

APPLICATION AND DEVELOPMENT OF ‘GREEN’ PREVENTIVE AND CONTROL TECHNOLOGIES IN GUIZHOU TEA PLANTATIONS

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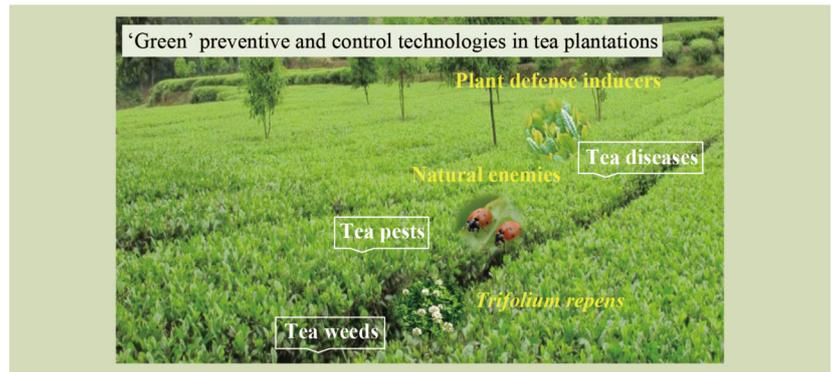
KEYWORDS

‘green’ prevention, natural enemies, plant defense inducers, tea plantations, *Trifolium repens*

HIGHLIGHTS

- Application of plant defense inducers against tea diseases.
- Application of natural enemies against insect pests.
- Application of *Trifolium repens* against weeds.

GRAPHICAL ABSTRACT



ABSTRACT

The application and development of ‘green’ preventive technologies in tea plantations is an important means of ensuring tea quality and ecological safety. Ecological, agronomic and biological controls are the main preventive measures used in Guizhou Province. This paper summarizes the ‘green’ preventive technologies being applied in Guizhou tea plantations, including the use of plant defense inducers to regulate tea plant responses to pathogens, natural enemies to control pest species causing damage to shoots and *Trifolium repens* to control the main weed species. In addition, it summarizes the integrated ‘green’ preventive technologies being used in Guizhou and provides a foundation for the ecological maintenance of tea plantations.

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1 INTRODUCTION

Tea quality and safety are the lifelines of the tea industry. Rampant insect pests and pesticide residues in tea plantations are the main factors affecting the healthy development of the tea industry^[1].

There are more than 180 tea plant diseases, 800 insect pests and 200 weed species in tea plantations, and 5–10 are common diseases, 10–20 are common insect pests and 3–5 are common weeds in Guizhou tea plantations. The main diseases^[2–6], insect pests^[7–13] and weeds^[14,15] are listed in Table 1.

Chemical use is the main practice used to control insect pests.

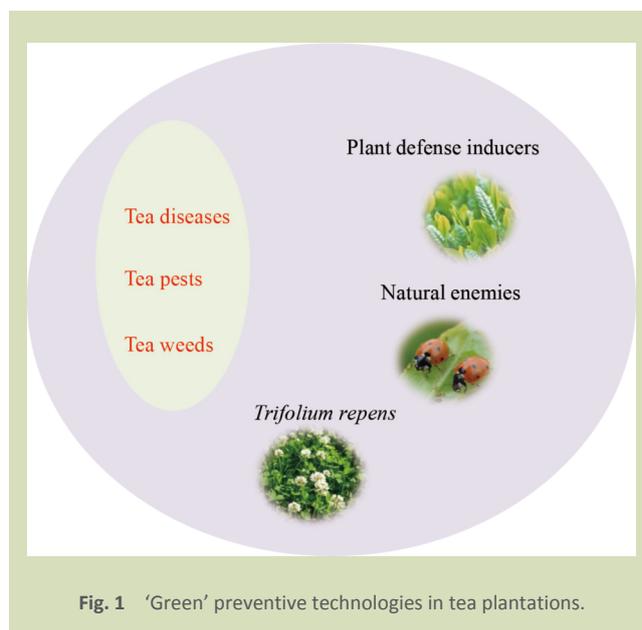
Table 1 Main diseases, insect pests and weeds in tea plantations

Type	Species	Reference
Pathogens	<i>Phyllosticta theaeifolia</i>	[2–4]
	<i>Exobasidium vexans</i>	[5,6]
Pests	<i>Dendrothrips minowai</i>	[7–9]
	<i>Empoasca onukii</i>	[10–12]
	<i>Dasychira baiбарana</i>	[13]
Weeds	<i>Pteridium aquilinum</i>	[14]
	<i>Digitaria sanguinalis</i>	[15]

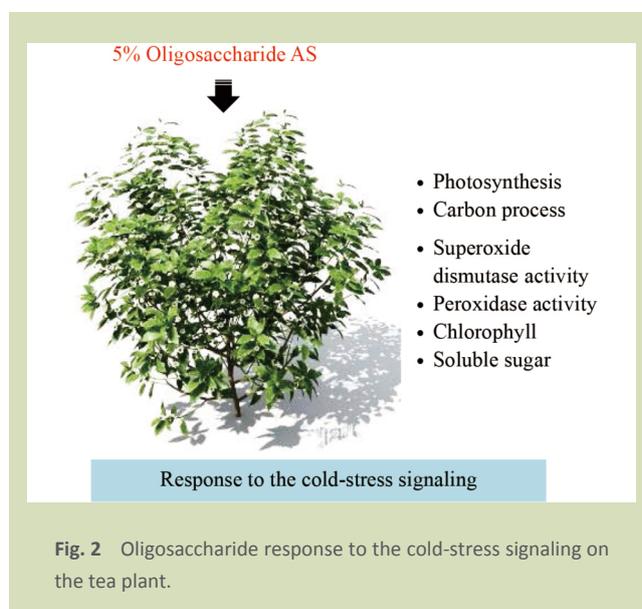
However, the long-term and non-standard use of chemical pesticides easily leads to resistance in pests, affecting the reproduction of natural enemy populations and the quality and safety of tea products, all combining to greatly threaten the sustainable development of the tea industry in Guizhou Province. Therefore, biological and ecological control technologies represent the inevitable trend in tea plant pest control in Guizhou Province. Preventive and control technologies are important for ensuring and supporting modern agriculture through high-output efficiencies, product safety levels, resource savings and environmental friendliness and are an important means of ensuring tea quality, safety, and ecological security, and supply and higher farmer incomes. Biological and ecological control technologies in tea plantations are therefore an important means of ensuring the safety of tea, improving tea quality and increasing farmer incomes. They help tea plantations become more ecological, environmentally friendly and ‘clean’. This review introduces tea diseases, insect pests and weeds that are the foci of ‘green’ control technologies (Fig. 1). We have selected research published in the past five years on biological and ecological control technologies for tea diseases, insect pests and weeds, and have extracted the appropriate technologies to provide technical support for the construction of an ecological tea plantation system.

2 ‘GREEN’ PREVENTIVE TECHNOLOGIES AGAINST TEA DISEASES

Phyllosticta theaeifolia and *Exobasidium vexans* are the main pathogens causing diseases of tea plants. Tea processed from diseased leaves is bitter and fragile, and this has a great influence on tea yield and quality. Oligosaccharides^[16–18] and shenqinmycin^[19] can induce antifungal activities in the plants and increase yields. In addition, oligosaccharides may also

**Fig. 1** ‘Green’ preventive technologies in tea plantations.

form responses to cold-stress signals in tea under high altitude and high humidity environmental conditions by increasing superoxide dismutase and peroxidase activity levels, as well as the chlorophyll and soluble sugar contents, in oligosaccharide-treated tea leaves (Fig. 2)^[20]. The relative control effect of oligosaccharides and shenqinmycin against *Phyllosticta theaeifolia* is about 86% ($P < 0.05$), which is greater than a single drug control^[21]. In addition, oligosaccharide and polyoxin significantly reduce the incidence of *E. vexans*. The relative control effect of oligosaccharide and polyoxin is 67% ($P < 0.05$), which is greater than a single drug control^[21], and after the treatment the new bud leaves generally have less, or no, disease spots.

**Fig. 2** Oligosaccharide response to the cold-stress signaling on the tea plant.

Other plant defense inducers, such as salicylic acid, laminarin, benzothiadiazole, β -aminobutyric acid, jasmonic acid, methyl jasmonate, and methyl salicylate, are important in the fields of plant physiology and plant protection. Salicylic acid acts as a key compound in the responses of tea plants to anthracnose disease^[22]. Laminarin enhances tea defenses against the tea green leafhopper by regulating signaling pathways in tea plants^[23]. Benzothiadiazole and β -aminobutyric acid are important in the induction or resistance in tea plants to tea geometrid^[24]. Jasmonates and salicylates increase tea plant volatile emissions and induce anti-pest reactions in tea plants^[25,26]. In brief, plant defense inducers not only reduce the disease incidence but also induce anti-pest reactions in tea plants.

3 'GREEN' PREVENTIVE TECHNOLOGIES AGAINST INSECT PESTS

Dendrothrips minowai, *Empoasca onukii* and *Dasychira baibarana* are the main insect pests in tea plantations. *Dendrothrips minowai* causes damage mainly to tender shoot bud leaves but then moves and feeds on the tender leaves, with adults and nymphs feeding on the phloem. The main veins of the injured leaves have a number of longitudinal concave scars. The leaves become slightly curled and brittle and then drop. *Dendrothrips minowai* and aphids are prey for *Amblyseius cucumeris*, *Harmonia axyridis*^[27] and *Orius sauteri*^[28], and the control of *A. cucumeris* and *H. axyridis* may reach 54% (60 d, $P < 0.05$) and 53% (60 d, $P < 0.05$), respectively, in Guizhou Meitan tea plantations (Fig. 3). To control the adult *D. minowai*, color-

optimized traps-lawngreens^[29] and spinetoram spraying^[30] may be used, with the control reaching $> 95\%$.

Empoasca onukii causes severe harm to summer and autumn tea in which the injured tea bud leaves curl up and harden. The leaf tips and edges turn reddish-brown and wither, and the bud shoot growth is slow, resulting in marked decreases in yield and quality. The nymphal stage of *E. onukii* can be controlled by *Orius strigicollis*^[28]. In addition, leafhopper attractants^[31] and *Metarhizium anisopliae*^[32] are used to control adult *E. onukii*, with control $> 60\%$.

Dasychira baibarana is an insect in the family Lepidoptera. Larvae eat tea leaves, resulting in gaps or holes affecting the yield and quality of tea in the following season^[33,34]. At the beginning of an infestation, *Trichogramma dendrolimi*^[35] has been used to control *D. baibarana* eggs, with parasitism reaching 90%, and at later stages of an infestation *Bacillus thuringiensis*^[36] has been used to control *D. baibarana* nymphs, with control $> 60\%$.

The control of the insect pests in tea plantations to below the economic threshold requires increasing the proportion of natural enemies and avoiding the use of chemical pesticides. In the spring, natural enemies such as *H. axyridis*, *A. cucumeris*, *O. sauteri* and *T. dendrolimi* are released. In the summer, a non-picking period, pruning and spinetoram (for emergency pest prevention and control) are the keys to ecologically healthy tea plantations. In the autumn, integrated preventive and control technologies of natural enemies and digital yellow boards are used. To eliminate insect pest eggs, picking of plantations can cease and tea plants pruned and treated with a

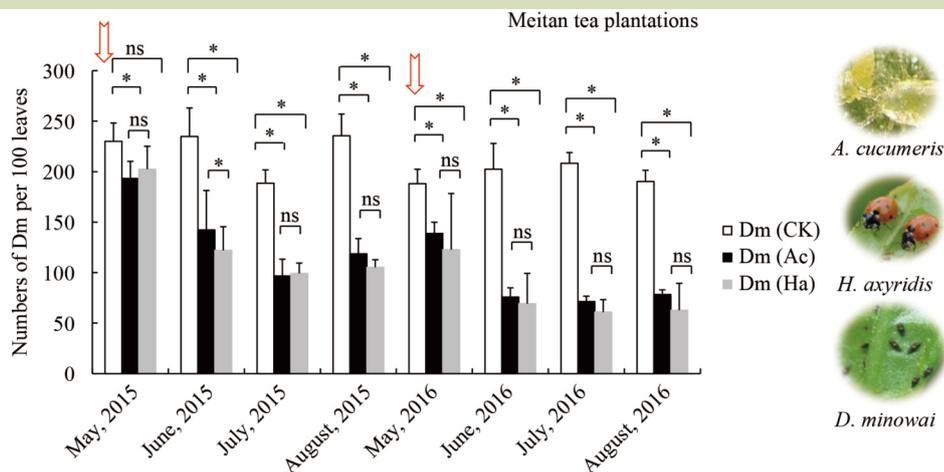


Fig. 3 Control of *Dendrothrips minowai* (Dm) with *Harmonia axyridis* (Ha) and *Amblyseius cucumeris* (Ac). CK, control; ns, not significant.

lime-sulfur mixture and some biological and botanical insecticides can be used.

4 'GREEN' PREVENTION TECHNOLOGIES AGAINST WEEDS

The main weeds in Guizhou tea plantations are *Pteridium aquilinum* and *Digitaria sanguinalis*, which generally occur over large areas of plantations more than five years old. They compete with the plants for nutrients and inhibit growth. Plants that control the main weeds in tea plantations, such as *Festuca arundinacea*, *Lolium perenne*, *Trifolium incarnatum*, *Trifolium repens*, *Lotus corniculatus* and *Medicago sativa*, have been interplanted in tea plantations for many years. Interplanting with *T. repens* effectively controls weeds through several mechanisms including the dispersal of allelochemicals into root systems and by occupying physiological space, which controls the roots and stems, and physical space which controls the stolons^[37]. Replacing the chemical herbicide glyphosate with *T. repens* interplanting in young tea plantations inhibits weed growth and also provides nitrogen for the tea plants^[38]. To interplant *T. repens* the ground is leveled and the soil loosened and aerated by harrowing. Seeds are sown at a depth of 1–2 cm (Fig. 4(a)). When interplanting with *T. repens* in young tea plantations *T. repens* growth is dominant after three months (Fig. 4(b)), and after six months it provides full cover of the soil surface (Fig. 4(c)). After six months, compared with tillage, *T. repens* interplanting in young plantations significantly controls weeds, reducing their density and biomass. There are 35 weed species in the *T. repens*-sown area and 58 weed species in the tilled areas of Guizhou tea plantations. The weed density can be reduced by *T. repens* interplanting to 16.7 g·m⁻² compared to 147 g·m⁻²^[37] in tilled areas. The weeding cost can be reduced by two-thirds using this strategy^[37]. Also, interplanting with *Vulpia myuros* is a good weed management strategy. Compared to tillage, *V. myuros* interplanting can increase soil fertility with soil organic matter, and available N and P increase significantly^[39].

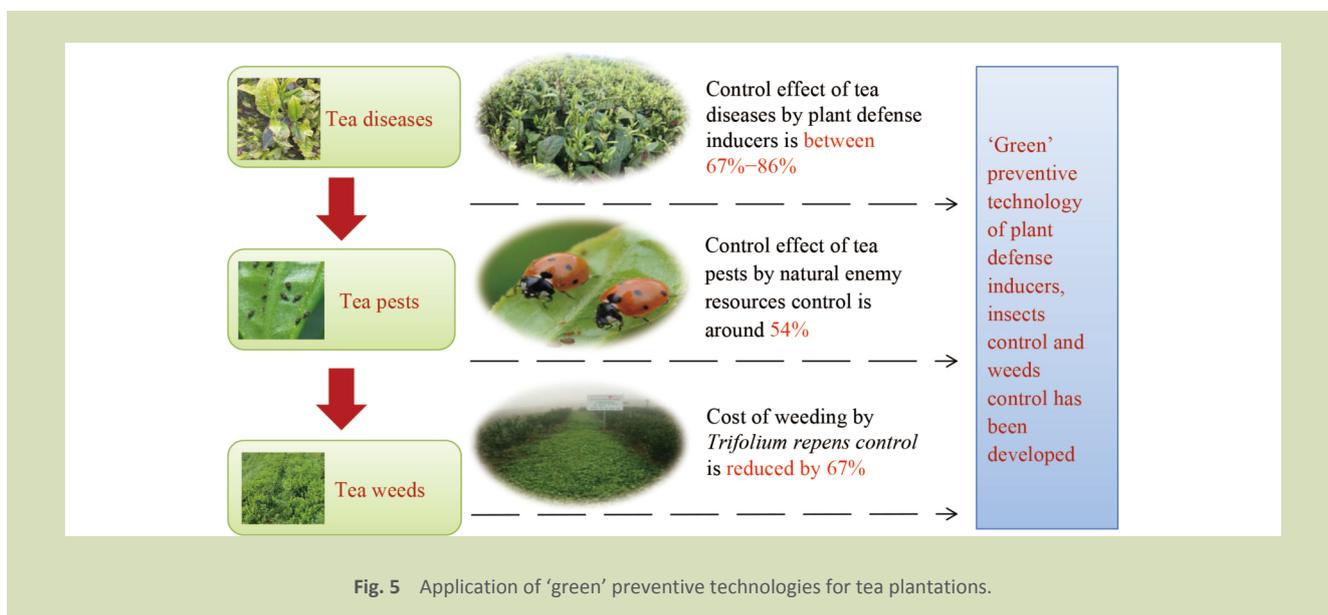
5 SUMMARY OF THE APPLICATION OF 'GREEN' PREVENTIVE MEASURES IN GUIZHOU TEA PLANTATIONS

To address the problems of increasing diseases, insect pests and annual weeds, 'green' preventive and control technologies have been used to remodel and construct stable tea plantation ecological control systems. Comprehensively implemented natural enemy-based prevention and control measures can replace chemical pesticides and interplanting with *T. repens* can replace herbicides in conjunction with pesticide monitoring and control. At the end of 2020 the management of plantations included defense-induction, beneficial insects and *T. repens* interplanting. The disease control achieved was between 67% and 86% and control of pests around 54%, and the cost of weeding was reduced by about 67% (Fig. 5).

Based on the Guizhou tea production cycle characteristics and disease and pest occurrences, 'green' prevention and control is proposed. Guidance documents from Guizhou Provincial Agricultural Commission have been compiled to form a three-year improvement plan of integrated development of unified control and 'green' control, a 'green' control plan of tea plant diseases and insect pests in Guizhou Province, recommended products of 'green' control of tea plant diseases and insect pests in Guizhou Province, and an implementation plan of integrated technology of 'green' control of tea plant diseases and insect pests in Guizhou Province, which have been promoted in 43 major tea-producing counties in Guizhou. In total, 81 demonstration areas for 'green' preventive and control technologies against tea plant diseases and insect pests have been established, 60 times more technical training has been carried out, 43 farmer field schools have been established, and > 5000 agricultural technicians and tea farmers have been trained. The value of tea leaves per m² has increased by > 2 CNY, raising > 100,000 farmers out of poverty and increasing their income. These guidelines provide important technical support for the sustainable and healthy development



Fig. 4 Interplanting with *Trifolium repens* to control weeds in tea plantations. (a) *T. repens* growth after one month. (b) *T. repens* growth after three months. (c) *T. repens* growth after six months.



of nearly half a million hectares of tea plantations in Guizhou Province.

6 FUTURE PERSPECTIVES

The development of good tea plantation ecosystems should be based on healthy cultivation of crops and strengthening of 'green' development. A 'green' management model for tea plantations includes the concept of ecology and agronomy as the foundation and biological control as the first defense. Preparations include loosening the soil by shallow plowing, increasing the ground temperature and promoting the early sprouting of spring tea. Commencement of picking on time is important and leaf batches collected in accordance with standards. As much tea as possible should be collected and the

pest population reduced to avoid outbreaks. Combining the EU pesticide residue limit standards and the background numbers of diseases and insect pests in tea plantations, with scientific research and judgment, will aid in the selection of high-efficiency, low-toxicity and low-residue pesticide products of guaranteed quality. Additionally, understanding the key periods for prevention and control applications, as well as safety intervals, is necessary to apply emergency prevention and control of diseases and insects in tea plantations if needed.

In the near future, a 'green' management model for tea plantations will involve harnessing tea plant defense regulation against diseases, dispersing natural enemies for pest control and interplanting *T. repens* for weed control. This will improve tea quality and increase yields.

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Compliance with ethics guidelines

Xiangyang Li, Linhong Jin, Zhuo Chen, and Baoan Song declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any study with human or animal subjects performed by any of the authors.

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