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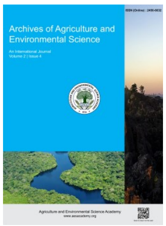

REVIEW ARTICLE

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Pests, pathogens, pathogenic diseases, and diseases control strategies of sal (*Shorea robusta*) in Nepal

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ABSTRACT

Sal (*Shorea robusta*) is one of the most indispensable species in Nepal, both ecologically and economically. This paper aims to provide updated guidance for the management and protection of this species in the future from various pests and pathogens. We reviewed 38 articles from Google Scholar and Research gate with keywords "*Shorea robusta*", "*Hoplocerambyx spinicornis*", "*Polyporus shoreae*", "Heart rot". *S. robusta* has the most insect fauna among the forest tree species. Out of the 346 insects reported on *S. robusta*, around 155 species of insects are associated with living trees. *Hoplocerambyx spinicornis* is the most destructive insect pest, wreaking havoc on *S. robusta*. *Polyporous shoreae* is the main cause of root rot in *S. robusta*, and spreads through root contact or root grafting. Heart rot in *S. robusta* is caused by the fungi *Hymenochaete rubiginosa*, *Fomes caryophylli*, and *F. fastuosus*. During the harvesting of *S. robusta*, the majority of the tree was observed to be faulty, resulting in a large amount of waste wood. The best way to determine the pathogen's "Achilles' heel" is to consider its life cycle. The Nepalese famous saying "prevention is better than cure" may be applicable in the management of *S. robusta* insect pests and pathogens. The current paper critically addresses these issues and argues the need for an improvised package of activities for insect pests, pathogens, prevention, and their control.

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INTRODUCTION

Sal (*Shorea robusta*) is an ecologically and economically important and widely used timber species for building and commercial purposes (Kanel *et al.*, 2012). *Shorea robusta* dominates more than half of Nepal's Terai forests (Webb and Shah, 2003). *S. robusta* can be found in both dry and wet evergreen forests (Jackson, 1994). It is a large semi-deciduous (Pandey and Shukla, 2001) and gregarious tree with a height of 18-32 m and a girth of 1.5-2 m in usual conditions (Orwa *et al.*, 2009). It coppices reasonably well up to a diameter of 20-30cm (Jackson, 1994). The occurrence of *S. robusta* is influenced by the moisture availability in the soil. It is a light-demanding, moderately frost hardy, drought-sensitive, and fire hardy species (Thakur, 2003). The primary associates' species for *S. robusta* are *Garuga pinnata*, *Litsea monopetala*, *Bauhinia variegata*, *Bauhinia purpurea*, *Adina cordifolia*, *Terminalia tomentosa*, *Toona ciliata*, *Lagerstromia parviflora*, etc. where *Clerodendron infortunatum* (Bhat) is a good site indicator and *Vitex Negundo* (Nigalo) is a bad site indicator of *S. robusta* (Thakur and Phulara, 2014).

S. robusta is a hermaphroditic (Bisexual) and self-incompatible (Outbreeding) species (Orwa *et al.*, 2009). *S. robusta* bears fruit every two or more years after reaching the age of 15, and a successful seeded year can be predicted every 3-5 years (Jackson, 1994). Wind and water are two major seed dispersing agents. Germination is completed within 10-28 days (Thakur, 2003). Seed viability is one week and the seed loses its viability very quickly. The durability of heartwood is very high and the wood is highly refractory to seasoning (Orwa *et al.*, 2009). *S. robusta* is one of the primary hosts of *Antheracia mylitta* (Tasar silkworm) and *Laccifer lacca* (kusumi strain of lac of insect). When the *S. robusta* tree is tapped, it produces an Oleo-resin known as Sal dammar, which is commonly used as incense (Thakur and Phulara, 2014).

Shorea robusta forests in Nepal are unquestionably infested with insect pests and pathogens (Malla & Pokharel, 2017). In Nepal's forestry discussion, the health of the *S. robusta* has been one of the most neglected concerns (Pokharel, 2017). During the harvesting of the *S. robusta* tree, the majority of the tree was reported to be faulty, resulting in a large amount of waste wood (Budha *et al.*, 2018). *S. robusta* was seriously affected by heart rot-causing fungi in Nepal, posing a serious problem because timber is one of the country's most important resources (Tripathi and Adhikari, 2021). There is no cost-effective fungicide that can be used in heart rot fungi (Jha, 2020).

The root rot fungus, *Polyporous shoreae*, destroyed a region of the forest at Hetauda (Jackson, 1994). Disease *prevalence* in *S. robusta* has already caused a huge economic loss in Nepal (Pokharel, 2017). Nepal's forest resource assessment (2010-2014) gathered information on the magnitude and existence of various forest disturbances, but no data on forest pests or pathogenic diseases was collected. In the Nepalese scenario, there is a significant gap in knowledge about the different issues and status of forest pests and pathogenic diseases (Pokharel, 2017). Insect pests and pathogenic diseases on *S. robusta* in Nepal have been studied before very minimally (Pokharel, 2017). Hollowness in wood is regarded as a major problem So, to avoid overestimation of timber volume, it's imperative to account for defects in wood (Tripathi and Adhikari, 2021). The pest and pathogen issue in the *S. robusta* forest must be addressed as soon as possible. Our review emphasizes the significance of *S. robusta* and will provide researchers with updated guidance for the management and protection of this species in the future from various pests and pathogens. This paper is important because it provides a comprehensive description of heartwood borer, root rot, and heart rot and proposes strategies for evaluating disease and techniques for disease prevention, important in Nepal today.

MATERIALS AND METHODS

The method involves reviewing both published and unpublished research articles. Google Scholar and Research gate were the primary databases for obtaining the pieces of literature with keywords "*Shorea robusta*", "*Hoplocerambyx spinicornis*", "*Polyporus shoreae*", "Heart rot". More than 60 articles related to *S. robusta* disease were downloaded and by inspection, the repeated papers on the same theme were removed. Finally, 38 papers were selected for this manuscript preparation which was limited to publications between 1941 to 2021. The pieces of literature were reviewed multiple times and the information about *S. robusta* pests, pathogens, pathogenic diseases, and disease control strategies were gathered, compiled, arranged, and finally drafted in a present manuscript. After all, the free version of Grammarly for the Microsoft Office version 6.8.249 was used to re-check the errors.

RESULTS AND DISCUSSION

Taxonomy of sal (*S. robusta*)

Distribution: *S. robusta* is native to Nepal, India, Bhutan, and Bangladesh (FAO, 1985). It is dominant in Bhabar, Terai, and Duns of Nepal (Table 1 and Figure 1). It can be found in the Himalayan plains and lower foothills (Gautam, 1990). *S. robusta* forests can be found in tropical and subtropical areas, as well as zones of rainfall ranging from 1000 to 2000 mm and a dry season of no more than 4 months. (Tewari, 1995). It can be found at elevations ranging from Terai to 1500m above sea level (Gautam and Devoe, 2006). According to Stainton (1972) *S. robusta* forest of Nepal is distinguished into two types:

1. Bhabar, Terai and Dun Sal forests
2. Hill Sal forest

Overview of insect pests: *S. robusta* is reported to be attacked by 346 insect fauna that target roots, seeds, seedlings, full-grown timbers, storage, foliage, and other parts of the plant (Table 2) (Mathur and Singh, 1960). Defoliators (114), seed-feeders (19), borers (18), and sap-suckers (4) are among the 155 species that attack living trees (Nair, 2007). The rest of the insects eat either freshly felled or dried wood (Figure 2 and 3).

Pest profile

***Hoplocerambyx spinicornis*, the Sal heartwood borer (Coleoptera: Cerambycidae):** *Hoplocerambyx spinicornis* can destroy healthy *S. robusta* trees (Beeson, 1941). *H. spinicornis* is the most destructive insect pest, wreaking havoc on *Shorea robusta* across its range. The borer kills trees of all ages above the girth of 20 cm (Bhandari and Singh, 1988), prefers trees between the girth classes of 91-150 cm (Beeson, 1941), where the girth class of 121-150 cm has the highest mortality rate (Roychoudhury *et al.*, 2004). The invasion of Sal borer is considered epidemic when the number of trees affected by the insects exceeds the Economic Threshold Level (ETL), which is more than 1% of the total number of trees (Beeson, 1941). According to Roychoudhury *et al.* (2019), the population will explode in favorable circumstances.

- A temperature of about 27-28 degrees Celsius
- Dense Generally, more humid condition, homogeneous, even-aged (older) Sal stand
- Stressed trees are more vulnerable to the threat

Life cycle of Sal heartwood borer: *H. spinicornis*, also known as Sal heartwood borer is a Coleoptera beetle. Egg, Larva, Pupa, and Adult are the four stages of the year-long life cycle

Table 1. Taxonomic classification of sal (*S. robusta*).

Kingdom	Plantae
Subkingdom	Virideaeplantae
Infrakingdom	Streptophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Infrakingdom	Angiospermae
Class	Magnoliopsida
Superorder	Rosanae
Order	Malvales
Family	Dipterocarpaceae
Genus	*Shorea*
Species	*Shorea robusta*

Source: (Satyanarayan *et al.*, 2019).

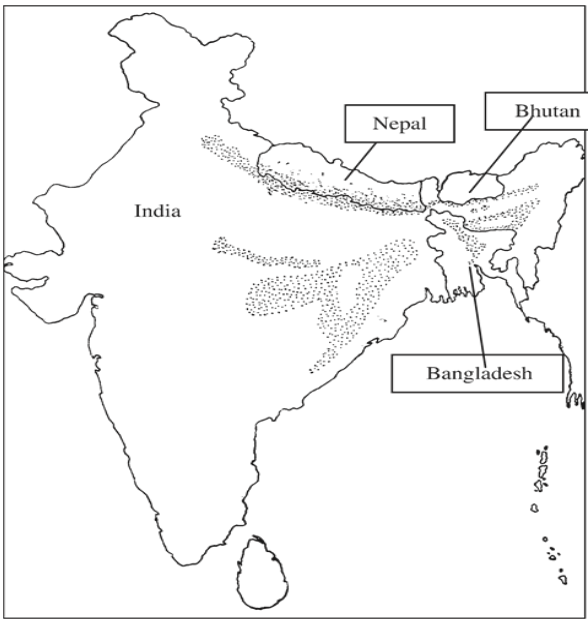

Figure 1. *Natural zone of S. robusta forests (Stainton, 1972; FAO, 1985).*

(Roychoudhury, 2019). Sal borer beetles emerge from infested trees every year when the monsoon season starts in June and lasts until the end of July. The beetles vary in size from 3 to 7 cm and are black to reddish-brown in color. After 3 to 5 days of fertilization, the female begins to lay eggs in June-July. The incubation period of the beetle is 3-7 days. The larva bores a horizontal tunnel through the sapwood to create a pupal chamber, where it pupates before pupating (Figure 4). After 39-52 days, the larva develops into pupa. The pupa develops into an immature beetle within 10-14 days, which will emerge when the monsoon ends in May. Male beetles have a lifespan of up to 9 days, while female beetles have a lifespan of up to 38 days (Table 4) (Prakasam *et al.*, 2000).

Control of *S. robusta* heartwood borer: "Trap Tree Operation" is used for trapping the beetles to combat this major pest of *S. robusta*. This is a non-toxic, environmentally sound management system that is currently viable (Roychoudhury *et al.*, 2018). *Shorea robusta* trees should be harvested prior to the start of the monsoon. Mature and over-mature *Shorea robusta* trees should be cut timely as they lose the resistance against insect pests and diseases (Appanah and Turnbull, 1998). Borer-attacked trees should be labeled and classified according to the type of attack. The 3D (dead, dying, and diseased) trees should be removed before the monsoon season begins (Joshi *et al.*, 2006). Forest hygiene should be maintained by removing the lops and tops of felled trees. Seed collection should be banned in the Sal borer-affected areas till the area gets fully regenerated. Timber depots should be built at least three kilometers away from the *S. robusta* forest (Khanna, 2010).

Pathogenic diseases: Fungal pathogens are the most common agents for *S. robusta* infections. *S. robusta* trees are infected by over 150 species of fungi (Thakur and Phulara, 2014). Young *Shorea robusta* saplings have been known to conform to Schyzophyllum commune cankers caused by frost or fire. At least 24 Hymenomycetes (Fungi) species act as facultative parasites of *S. robusta* (Bagchee, 1954). The majority of these fungi are weak pathogens, but only a few of them can infect living trees, such as *Hypoxylon mediterraneum*, which attacks *S. robusta* woods and trees, hastening their demise (Bakshi and Boyce, 1959). The major fungal diseases of *S. robusta* are of two types (Table 5). They are discussed below:

Root rot

Causes: It occurs in *S. robusta* throughout its range. It is intermittent in drier *Shorea robusta* species and typical in higher rainfall areas. *Polyporous shoreae* is the main cause of root rot in *S. robusta*, and spreads through root contact or root grafting. *P. shoreae* infect healthy roots and cause root rot, as well as bark and sapwood decay (Figure 5). The infection begins at the proximal end of the roots and progresses up the roots to the collar area, seldom reaching the stem. It is economically significant in high rainfall areas above 2000 mm. Fire defense causes excessive soil moisture and weed growth, making the roots vulnerable to *Polyporous shoreae* (Bakshi, 1976).

Symptoms: The tree exhibits top-dying which eventually extends downward till the trees are dead. Trees are uprooted by the wind. Trees die slowly in drier areas; however, they die quickly in moister areas. The trees develop epicormic branches and white pocket rot is found in the bark and sapwood (Bakshi, 1976). The sporophores of the fungus are usually formed on affected trees at the base or exposed roots of wind-blown trees

Table 2. Insects recorded on *S. robusta*.

Orders	Number of insect species	Percentage of insect species	Reference
Coleoptera	191	55.20	Roychoudhury *et al.* (2018)
Lepidoptera	126	36.42	
Thysanoptera	10	2.89	
Isoptera	9	2.60	
Hemiptera	4	1.16	
Orthoptera	4	1.16	
Ephemeroptera	1	0.29	
Hymenoptera	1	0.29	
Total	346	100	

Table 3. Insect orders associated with living *S. robusta*.

Insects	Number of insects	Order	Number of insects species	Reference
Defoliator	114	Coleoptera	15	Roychoudhury *et.al.* (2018)
		Lepidoptera	92	
		Orthoptera	3	
		Thysanoptera	4	
Borers	18	Coleoptera	10	
		Ephemeroptera	1	
		Isoptera	1	
		Lepidoptera	2	
		Orthoptera	1	
		Thysanoptera	3	
Seed- feeders	19	Coleoptera	6	
		Lepidoptera	11	
		Thysanoptera	2	
Sap- suckers	4	Hemiptera	4	
Total			155	

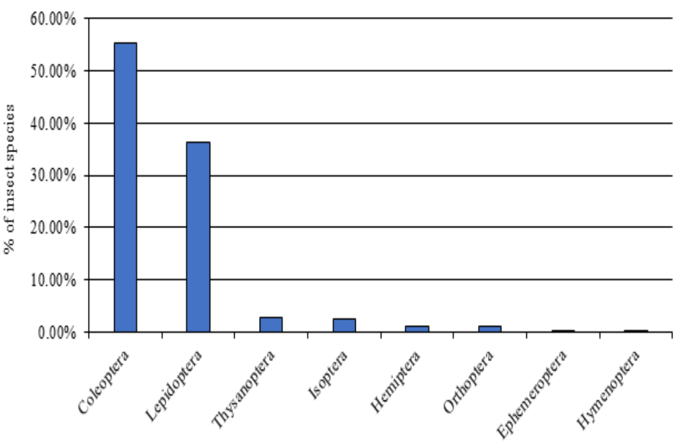

Figure 2. *Insects recorded on S. robusta*

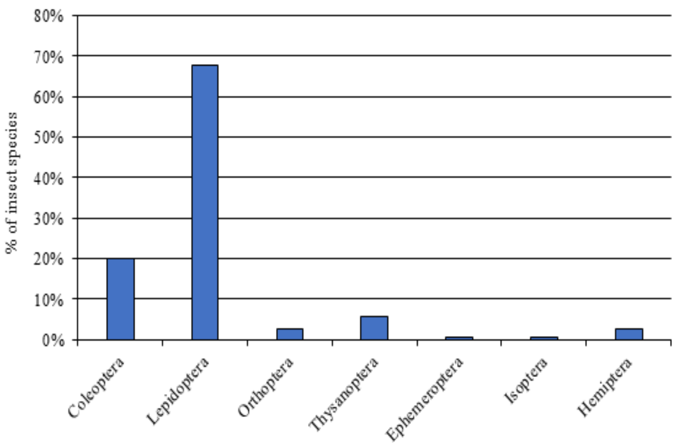

Figure 3. *Insect orders associated with living S. robusta.*

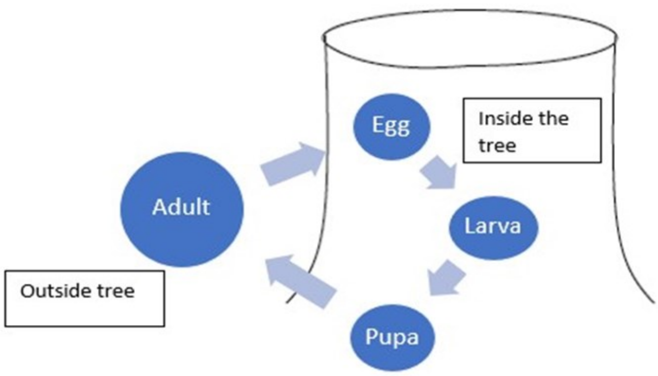

Figure 4. *Life cycle of S. robusta heartwood borer (Source: Prakasam et al., 2000).*

during the rainy season. Sporophores are sessile, rarely sub-stipitate, sometimes funnel-shaped, light in weight, single or imbricate; upper surface is brown to black, glabrous; the hymenial surface is brown to dark brown (Bakshi, 1976).

Other Root rots causing fungi: *Ganoderma lucidium* and *Fomes lamaoensis* also cause root rot in *S. robusta* in Nepal (Thakur and Phulara, 2014).

Heart rot

Causes: *S. robusta* heart rot is caused prominently by the fungi *Hymenochaete rubiginosa*, *Fomes caryophylli*, and *F. fastuosus*. *S. robusta* is attacked by *H. rubiginosa* through fire wounds and accounts for around 50% of the overall decay due to all causes in it (Khanna, 2010). In the majority of cases, these pathogens enter a tree as a result of a wound. Broken branches

Table 4. Development duration of *S. robusta* borer.

Stages	Duration (days)	Seasons	Reference
Eggs	3-5	June-July	Roychoudhury (2017)
Larva(grub)	294-307	July-April	
Pupa	39-52	April-May	
Adult	10-14	May-July	

Table 5. Types of wood decay.

Type	Agents	Chemistry	Texture	Color
Soft Rot	Ascomycota	Carbohydrates preferred, but some lignin lost too	Usually, on the surface, some fibrous texture lost, cross-checking in some cases	Bleached or brown
White Rot	Basidiomycota	All components removed	Fibrous	Bleached
Brown Rot	Basidiomycota	Primarily carbohydrates lost, lignin mostly remains	Fibrous texture lost early, cross-checking	Brown

Source: https://forestpathology.org/general/wood-decay/

Figure 5. *Polyporous shoreae* grown on *S. robusta* (Source: Verma, 2014).

Figure 6. *Heart rot of S. robusta (Source: Bandevi CF, Kapilvastu).*

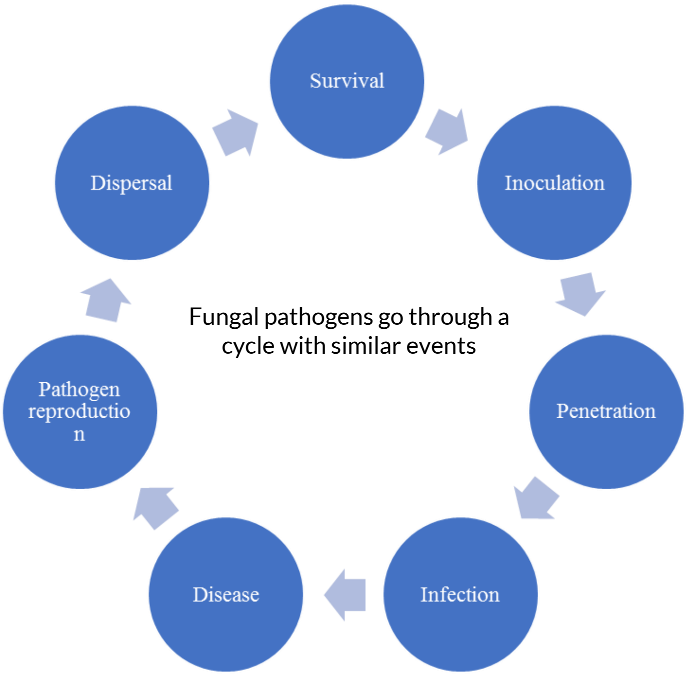

Figure 7. *Disease Cycle of Fungal pathogen (Source; Kukarni, 2020).*

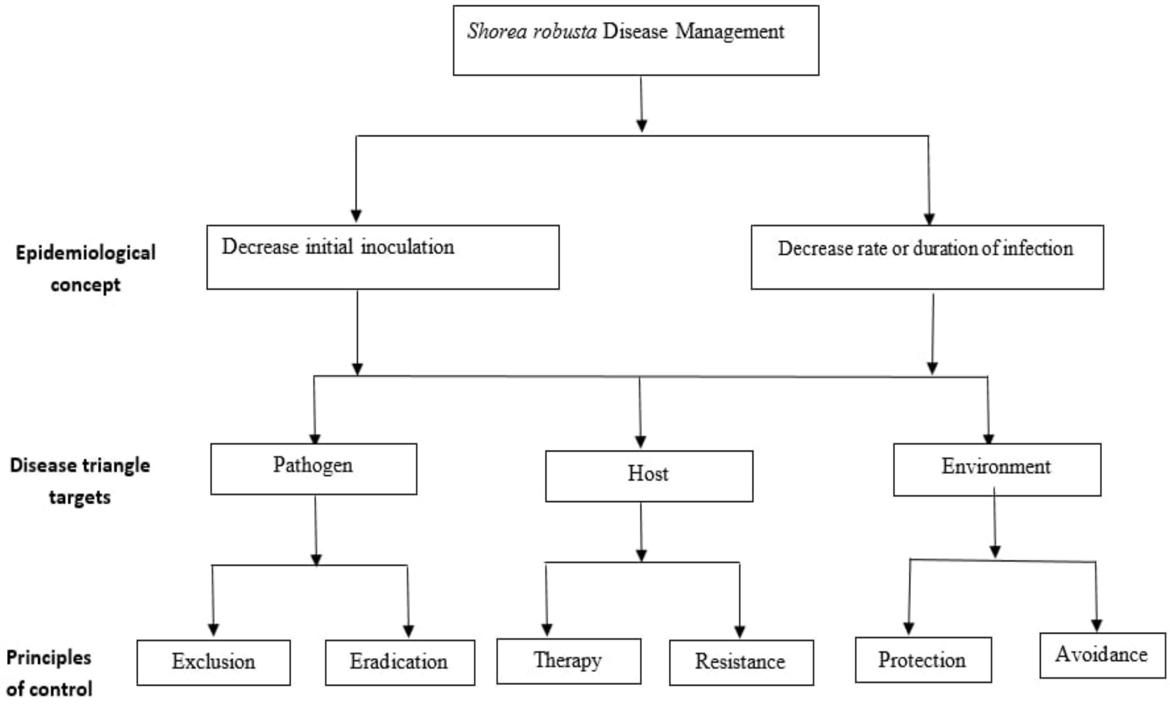

Figure 8. *Principle of disease control (Authors conceptualized this concept in S. robusta).*

triggered by wind, fire, or lightning, as well as excessive pruning by humans, may all be sources of entry. Fungi deplete the tree's hemicellulose, cellulose, and, in some cases, lignin, resulting in the tree's death (Figure 6) (Tripathi and Adhikari, 2021).

Symptoms: Heart rot is difficult to diagnose since it occurs internally and can go undetected for years (Jha, 2020). Mushrooms typically grow on the trunk or branch of a tree in the later stages of heart rot. This is one of the first visible signs of fungal pathogens before infection has infiltrated a tree (Shortle *et al.*, 1996). External mushrooms are the fruiting bodies of fungi known as "conks" or "bracket fungi." (Jha, 2020) Wood decay is caused by heart rot fungi and following describes the types of wood decay.

Disease control strategies: The primary goal of disease control strategy is to mitigate disease to a tolerable level (threshold) in a cost-effective, practical, and environmentally friendly manner by using a range of management practices i.e., cultural, chemical, physical, and biological. Forest managers must be familiar with a variety of disciplines, including plant pathology, entomology, genetics, dendrology, mycology, taxonomy, silviculture, and forest management (Figure 7) (Pokharel, 2017). Forest pests and diseases are treated with chemicals, but this is limited to forest nurseries or small forest patches. When they've spread to a wider region, it's extremely difficult to keep them under control. Controlling insect pests and diseases until they spread over a wide area is a cost-effective and dependable method of keeping natural forests protected (Pokharel, 2017). A review of studies performed by Timilsina *et al.* (2020) states that preemptive measures, regular monitoring and survey of signs and symptoms, and reactive measures can also be useful for pest and pathogen control in *S. robusta* although that study was performed on *Dalbergia sissoo* (Sissoo). The knowledge of the disease cycle is important in formulating management strategies. The information on Etiology, Symptoms, Pathogenesis, and Epidemiology of disease are the most considered points for control strategies. The purpose of plant disease control is indeed to disrupt the disease cycle and prevent it from completing a complete cycle. Understanding the disease cycle and how management strategies interrupt it will allow the most efficient plant disease management strategies to be used (Chintkuntla, 2015). The flowchart explains disease management in S. robusta at three stages, where epidemiological concepts include reducing the duration of infection and decreasing the initial inoculation. Both concepts tackle at least one of the disease triangle's components i.e., pathogen, host and environment. According to the flowchart, one of the principles such as exclusion, eradication, therapy, resistance, protection, and avoidance should be followed as per the disease triangle targets to make the tree robust to the infection (Figure 8).

Control measures based on the above principle

Control of Heart rot: Canopy adjustment is critical in preventing frost damage and suppression since understory trees may suffer from dead branches, branch stubs, and knots as a result of suppression, all of which serve as infection courts for heart rot (Bakshi, 1971). Controlled burning at an early stage lowers the risk of severe fire damage, which can result in heart rot. During felling operations, falling trees can injure remaining trees and create wounds that serve as breeding grounds for decay fungi (Bakshi, 1976). A pathologist should identify and inspect the trees accused of having heart rot. Heart-rot can be difficult to prevent and maintain, but it can be avoided if a tree is closely monitored during its life (Figure 8) (Jha, 2020).

Control of root rot: The isolation trenches should be dug between rows of trees to avoid the spread of the diseases. Creosote, Ammonium fluoride, Sodium nitrite, Borax, Urea, and Ammonium sulfate should be used to treat the stump chemically (Bakshi, 1976). Non-pathogenic rivals are introduced as biological control. *Peniophora gigantea*, a rival of *F. annosus*, is inoculated into stumps shortly after felling. In wet *S. robusta* forests, control burning is recommended as an effective method of reducing soil moisture to decreasing fungal infection (Khanna, 2010). Burning also helps to control weed growth and reduces favorable conditions for disease development (Bakshi and Boyce, 1959). Dry marking is prescribed in the *Shorea robusta* forest, where the disease is ubiquitous (Figure 8) (Bakshi, 1976).

Conclusion and recommendation

S. robusta forests are semi-deciduous and have higher biodiversity levels. Despite the numerous benefits of *S. robusta* trees, the entomologists and foresters have long been perplexed by the notorious pest's invincibility and inexorable disastrous effect. The Nepalese proverb "Prevention is better than cure" can be used to guide the management of *S. robusta* insect pests and pathogens. It is a cost-effective and efficient method of improving *S. robusta* health conditions. Nepal must upgrade existing laboratory facilities, conduct training programs for forest technicians, raise awareness among various forest stakeholders. Furthermore, the use of drones and remote sensing technologies in conjunction with spectroscopy-based methods may be beneficial for monitoring forest pests and pathogens. It allows for the tracking of the trend of forest insect, pest, and pathogen infestations over time as well as the prediction of areas that will be infested in the future. Accurate documentation of insect pests and pathogenic diseases is also essential for developing effective Integrated Pest Management (IPM) strategies, which will be critical shortly to protect valuable *S. robusta* species from various regions. Similarly, the government and other sectors should map and monitor the nature and severity of the infestation, as well as conduct action research on prevention and control. The government's focus program in Nepal's forestry sector should be the prevention and control of forest insect pests and pathogens.

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Conflicts of interest

The authors declare no conflict of interest.

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