzaman and Das, 2016

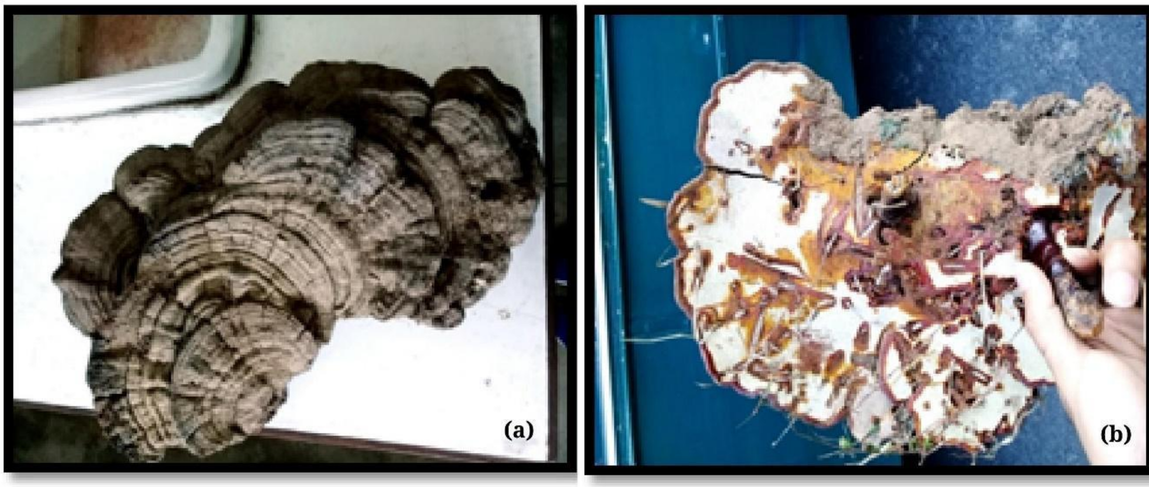

Figure 3: (a) Dorsal view, and (b) Ventral view of the *G. lucidum* fruiting body

Control Measures of G. lucidum

Similar to the biological control measures applied for *F. solani*, *Trichoderma* species themselves are the most effective biocontrol agents for *G. lucium* reported so far because of their considerable potential on growth reduction of *G. lucidum* in vitro (Srilakshmi *et al*., 2001). Among the three species of *Trichoderma, T. viride, T. harzainum,* and *T. pseudokoningii* the maximum reduction of fungal growth was showed by *T. harzianum* (68.5%) followed by *T. viridae* (65.7%) and *T. pseudokoningii* (Nirwan *et al*., 2016). In plantation, we can directly apply the fungus (available in market under different trade names) on the seed/seedling or in the soil.

In vitro studies performed by Nirwan *et al*. (2016) on the management of root rot disease (caused by *G. lucidum*), the fungicides, Bavistin 50% WP, Mancozeb (Dithane M-45 75% WP), propiconazole 25% EC, and Copper oxychloride 50% WP, were tested at four different concentrations (0.1%, 0.15%, 0.2%, and 0.25%) against the target fungus. Amongst four of them, Bavistin, Mancozeb, and Propiconazole suppressed the fungal growth (100%) at even the lowest chemical concentration. Chakrabarty, Acharya and Sarma (2013) in their study experimenting on similar fungicides (Calixin (tridemorph), Bavistin, and Mancozeb) experimented in-vitro reported higher strength of Bavistin (100% inhibition) and Calixin (Tridemorph) (91.3 % inhibition) for fungal growth control. The study also compared Bordeaux mixture with Bavistin and claimed to be equally efficient in reducing the growth of *G. lucidum.* Additionally, Bhattarai *et al*. (2020) also recommend the use of tridemorph containing fungicides to control the fungus.

Health Management Plan of Sissoo against F. solani and G. lucidum

The management plan is designed based on the prevalent risk factors and host-pathogens biology. The plan comprises three fundamental working units. The overall management plan strongly emphasizes on the preemptive measures to avoid the disease incidence and later focuses on the implementation of control measures. Figure 4 summarizes the management plan of sissoo in the form of a flow chart.

Preemptive Measures

These measures are applied before the disease incidence takes place. They help to cope with the risk factors and prevent the disease outbreak. Given that the over-aged sissoo trees are highly susceptible to the fungal attack (Acharya and Subedi, 2000; Ahmad *et al*., 2019) their removal from the forest stand is highly recommended. The first step before the new plantation to prevent the disease should be the elimination of decayed wooden fragments and fungal fruiting bodies from the last plantation. Disinfecting the nursery beds with any fungicide before sowing sissoo seeds and cuttings should be mandatory. Moreover, focusing on light-textured soil, better drainage conditions, deep planting and irrigation to develop a deep and healthy root system will make sissoo trees less susceptible from *F. solani* and *G. lucidum* both.

Growing disease-resistant trees is another simple and effective measure to discourage disease incidences. Among several ways of obtaining disease-resistant breeds, quality seeds from breeding seed orchards (BSOs) (stand grown to produce superior seeds) could be considered. Moreover, time to time consultation with the forest department for acquiring improved seeds and seedlings with strict quarantine during their transport from one site to another will also aid in disease control. Besides, promoting mixed plantation of sissoo with resistant varieties like *Acacia nilotica*, and *Morus* species should be encouraged since these species are widespread in Nepal. Since the high forest sissoo trees are facing a severe risk of dieback in the South Asian subcontinent (Singh, Yadav and Bhatt, 2011), the cultivators would benefit from adopting vegetative propagation (branch cutting) to mitigate this issue. Taking into account the fact that wounds in the plant body are the entry point for the fungi (Khan *et al*., 1965), silvicultural practices like pruning and thinning should be strictly followed as suggested by the forestry experts to prevent and treat the wound to discourage the entry of fungi.

Regular Monitoring and Survey of the Signs and Symptoms

Monitoring is an intermediate step focused on the identification of disease and preventing its spread from the infected to healthy trees. Aim of this approach is to identify the disease as soon as possible from the disease signs and symptoms. During monitoring, observed wounds in roots and trunks should be sealed with rubber latex and grafting wax or treated with fungicides to prevent the fungal infection. The monitoring should be performed in a participative way between the locals and forest technicians, for the better identification of signs and symptoms. In case of unidentified signs and symptoms, fertilization and watering the trees (especially in private or accessible stands) enhance the concentration of the nutrients in soil that provides resistance power to the tree against the fungi. Use of farmyard manure (possessing antifungal characteristics) is highly recommended for fertilizing the soil.

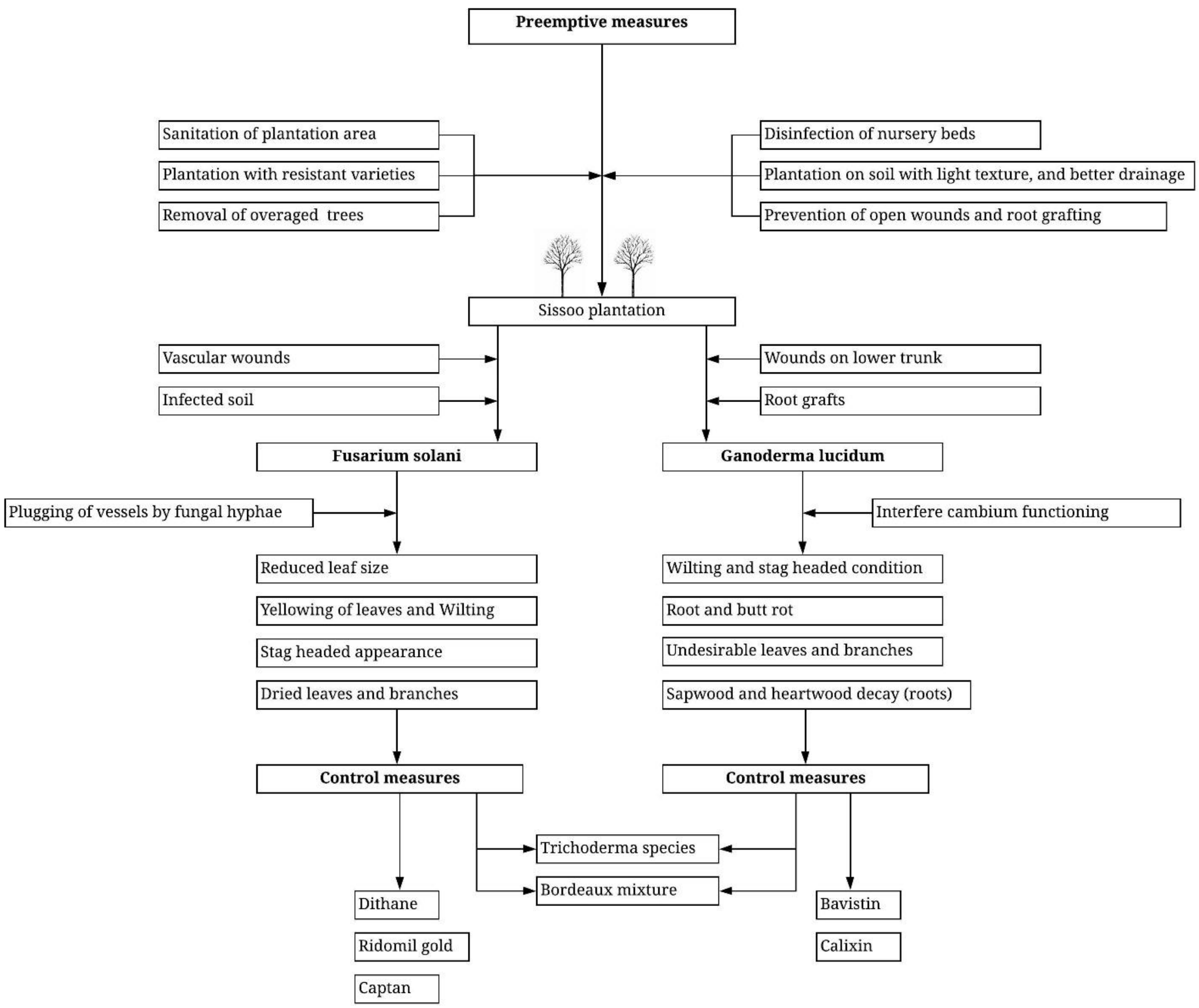

Figure 4: Health management plan of sissoo. The flow chart emphasizes on the causal agents of diseases, their identification, and measures to prevent and control them. Authors conceptualized the flowchart.

Reactive Measures

This section deals with treatment of the disease to prevent further loss and spread. For treating a diseased tree, first, biological measures to avoid the side effects of chemicals in the environment and human health are recommended. In case the biological methods fail to perform, the adoption of chemical controls is justifiable. Analyzing the adopted control measures against *F. solani* and *G. lucidum*, test of *Trichoderma* species as a biological control measure is proposed in Nepal. In case of chemical control measures, wide varieties of chemicals have been experimented against *F.*

solani so far, but their credibility for use in Nepalese context is uncertain. Still, observing the repetitive success of Dithane M-45, Ridomil gold and Captan in other countries, such chemicals for testing their effectiveness are recommended. However, use of Bordeaux mixture can be introduced as new control measure. Similarly, for *G. lucidum*, the fungicides, namely Bavistin, Calixin and Bordeaux mixture, have been observed promising.

Furthermore, if the treatment and cure are not possible or none of the treatment methods is proving useful, then extraction and destruction of the diseased component is recommended. The Government of Nepal reported the implementation of one farmer strategy in Nepal to remove dead and dying trees from the site, to inhibit the spread of *Fusarium* throughout the plantation (DoFRS, 2000). Still, the effectiveness of this strategy is unproven (Webb and Hossain, 2005). However, the best idea is to remove the infected trees immediately after it starts showing the symptoms of dieback to prevent the further spread of *F. solani* and destroy the whole tree along with fruiting bodies to restrict the spread of *Ganoderma lucidum*.

Conclusion

Sissoo is a multi-use tree species with a huge traditional and ecological significance especially in the South Asian region; however, *Fusarium solani* and *Ganoderma lucidum* are causing the serious problem of dieback and root rot, respectively, in almost all the countries where it grows. The past and current health management practices for sissoo against the pathogenic fungi are heavily relying on the chemical control strategies, which are polluting the environment as well as imparting complexity of use among the cultivators. The health management plan, which encourages the use of fewer chemicals, and more biological and silvicultural control measures, is proposed in this article. Among the chemicals suggested for control, Bordeaux mixture is serving to prevent both the fungi and should be adopted before trying others. The suggested management plan is a blend of strategies for all growing areas of sissoo in Nepal. A trial of the suggested management approach is recommended first on a small scale with possible upscaling upon the success. Therefore, there is abundant scope to use the recommendations given in this article incorporating the policy part for Nepal government. Further, investigations on additional stress agents interfering the growth and development of sissoo should also be taken up in the future.

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