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Integrated Prevention and Control Technology for Coffee Leaf Rust in Yunnan Province

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Abstract This paper investigates the damage symptoms and occurrence regularity related to coffee leaf rust, and proposes a comprehensive prevention and control strategy grounded in the principle of prioritizing prevention and implementing integrated prevention and control. This strategy encompasses the cultivation of rust-resistant varieties, the implementation of agricultural practices, the application of chemical interventions, the utilization of hyperparasitic fungi, and the protection and utilization of natural enemies. The paper further outlines the necessary requirements for effective prevention and control, emphasizing the importance of enhancing responsibility implementation, fostering systematic prevention and control measures, enhancing guidance services, and increasing publicity and guidance. The aim is to offer technical guidance for the integrated prevention and control of coffee leaf rust in Yunnan Province.

Key words Coffee leaf rust disease, Damage symptoms, Occurrence regularity, Integrated prevention and control, Yunnan Province

1 Introduction

As one of the most widely consumed beverages globally, the industrial chain of coffee encompasses various stages, including breed selection, cultivation, processing, and trade[1]. Coffee production faces significant threats from various pests and diseases. Among these, coffee leaf rust, which is caused by the specialized parasitic fungus *Hemileia vastatrix*, represents a major global disease that adversely affects coffee crops. This disease has been a critical factor jeopardizing the safe production and yield stability of coffee on a worldwide scale[2-3]. Yunnan Province is recognized as the most significant region for small grain coffee production in China, accounting for over 98% of the nation's small grain coffee cultivation area. This cultivation spans across 9 cities (prefectures) and encompasses 33 counties (cities and districts). The number of households engaged in coffee cultivation is substantial, reaching approximately 252 300[4]. The coffee cultivation regions across 33 counties (including cities and districts) within 9 cities (prefectures) of Yunnan Province are experiencing varying degrees of impact from coffee leaf rust. The rapid spread of this disease, coupled with the challenges associated with its prevention and control, presents a significant threat to the safe production of coffee. To enhance the understanding of coffee leaf rust disease among the 252 300 coffee growers in Yunnan Province and to facilitate timely and effective field prevention and control measures, the author elucidates the damage symptoms and occurrence regularities associated with this disease. Furthermore, based on the biological characteristics of *H. vastatrix*, the pathogen responsible for coffee leaf rust, an integrated pest prevention and control strategy is proposed. This strategy encompasses four key components: the selection of rust-resistant coffee varieties, agricultural preventive measures, chemical control methods, and the conservation and utilization of hyperparasitic fungi. Specific requirements for prevention and control are outlined, in order to provide technological support and innovative approaches for the integrated prevention and control of coffee leaf rust in Yunnan Province.

2 Damage symptoms

Coffee leaf rust is a fungal disease affecting coffee plants, caused by the specialized parasitic fungus *H. vastatrix*. This pathogen primarily infects mature coffee leaves. However, it can also affect young leaves. The aecidiospores of *H. vastatrix* exhibit rapid germination at temperatures between 18 and 26 ℃. Damage may occur throughout the reproductive period of coffee plants. In the initial stages of damage, small yellowish round spots, measuring approximately 1.0 to 1.5 mm in diameter, can be observed on the abaxial surface of the leaves. Additionally, transparent yellowish infestation spots are also present on the abaxial surface, with the coloration of these spots gradually fading from the center to the periphery (Fig. 1A). As the duration of the infestation progresses, the diameter of the lesions increases significantly, reaching 2.0 to 3.0 mm within a brief timeframe. Additionally, yellow sori emerge on the dorsal surface of the leaf lesions, accompanied by the development of yellow-green halos surrounding the spots on both the adaxial and abaxial surfaces (Fig. 1B). As the lesions progressively enlarge, they coalesce to form irregularly shaped spots. In the advanced stages of infestation, the central region of the lesion begins to desiccate and assumes a brown coloration. Defoliation initiates when the infested area of the leaf reaches between 2.01% and

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4.0%, with over 90% of defoliation occurring when the infested area surpasses 4.01%. In years characterized by epidemics, it is possible for over 50% of the leaves to be shed, and in extreme instances, the entire plant may be affected. This phenomenon can hinder bud differentiation in the subsequent year, resulting in yield reductions of up to 30% –50% (Fig.1C).

3 Occurrence regularity

Coffee leaf rust can manifest year-round in Yunnan. However, the extent of damage is comparatively lower in arid and hot regions, such as Baoshan City and Nujiang Prefecture, than in humid and warm areas, including Pu'er, Xishuangbanna, Dehong, and Lincang. The disease is attributed to the invasion of aecidiospores through the stomata located on the abaxial surface of the leaves. Under optimal temperature conditions, these spores can germinate within a timeframe of 2 –4 h. The period of peak damage predominantly occurs from December to April of the subsequent year. Altitude is a significant variable influencing the extent of damage caused by coffee leaf rust. As altitude increases, the severity of coffee leaf rust damage tends to escalate.

4 Integrated prevention and control technology

Coffee leaf rust is both preventable and manageable. It is imperative to prioritize prevention, employing an integrated approach to control the disease. This includes cultivating healthy plants and enhancing field management practices to safeguard functional leaves, promote bud differentiation, and ultimately protect yield. It is essential to address coffee leaf rust infestations when the affected leaf area is below the 4.01% prevention and control threshold. Additionally, integrating harvesting and garden clearing with the timely application of appropriate treatments is crucial for effective management.

4.1 Planting rust-resistant varieties According to the *Recommended Map of High – Quality Varieties for Main Coffee Producing Areas in Yunnan Province*, issued by the Department of Agriculture and Rural Affairs of Yunnan Province in 2023, the suggested coffee varieties that exhibit resistance to coffee leaf rust include, but are not limited to, Dere 397, Dere 399, Dere 401, Dere 402, and Dere 132. The specific rust-resistant varieties recommended for cultivation in each coffee-producing area of Yunnan Province are presented in Table 1.

Table 1 Recommended rust-resistant varieties for each coffee-producing region in Yunnan Province[5]

Producing area	Coffee variety	Suitable altitude//m	Variety characteristics
Pu'er City	Dere 397, 399, 401, 402	<1 200	Dere 397: cupping score 80 –85 points; yield 110 –200 kg/667 m^2; planting density 1.5 m×2.0 m, 222 plants/667 m^2; medium-sized plant, open shape, wide crown, light green leaves, medium spacing between trunks, red and oval fruits, medium granularity of commercial beans, rust resistance.
	Dere 132	<1 200	
Baoshan City	Dere 397, 399, 401, 402	<1 100	Dere 399: cupping score 80 –85 points; yield 130 –200 kg/667 m^2; planting density 1.5 m×2.0 m, 222 plants/667 m^2; medium-sized plant, wide crown, cylindrical shape, medium spacing between trunks, red and long oval fruits, large granularity of commercial beans, rust resistance.
Lincang City	Dere 397, 399, 401, 402	<1 200	Dere 401: cupping score 80 –85 points; yield 150 –200 kg/667 m^2; planting density 1.5 m×2.0 m, 222 plants/667 m^2; dwarf plant, lush growth, wide crown, cylindrical shape, medium spacing between trunks, red and oval fruits, medium granularity of commercial beans, rust resistance.
Dehong Prefecture	Dere 397, 399, 401, 402	<1 200	Dere 402: cupping score 80 –85 points; yield 110 –200 kg/667 m^2; planting density 1.5 m×2.0 m, 222 plants/667 m^2; medium-sized plant, lush growth, wide crown, cylindrical shape, medium spacing between trunks, red and long oval fruits, large granularity of commercial beans, rust resistance.
	Dere 132	>1 200	
Xishuangbanna	Dere 397, 399, 401, 402	<1 200	Dere 132: cupping score 82 –85 points; yield 120 –150 kg/667 m^2; planting density 1.0 m×2.0 m, 333 plants/667 m^2; medium-sized plant, moderate crown, slender leaves, clear corrugation at leaf margin, cylindrical shape, a pendulous branch, medium spacing between trunks, yellow and oval fruits, small beans, jasmine scent, rust resistance.
Prefecture	Dere 132	>1 200	

4.2 Agricultural prevention and control

4.2.1 Management of shade trees. The cultivation of coffee requires suitable shading conditions, which, when combined with effective production practices, necessitates the careful management of shade levels provided by forest tree species in composite plantations. In general, the height of the trunk of a shade tree should not be less than 1.5 m. Regular practices such as shaping, pruning, and canopy management are employed to maintain the tree's structure, ensuring that the shaded area does not exceed 40% of the total canopy.

4.2.2 Garden clearing management. Coffee garden clearing is performed following the final harvest of fruits. This process involves pruning the trees to maintain their shape, removing weeds and debris from the garden, organizing the garden layout, and implementing other management practices. The primary objective of these activities is to decrease the initial population of overwintering pests and diseases, thereby reducing the incidence of such issues in the subsequent year. This approach aims to achieve both sterilization and the promotion of healthy tree growth. Specific measures include: (i) timing for clearing the garden: the optimal period is

3 – 5 d following the final harvest of fruits in the coffee garden; (ii) steps to be taken: *H. vastatrix* spores overwinter in infested branches, and it is essential to remove diseased dry branches, infected leaves, withered fruits, and clusters of branches during winter pruning. This practice effectively reduces the initial population of *H. vastatrix* and minimizes the nutritional depletion of the coffee trees. The dead branches, fallen leaves, and weeds present beneath the coffee garden trees serve as wintering habitats for coffee rust. It is imperative that these materials should be entirely removed from the garden and then incinerated or buried deeply. This practice is essential to sever the connection to the source and effectively eliminate the overwintering pathogen. Rust affixed to garden soil, coffee trunks, and leaf undersides should be treated with copper oxychloride or Bordeaux mixture to achieve comprehensive control throughout the garden, thereby effectively eradicating *H. vastatrix*.

4.2.3 Water and fertilizer management. Following the clearing of the garden, a fertilization trench measuring approximately 15 – 20 cm in width and 20 – 25 cm in depth is excavated directly beneath the drip line of the plants. This trench is designed to facilitate the application of decomposed organic fertilizer at a rate of 2 – 5 kg/plant. An additional application of 15-15-15 compound fertilizer at a rate of 60 kg/667 m^2 is recommended on the eve of the rainy season in June. A second application of the compound fertilizer should be conducted prior to the conclusion of the rainy season in September. It is advised against the spreading of compound fertilizer during this period. The growth of coffee plants is enhanced by the timely application of fertilizers containing boron, zinc, magnesium, and other trace elements.

4.2.4 Tree management. To enhance ventilation and light transmittance among the trees, optimize nutrient supply, and promote tree growth, it is essential to promptly remove redundant straight branches, barren branches, excessively dense first and second branches, branches affected by insect infestations, and dead branches.

4.2.5 Weed management. Weeds are systematically removed in accordance with their growth potential, with particular attention given to invasive species such as *Chromolaena odorata*, *Setaria viridis*, *Alternanthera sessilis*, *Digitaria sanguinalis*, *Bidens pilosa*, *Cyperus rotundus*, and *Ageratina adenophora*. It is essential to mitigate competition for water, nutrients, and space between weeds and coffee plants in order to enhance the growth potential of the latter. In coffee gardens, the application of ground cloth can be utilized to suppress grass; however, it is imperative that the cloth is removed periodically to prevent soil compaction resulting from prolonged coverage. Furthermore, the use of herbicides is not advisable in coffee gardens.

4.3 Chemical prevention and control

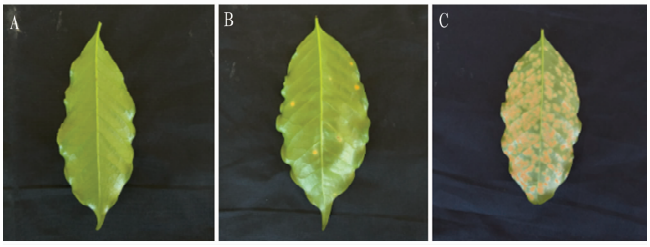
4.3.1 Scientific selection of drugs for control. In the initial stages of coffee leaf rust disease, characterized by an infected area of equal to or greater than 4.01%, agents containing various effective active ingredients may be utilized. These include difenoconazole · propiconazole, pyraclostrobin, isopyrazam · tebuconazole, propiconazole, prothioconazole, prothioconazole · tebuconazole, propiconazole · tebuconazole, picoxystrobin · propiconazole, flutriafol, epoxiconazole · azoxystrobin, epoxiconazole, propiconazole · azoxystrobin, cyproconazole, cyflufenamid · tebuconazole, hexaconazole, thiophanate-methyl · epoxiconazole, kresoxim-methyl · epoxiconazole, kresoxim-methyl, azoxystrobin, phenamacril · tebuconazole, thifluzamide, triadimefon, trifloxystrobin · tebuconazole, tebuconazole · kresoxim-methyl, tebuconazole, fenaminstrobin · tebuconazole, diniconazole, metconazole, pyraclostrobin · epoxiconazole, pyraclostrobin · hexaconazole, and pyraclostrobin · tebuconazole. In accordance with the recommended dosage indicated on the label for foliar spray application, agents should be applied every 7 – 10 d for a duration of 2 – 3 consecutive applications, depending on the severity of the disease and prevailing climatic conditions. Immunity resistance inducers, such as aminooligosaccharides, and plant growth regulators, including brassinolide, triacontanol, thidiazuron, 2-diethylaminoethyl hexanoate, and hematin, can be applied to enhance the growth recovery of coffee plants and to improve their resistance to diseases and adverse conditions.

4.3.2 Safe and efficient application of drugs. It is advisable to employ unmanned aerial vehicles for plant protection spraying operations. During these operations, the ambient wind speed should not exceed level 3, and the recommended spray volume should be 1.5 – 3.0 L/667 m^2. Furthermore, the formulation includes plant oils, organosilicone compounds, polymer sedimentation agents, anti-evaporation agents, and other appropriate additives for fly control. The application rate is calibrated based on the height of the plants and their planting density to ensure uniform coverage of the entire leaf surface. It is advisable to schedule applications during cooler periods, specifically before 9:00 or after 14:00, in order to avoid high temperatures typically experienced at noon. Additionally, if wind speeds exceed level 3 or if rainy weather occurs, the application should be halted. Operators are required to wear the appropriate personal protective equipment, refrain from spraying in a downwind direction, and are strictly prohibited from walking through the application area. Additionally, smoking, eating, and drinking are not permitted during operations.

4.4 Conservation and utilization of hyperparasitic fungi and natural enemies

It is a well-documented phenomenon that the pathogenic fungi responsible for coffee leaf rust are subject to parasitism by other fungal species and predation by various arthropods. The monitoring surveys conducted on coffee leaf rust revealed a significant presence of hyperparasitic fungal resources, as well as an insect that feeds on the spores of leaf rust. These findings indicate that the coffee-producing regions of Yunnan Province are abundant in hyperparasitic fungi and natural enemy resources (Figs. 2 – 3). Consequently, the application of chemicals should be minimized and implemented in a scientifically informed manner within practical production settings. It is essential to utilize highly efficient, environmentally friendly, and low-toxicity fungicides to establish habitats conducive to the survival and proliferation of natural enemies and beneficial microorganisms. Additionally, the management of coffee leaf rust can be effectively achieved through the use of hyperparasitic fungi and natural predators. Chemical control measures are not advisable during the peak period of hyperparasitic fungi and natural enemies of coffee leaf rust, which oc-

curs from November to April. This timeframe coincides with the critical period for coffee fruit harvesting.



NOTE A. Early stage of infestation; B. Middle stage of infestation; C. Late stage of infestation.

Fig. 1 Symptoms in leaves affected by coffee leaf rust

Fig. 2 Hyperparasitic phenomenon of coffee leaf rust

Fig. 3 Natural enemies feeding on aeciospores

4.5 Requirements for prevention and control The prevention and control of coffee leaf rust necessitates the enhancement of responsibility implementation, the fortification of systematic prevention and control measures, the improvement of guidance services, and the amplification of publicity and guidance. The specific requirements are outlined as follows.

4.5.1 Enhancing the implementation of responsibilities. It is imperative to acknowledge the significance of preventing and controlling coffee leaf rust to ensure high and stable coffee production. This necessitates the effective implementation of a government-led, regionally accountable prevention and control mechanism. Emphasis should be placed on proactive prevention and early intervention, alongside the enhancement of organizational leadership. Furthermore, it is essential to refine prevention and control strategies to guarantee the systematic implementation of these efforts.

4.5.2 Strengthening systematic prevention and control. The implementation of a singular spray application to enhance promotional efforts for food or cash crops in coffee production regions is essential. This can be achieved through the procurement of services and the implementation of various strategies that leverage the capabilities of diverse professional and social service organizations. It is imperative to actively promote standardized application and spraying prevention operations to significantly enhance the timeliness, organization, and scientific rigor of efforts aimed at preventing and controlling coffee leaf rust.

4.5.3 Enhancing guidance services. Plant protection agencies at all levels should enhance their monitoring and investigative efforts to accurately assess the occurrence and impact of coffee leaf rust. It is essential to refine technical measures, prioritize the selection of effective pesticides, and ensure timely intervention during critical periods. Furthermore, these agencies should provide guidance services on the ground to ensure the effective implementation of prevention and control measures.

4.5.4 Strengthening publicity and guidance. It is essential to fully utilize various media platforms, including radio, television, newspapers, networks, and WeChat, alongside traditional methods such as printed materials, technical training, and field observations. This comprehensive approach aims to raise awareness about the severity of the damage inflicted by coffee leaf rust and the imperative for effective prevention and control measures. Furthermore, it is crucial to disseminate knowledge and skills related to disease prevention and control, thereby enhancing the motivation and proactive engagement of growers in combating this disease.

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