



RESEARCH ARTICLE

Herbicidal potential of *Shorea robusta* C.F. Gaertn. in agroforestry: A sustainable approach to weed management in agroecosystems

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Abstract

In agroforestry systems, the integration of trees and shrubs into agricultural landscapes presents a promising approach for sustainable weed management. Certain tree species, like *Shorea robusta* (Sal), exhibit allelopathic properties that may naturally inhibit weed growth. This study explores the herbicidal potential of *S. robusta* by assessing the impact of its leaf and bark extracts on the growth of two prevalent weeds, *Crotalaria retusa* and *Senna occidentalis*. Aqueous and methanolic extracts were prepared from the leaves and bark of *S. robusta*. These extracts were applied to weed seedlings at various concentrations (5%, 10%, 15%, and 20%) in a controlled environment. The growth of *C. retusa* and *S. occidentalis* seedlings was measured by assessing parameters such as shoot length, root length, and biomass weight over a period of 14 days. The results revealed that both leaf and bark extracts of *S. robusta* exhibited concentration-dependent inhibition on the growth of the weed seedlings. Aqueous leaf extracts demonstrated the strongest inhibitory effect, significantly reducing shoot and root length as well as biomass compared to control plants. Methanolic extracts were less effective, with bark extracts showing a weaker inhibitory response than leaf extracts. The 20% concentration of leaf extract caused the most pronounced reduction in growth parameters, with *C. retusa* being more sensitive than *S. occidentalis*. This study highlights the potential of *S. robusta* as an eco-friendly, natural herbicide for weed management in agroforestry systems. The allelopathic properties of *S. robusta* may provide an alternative to chemical herbicides, supporting sustainable agriculture practices. Further research is needed to isolate the specific allelopathic compounds responsible for these effects and to explore their broader applications in integrated weed management.

Keywords: *Shorea robusta*, *Crotalaria retusa*, *Senna occidentalis*, Agroforestry, Plant extracts, Sustainable agriculture, Herbicide resistance.

Introduction

Effective weed management is a critical component of sustainable agriculture, as weeds can significantly reduce crop yields and quality by competing for essential resources (Zimdahl 2007). Traditional reliance on chemical herbicides has led to environmental concerns and the emergence

of herbicide-resistant weed species, necessitating the exploration of alternative, eco-friendly weed control methods (Duke and Powles 2008). Agroforestry, the intentional integration of trees and shrubs into crop and livestock systems, offers a promising avenue for sustainable weed management. Certain tree species possess allelopathic properties, releasing secondary compounds that can suppress weed growth, thereby reducing the need for synthetic herbicides. This approach not only manages weeds but also enhances biodiversity and ecosystem services within agricultural landscapes (Koo and Choi 2012).

S. robusta, commonly known as Sal tree, is a deciduous tree native to the Indian subcontinent. Traditionally valued for its timber and medicinal properties, recent studies have indicated that *S. robusta* exhibits significant biological activity, including antimicrobial effects, which may be attributed to its rich phytochemical composition. These bioactive compounds suggest potential allelopathic effects, positioning *S. robusta* as a candidate for natural weed suppression in agroforestry systems (Subedi et al. 2021).

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Recent studies have provided empirical evidence supporting the allelopathic potential of *S. robusta*. For instance, Das and Bandyopadhyay (2021) investigated the effects of *S. robusta* leaf extracts on the germination of the weed species *Eupatorium odoratum* and the crop *Triticum aestivum*. Their findings revealed a concentration-dependent inhibitory effect on seed germination, with higher extract concentrations leading to greater suppression of *E. odoratum* germination rates. This suggests that compounds present in *S. robusta* leaves may effectively hinder the establishment of certain weed species in agroecosystems. Therefore, this study aims to investigate the herbicidal potential of *S. robusta* within agroforestry practices, evaluating its efficacy as a sustainable approach to weed management in agroecosystems. By exploring the allelopathic interactions between *S. robusta* and common weed species, we seek to contribute to the development of integrated weed management strategies that align with ecological and agricultural sustainability goals.

Materials And Methods

Preparation of plant materials to study herbicidal effect

Mature fresh leaves and bark of *Shorea robusta* Gaertn f. (Sal tree) were collected from Srivilliputtur Reserve Forest, Tamil Nadu, India. The weed species like *C. retusa* and *S. occidentalis* were collected from Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The leaves and bark materials were dried in an oven at 60°C for four days, powdered (40 mesh), and used for bio-assay and pot experimental analysis (Singh and Ghos 2021).

Preparation of aqueous extracts

10 grams of leaf and bark powder were dissolved separately in 10 mL of distilled water in a beaker and kept for 24 hours at room temperature with occasional swirling. The solution was filtered through Whatman No. 1 filter paper and the volume was made up to 100 mL with distilled water. The aqueous extract was diluted with water to get 5%, 10%, 15%, and 20% concentrations (Singh *et al.* 2018).

Preparation of methanol extract

10 grams of powdered leaves and bark were extracted with methanol in a Soxhlet apparatus for 24 hours with solvent cycling every 15-25 minutes. After 24 hours, the extracts were collected from the Soxhlet apparatus, and the excess solvent was evaporated. The residue was dissolved in 100 mL of distilled water. The extract was diluted with water to get 5%, 10%, 15%, and 20% concentrations. These dilutions corresponded to 0.05%, 0.1%, 0.15%, and 0.2% of water-extractable materials (Heisey 1990, Kumar and Raj 2022).

Bioassay studies

Bioassay studies were carried out following the methods of Heisey (1990). Ten seeds of *C. retusa* and *S. occidentalis*

were placed on Whatman No. 1 filter paper in Petri plates (9 cm x 2 cm). Petri plates were moistened with 10 mL per plate of leaf and bark extract and distilled water as control, and incubated at 28°C. The experimental design was a randomized complete block with three replicates for each treatment and control. Germination percentage, plumule, and radicle length were measured after three days (Singh *et al.* 2023).

Study of herbicidal effect by post-emergence treatment

Post-emergence treatments were given following the methods of Heisey (1990). Ten weed seeds were sown individually in plastic pots (7 cm x 6.5 cm). The soil consisted of silt, humus, and river sand in the ratio of 1:1:2. Only five seedlings were allowed to grow in each pot after thinning. The treatments (aqueous/methanol extract) were started 8 days after sowing. Few drops of 0.1% Triton-X were added to the extracts to avoid evaporation of substances from the surface of the leaves of the experimental seedlings (Ravi *et al.*, 2023).

Aqueous and methanolic leaf and bark extracts (12 mL) were sprayed on each set of seedlings using an atomizer. The control seedlings were sprayed with 12 mL of distilled water containing 0.1% Triton-X. Before post-emergence treatments, the seedlings were irrigated thoroughly. After the treatment, the seedlings were not irrigated again until 4 days to allow time for foliar absorption. Post-emergence treatments were subsequently watered from above as needed. Shoot length, root length, biomass, and mortality of the seedlings were recorded on the 15th day after sowing (Singh and Ghosh 2021).

Results

Aqueous and methanolic leaf and bark extracts of *S. robusta* on *C. retusa*

Leaf aqueous extract

The application of aqueous leaf extracts demonstrated a clear concentration-dependent reduction in seedling growth. At the control treatments, shoot length, root length, and biomass weight were all stable, with measurements of 5.5 cm, 5.5 cm, and 10.2 mg, respectively. As the concentration of the aqueous extract increased, both shoot length and root length showed a significant decline. At 20% concentration, shoot length reduced to 3.9 cm, root length to 3.0 cm, and biomass weight dropped to 6.9 mg. These results indicate a detrimental effect on seedling development with increasing extract concentration (Table 1).

Leaf methanolic extract

The methanolic leaf extract produced similar trends, with a decrease in all growth parameters as concentration increased. Seedlings in the control group exhibited a shoot

length of 5.5 cm, root length of 5.5 cm, and biomass weight of 10.2 mg. At the 20% concentration, shoot length, root length, and biomass weight were reduced to 3.8 cm, 3.8 cm, and 7.9 mg, respectively. This suggests that methanolic leaf extracts also inhibit seedling growth in a concentration-dependent manner, though the overall effect was slightly less pronounced than that of the aqueous extract (Table 1).

Bark aqueous extract

In contrast to the leaf extracts, the bark aqueous extract showed a milder effect on seedling growth. The control group exhibited stable growth, with shoot length and root length both measuring 5.5 cm, and biomass weight at 10.2 mg. With increasing concentrations, shoot length and root length gradually decreased. At 20% concentration, shoot length and root length were 3.8 cm and 3.9 cm, respectively, while biomass weight dropped to 7.8 mg. While these reductions were statistically significant, they were less severe than those observed with leaf extracts (Table 2).

Bark methanolic extract

The bark methanolic extract produced similar results to the aqueous bark extract, with less inhibition observed in comparison to the leaf extracts. Seedlings in the control group had a shoot length of 5.5 cm, root length of 5.5 cm, and biomass weight of 10.2 mg. The shoot length and root length decreased gradually as the concentration increased, reaching 3.9 cm and 4.0 cm, respectively, at 20%. Biomass weight also decreased from 10.2 mg to 8.0 mg at the highest concentration (Table 2).

Aqueous and methanolic leaf and bark extracts of S. robusta on S. occidentalis

The effects of aqueous and methanolic extracts from the leaves and bark of *S. robusta* on the seedling growth of *S. occidentalis* were examined by evaluating three growth parameters: shoot length, root length, and biomass weight. The seedlings were exposed to different concentrations of the extracts (Control, 5%, 10%, 15%, and 20%), and the results showed a clear, concentration-dependent reduction in growth (Table 2).

Leaf aqueous extract

In the treatment with leaf aqueous extract, the control group exhibited a shoot length of 10.2 cm, a root length of 5.5 cm, and a biomass weight of 14.2 mg. However, as the concentration of the aqueous extract increased, there was a noticeable decrease in all growth parameters. At 5%, shoot length decreased to 8.4 cm, root length to 3.9 cm, and biomass weight to 13.3 mg. At higher concentrations, this inhibitory trend continued, with the shoot length at 20% reducing to 6.8 cm, root length to 2.6 cm, and biomass weight to 8.2 mg (Table 3).

Leaf methanolic extract

In the control group, the shoot length was 10.2 cm, the root length was 5.5 cm, and biomass weight was 14.2 mg. As the concentration of methanolic leaf extract increased, a decrease in all parameters was observed. At 5%, the shoot length decreased to 8.0 cm, root length to 5.0 cm, and biomass weight to 11.2 mg. At 20%, the shoot length

Table 1: Post emergency treatment of aqueous and methanol leaf extracts of *S. robusta* on seedling growth of *C. retusa*

Concentration (%)	Leaf Aqueous Extract			Leaf Methanolic Extract		
	Shoot length (cm)	Root length (cm)	Biomass wt (mg)	Shoot length (cm)	Root length (cm)	Biomass wt (mg)
Control	5.5 ± 0.4	5.5 ± 0.4	10.2 ± 1.0	5.5 ± 0.6	5.5 ± 0.6	10.2 ± 1.0
5	5.1 ± 0.5	5.0 ± 0.5	9.2 ± 0.8	5.1 ± 0.5	5.1 ± 0.5	9.5 ± 1.0
10	5.1 ± 0.3	4.0 ± 0.4	8.2 ± 0.8	4.9 ± 0.5	4.9 ± 0.4	9.0 ± 0.8
15	4.3 ± 0.4	3.3 ± 0.3	7.3 ± 0.7	4.1 ± 0.3	4.1 ± 0.4	8.3 ± 0.7
20	3.9 ± 0.4	3.0 ± 0.3	6.9 ± 0.7	3.8 ± 0.3	3.8 ± 0.2	7.9 ± 0.6

Table 2: Post emergency treatment of aqueous and methanol bark extracts of *S. robusta* on seedling growth of *C. retusa*

Concentration (%)	Bark Aqueous Extract			Bark Methanolic Extract		
	Shoot length (cm)	Root length (cm)	Biomass wt (mg)	Shoot length (cm)	Root length (cm)	Biomass wt (mg)
Control	5.5 ± 0.5	5.5 ± 0.5	10.2 ± 1.0	5.5 ± 0.4	5.5 ± 0.5	10.2 ± 0.9
5	5.0 ± 0.5	5.5 ± 0.5	10.1 ± 1.0	5.1 ± 0.5	5.5 ± 0.4	9.3 ± 0.8
10	5.0 ± 0.5	5.0 ± 0.4	9.9 ± 0.9	4.8 ± 0.4	5.0 ± 0.3	9.0 ± 0.9
15	4.1 ± 0.4	4.5 ± 0.4	9.2 ± 0.8	4.6 ± 0.4	4.2 ± 0.4	8.4 ± 0.7
20	3.8 ± 0.3	3.9 ± 0.3	7.8 ± 0.7	3.9 ± 0.3	4.0 ± 0.3	8.0 ± 0.7

Table 3: Post emergency treatment of aqueous and methanol leaf extracts of *S. robusta* on seedling growth of *S. occidentalis*

Concentration (%)	Leaf Aqueous Extract			Leaf Methanolic Extract		
	Shoot length (cm)	Root length (cm)	Biomass wt (mg)	Shoot length (cm)	Root length (cm)	Biomass wt (mg)
Control	10.2 ± 1.0	5.5 ± 0.4	14.2 ± 1.2	10.2 ± 1.0	5.5 ± 0.4	14.2 ± 1.0
5	8.4 ± 0.8	3.9 ± 0.3	13.3 ± 1.2	8.0 ± 0.7	5.0 ± 0.4	11.2 ± 1.0
10	7.7 ± 0.6	3.5 ± 0.3	11.0 ± 1.0	6.0 ± 0.5	4.9 ± 0.5	10.2 ± 1.0
15	7.4 ± 0.6	3.0 ± 0.3	9.6 ± 0.8	5.5 ± 0.5	4.1 ± 0.3	9.5 ± 0.8
20	6.8 ± 0.5	2.6 ± 0.2	8.2 ± 0.8	5.0 ± 0.5	3.8 ± 0.3	9.0 ± 0.8

Table 4: Post emergency treatment of aqueous and methanol bark extracts of *S. robusta* on seedling growth of *S. occidentalis*

Concentration (%)	Bark Aqueous Extract			Bark Methanolic Extract		
	Shoot length (cm)	Root length (cm)	Biomass wt (mg)	Shoot length (cm)	Root length (cm)	Biomass wt (mg)
Control	10.2 ± 1.0	5.5 ± 0.5	14.2 ± 1.2	10.2 ± 1.0	5.5 ± 0.5	14.2 ± 1.3
5	8.8 ± 0.8	4.0 ± 0.3	13.3 ± 1.2	8.2 ± 0.7	4.5 ± 0.4	11.0 ± 1.0
10	8.1 ± 0.8	3.5 ± 0.2	12.3 ± 1.2	6.4 ± 0.6	4.0 ± 0.3	9.3 ± 0.8
15	7.4 ± 0.7	3.0 ± 0.8	11.1 ± 0.9	6.0 ± 0.6	3.6 ± 0.3	9.0 ± 0.6
20	7.0 ± 0.5	2.6 ± 0.2	10.0 ± 1.0	5.8 ± 0.4	3.1 ± 0.3	8.4 ± 0.7

reduced to 5.0 cm, root length to 3.8 cm, and biomass weight to 9.0 mg. These results demonstrate the negative impact of the methanolic leaf extract on the growth of *S. occidentalis* seedlings (Table 3).

Bark aqueous extract

The bark aqueous extract produced a somewhat milder effect compared to the leaf extracts. In the control group, the shoot length was 10.2 cm, root length was 5.5 cm, and biomass weight was 14.2 mg. As the concentration of the aqueous bark extract increased, there was a gradual reduction in all growth parameters. At 5%, shoot length decreased to 8.8 cm, root length to 4.0 cm, and biomass weight to 13.3 mg. At 20%, the shoot length reduced to 7.0 cm, root length to 2.6 cm, and biomass weight to 10.0 mg. Although the bark extracts were inhibitory, the effects were less severe than those observed with leaf extracts (Table 4).

Bark methanolic extract

The bark methanolic extract also showed an inhibitory effect, though less intense than that of the leaf extracts. In the control group, the seedlings had a shoot length of 10.2 cm, root length of 5.5 cm, and biomass weight of 14.2 mg. With increasing concentrations of methanolic bark extract, the growth parameters decreased. At 5%, the shoot length was 8.2 cm, root length was 4.5 cm, and biomass weight was 11.0 mg. At 20%, the shoot length decreased to 5.8 cm, root length to 3.1 cm, and biomass weight to 8.4 mg (Table 4).

Discussion

The study investigates the effects of aqueous and methanolic leaf and bark extracts of *S. robusta* on the seedling growth of two plant species, *C. retusa* and *S. occidentalis*. The results consistently demonstrate a concentration-dependent inhibitory effect on various growth parameters, including shoot length, root length, and biomass weight. This inhibition is more pronounced with leaf extracts compared to bark extracts, which aligns with previous studies that have indicated the potent allelopathic potential of *Shorea robusta* leaf extracts (Singh *et al.* 2018, Verma *et al.* 2020).

Leaf extracts on seedling growth

For *C. retusa* and *S. occidentalis*, the leaf aqueous extracts of *S. robusta* exhibited a clear reduction in seedling growth with increasing concentration, which is consistent with findings by Sharma *et al.* (2017), who demonstrated the growth-suppressing effect of plant extracts at higher concentrations. In the case of *C. retusa*, shoot and root lengths were significantly reduced at 20% concentration of both aqueous and methanolic extracts, with biomass weight also showing a marked decline. Similarly, the methanolic leaf extract showed growth inhibition, but to a slightly lesser degree. These results reflect the general trend that methanol extracts tend to have a milder effect compared to aqueous extracts due to the difference in solubility and the nature of compounds extracted (Patel *et al.* 2019).

In *S. occidentalis*, the leaf aqueous extract at higher concentrations led to a significant reduction in growth parameters, especially shoot and root lengths, which corroborate findings from similar allelopathic studies (Pandey *et al.* 2021). The methanolic leaf extract also caused a reduction in seedling growth, although the effect was not as drastic as that seen with the aqueous extract. This suggests that the compounds responsible for the allelopathic effect might be more efficiently extracted in water, as noted by Dey *et al.* (2022), who reported that water-soluble compounds in plant extracts often exhibit stronger growth inhibitory effects.

Bark extracts on seedling growth

The bark extracts of *S. robusta* displayed a relatively milder inhibitory effect compared to the leaf extracts, which is in agreement with the findings of Roy and Chattopadhyay (2018), who noted that bark extracts often have less pronounced allelopathic effects than leaf extracts. Both aqueous and methanolic bark extracts reduced growth in a concentration-dependent manner, but the reductions were less severe compared to those observed with the leaf extracts. In *C. retusa*, the decline in shoot and root length at 20% concentration was significant but less than that induced by leaf extracts, suggesting that the bark of *S. robusta* contains fewer or less potent allelopathic compounds compared to the leaves. This observation aligns with findings by Das and Bandyopadhyay (2021), who reported that allelopathic effects are more pronounced in leaf extracts due to higher concentrations of secondary metabolites such as phenolics, flavonoids, and tannins. The relatively milder impact of bark extracts in the present study indicates that the composition or abundance of these bioactive compounds may be lower in the bark compared to the leaves, as also suggested by Patra *et al.* (2019). Further studies analyzing the phytochemical profiles of different plant parts could provide deeper insights into the differential allelopathic potential of *S. robusta*. The bark aqueous extract showed a slight reduction in biomass weight and seedling growth at higher concentrations in *C. occidentalis*, and similar patterns were observed with the methanolic bark extract. Although both bark extracts exhibited inhibitory effects, the severity was lower than that of the leaf extracts, which has been explained in part by the variation in the chemical composition of the bark and leaf tissues (Singh *et al.*, 2018). The compounds in the bark may include secondary metabolites that act more subtly or require higher concentrations to exert significant allelopathic effects.

Mechanism of inhibition

The secondary compounds responsible for these inhibitory effects are likely secondary metabolites such as polyphenols, flavonoids, and tannins, which are known for their allelopathic properties (Patel *et al.* 2019). The concentration-

dependent reduction in seedling growth observed in this study may be attributed to these compounds interfering with seedling development by disrupting nutrient absorption, inhibiting root growth, and affecting the photosynthetic efficiency of the plants (Dey *et al.* 2022). The differences in the inhibitory potency between the leaf and bark extracts could be explained by the variation in the concentration of these compounds in different plant parts, as well as the differences in their solubility in water and methanol.

Conclusion

In conclusion, both aqueous and methanolic extracts of *S. robusta* from both leaf and bark tissues exhibited concentration-dependent inhibitory effects on the growth of *C. retusa* and *S. occidentalis*. The leaf extracts, especially the aqueous form, were more inhibitory than the bark extracts, likely due to higher concentrations of allelopathic compounds. These findings contribute to our understanding of the potential use of *S. robusta* in controlling unwanted plant growth, offering insight into its potential as a natural herbicide. Further studies are required to isolate and identify the specific allelopathic compounds responsible for the observed effects, and to explore their potential applications in agricultural and ecological management.

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