Evaluation of the attractive effect of coloured sticky traps for *Aleurocanthus spiniferus* (Quaintance) and its monitoring method in tea garden in China

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Abstract

Aleurocanthus spiniferus (Quaintance), namely tea spiny whitefly (TSW), belongs to the family Aleyrodidae in the order Homoptera, widespread in tea trees and fruit trees in many countries or regions. In this study, the preference of TSW for different colours was evaluated in tea gardens. Yellow was the colour most preferred by TSW, followed by pink, red, white and other colours. The controlling technologies about the number of sticky traps in a certain area of tea garden and the height of sticky traps above tea canopy were also evaluated, the results indicated that the attractive effect of 20 traps/667 m^2 of trials area and the height of 10 cm above tea canopy were significantly higher than others treatments. In addition, more TSW was caught at 11:00-15:00, followed by 7:00-11:00, and 15:00-19:00 in a daytime; higher activity level of male adults was at 7:00-11:00 and 11:00-15:00 in day time (95.13% and 94.97% of caught TSW), indicating a higher activity level for male adult.

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Introduction

Light signals play an important role in searching for mate, foraging and selecting habitat in insects (Elgar *et al*., 1996; Lelito *et al*., 2007; Jiang *et al*., 2008). The colour preference is utilised to monitor population dynamics or to control insects' numbers in crop protection (Gu *et al.*, 2008; Broughton & Harrison, 2012). For instance, white was the colour most preferred by female *Trichogramma* spp.; yellow and green were the colour most preferred by male *Trichogramma* spp. Colour preference was also used to monitor *Trichogramma* spp. in the field in India (Romeis *et al*., 1998). In comparison with other colours, yellow attracts *Siphoninus phillyreae* (Haliday), a species of ash whitefly infesting ornamental trees and shrubs. Yellow traps were utilised to monitor population dynamics of the ash whitefly in California (Pickett & Pitcairn, 1999). *Byturus tomentosus* Degeer prefers white, so, white traps were used to monitor its population dynamics and control its number (Schmid *et al*., 2006). Green with a wavelength 300-380 nm and 500-570 nm, and ultraviolet light can trap more oriental fruit fly (*Bactrocera dorsalis*) by the method of receptor quantum catch (Wu *et al*., 2007). Yellow-green or yellow was the colour most preferred by *Pseudaulacaspis pentagona* (Targioni), *Dendrothrips minowai Priesner*, *Empoasca vitis* Göthe and *Ectropis obliqua* (Xiao, 1997; Kaneko *et al*., 2006). Bright yellow or green can trap more *Empoasca vitis* Göthe, and rape flower yellow can trap tea aphid (Han *et al*., 2012). Therefore, trapping technology based on colour preference of tea insect was designed to monitor and control some pests.

Tea tree, *Camellia sinensis* (L.) Kuntze, belonging to *Camellia* genus in the family *Theaceae*, is the evergreen shrub or small tree plant. At present, tea tree is cultivated in 46 countries in Asia, Africa, Latin America and Oceania (Hazzrika *et al*., 2009). China, which was regarded as the cradle of tea, has a long history of culturing tea (Chen, 2013). Because of possessing many advantages of edaphic factors, rainfall, temperature, altitude and sunlight, tea-growing regions were covered over 20 provinces or cities in China (Chen, 2013). As a perennial plant, tea tree has a stable ecological structure, which consisted of tea, other plants, animal, microorganism and insect. Chen (2013) reported that the kinds of pests and injurious mites in tea garden

reached 800 species and the customary tea pests reached 400 species.

Tea spiny whitefly (TSW), *Aleurocanthus spiniferus* (Quaintance) (*Aleyrodidae*: *Homoptera*), is present in different metamorphic stages, including adult, spawn, larva and nymph. The larvae can damage tealeaves by sucking juices of the leave. The honeydew secreted by TSW can cause sooty blotch, and tree vigour was finally influenced (Van den Berg & Greenland, 1997; Jin *et al*., 2007). TSW has 4 generations per year in China, and overwinters as larva (Jin *et al*., 2007). TSW wildly exists in many provinces or areas in China, such as Jiangsu, Anhui, Guizhou, Henan, Guangdong, Guangxi, Yunan and Guizhou in China (Qi & Wang, 2007; Tang *et al.*, 2015). At present, controlling technology against TSW is involved in biological control measures, such as *Encarsia smithi* (Silvestri) (Hymenoptera: Aphelinidae), *Trichogramma* sp., *Serangium japonicum* Chapin and entomogenous fungi (Han, 1996; Smith, 1996; Van den Berg & Greenland, 1997; Huang *et al*., 1999; Han & Li, 2001; Ye *et al*., 2013). Although spraying pesticides is considered an effective control measure, high dosage of pesticides can induce insecticide resistance for tea pests, pesticide residue in tea drinks, toxicity hazards to human being, *etc*. (Gurusubramanian *et al*., 2008). Controlling measures like sticky traps have many advantages in controlling the population radix of the pest, reducing the number of spraying pesticides and delaying the outbreak of the pest. So, the coloured sticky trap is wildly used in tea garden in China (Ye *et al*., 2013).

In this study, the preference for different colours was studied in TSW, a reasonable height above tea canopy and the number of placing the sticky traps in certain area of tea garden was studied in many tested sites in Guizhou province; meanwhile, activity level about adult male and female was investigated in a daytime.

Materials and methods

Trial sites

Fenggang County (27° 95' N, 107° 71' E), Huishui County (26° 11' N 106' E, Guiding County (26° 21' N, 107° 09' E) in Guizhou province were selected as field trial sites. The field experiments were conducted over a 2 month period during 3 years (April-May in 2012-2014). No pesticides had been applied during the experiments. The cultivation conditions and the field management were nearly same at field experiment sites. The experiments were conducted when the rate of adult emergence is nearly accounted for 70-80% of all TSW. The ratio of males to females remained almost the same at three trials sites.

Comparative trial of attractive effect of coloured sticky traps

The surface area of tested sticky traps was 480 cm^2 (20×24 cm), and the colour value (RGB) of traps was shown in Table 1. The coloured sticky traps were used to evaluate attractive effect at 3 tested sites (Fenggang, Huishui and Guiding County). The attractive effect about all coloured traps was investigated via counting the individuals number of adult TSW on the trap, and a randomised block design method was used, with 10 treatments and 4 times of repetition in experiment (Schmid *et al*., 2006; Lin *et al*., 2009). Each treatment consisted of three rows of tea bush spaced 4.5 m apart and 14.8 m long (area: 67.7 m^2). The traps were placed from the middle row of each treatment, and the trap was placed 10 cm from tree canopy. Interval of 12 days, the population number on both sides of the sticky traps was calculated.

In addition, the traps with different yellow colour (ivory yellow RGB: 200, 193, 29; medium yellow RGB: 206, 201, 46; deep yellow RGB: 214, 194, 0) were further used to evaluate the attractive effect. In each treatment group, 2 traps were placed above the height of 10 cm from tree canopy, with its trials area of 67.7 m^2. After interval of 12 days, the individuals were calculated on both sides of the sticky traps.

Optimisation trial of trap's height and number

These two trials were conducted in Fenggang trial site. For trial of height optimisation, the height of deep yellow sticky traps above tea canopy was 0, 10, 20 and 30 cm in each treatment. The experimental design was similar to the trials of different coloured traps. For trial of number optimisation, 10, 20, 30 and 40 of deep yellow sticky traps was applied in each trials treatment, with its area being 667 m^2. Interval of 12 days, the individual number of adult TSW on both sides of traps was calculated. In addition, the controlling effect of TSW was also investigated as follow: the population base of TSW was investigated before placing the traps. Then the number of residual surviving pests was investigated at 12 days after placing the traps. The adult- and nymph- TSW were investigated from 20 leaves at each points containingthree spatial position (upper-, middle- and lower-part of tea canopy), and the data was acquired from 10 investigated sites at each treatment (Han, 2002).

$$R = \frac{T1 - T2}{T1} \times 100\% \quad (1)$$

$$Rdr = \frac{R(treat) - R(control)}{100 - R(control)} \times 100\% \quad (2)$$

Formula (1) and (2): R represented that mite population declining rate of pest in population. Formula (1): $T1$ and $T2$ represented that *the population radix of the pest before applying the sticky traps* and *the population radix of the pest after applying the sticky traps*, respectively. Formula (2): the letter of *Rdr* represent *rectifying decline rate*; *treat* and *control* represented that *the treatment group of applying the sticky traps* and *the treatment group of non-applying the sticky traps*.

Analysis of trap's attractive effect during different time period in the daytime and different area on trap

Three time periods (7:00-11:00, 11:00-15:00 and 15:00-19:00) in the daytime were used to investigate the attractive effect. Each treatment consisted of three rows of tea bush spaced 6.0 m apart and 7.0 m long (area: 42.0 m^2), and 1 trap was placed from the middle row of each treatment, with placing height being 10 cm. The sticky trap was placed in tea canopy before 15 min of conducting experiments. The female and male adult on both sticky traps was calculated at each treatment.

Twenty yellow sticky traps were applied in each treatment with its area being 677 m^2. The distance of the sticky trap was 3.7 m and 2.25 m apart from field edge. The individual number of adult TSW was investigated from 8 traps randomly selected in each treatment. Interval of 12 days, the individual number of TSW on traps was investigated as follow: the trap was divided into 4 rows of *A-D* or 6 columns of *1-6* using photograph, TSW caught on trap was counted according to the region of the mode of *rows* × *columns* on both sides of trap using computer monitors (Figure 1).

Table 1. The colours value about the sticky traps.

Colour	Value (RGB)	Colour	Value (RGB)
Red	226,06,0	Pink	218,42,57
Blue	0,112,188	Grey	125,127,118
Green	0,174,91	Purple	116,99,174
White	159,162,149	Cyan	52,147,149
Black	41,47,35	Yellow	214,194,0

Data processing

Data was analysed using SPSS statistic software (version: 11.5). The data of the trapped individuals on the coloured sticky trap were tested for normal distribution, and then the data were analysed by a one-way analysis of variance (ANOVA) and Homogeneity of variance test. Dunnett's T3 method was used to analyse the attractive effect among treatment groups at the level of 0.05 or/and 0.01 (P value). The difference was labelled with the letter marking method, which indicated there was significant difference when the letter was different.

Results

Attractive effect of tea spiny whitefly to the colour sticky traps

The individuals of TSW caught on the sticky traps were significantly different among different treatments (test of homogeneity of variances, Levene statistic=1.986; df1=9, df2=30, Sig=0.077), with 927.8, 911.8 and 943.3 individuals caught on yellow sticky trap at Fenggang, Huishui and Guiding County (Table 2). By comparison to others coloured traps, yellow trap can significantly attract more TSW. A certain number of adult TSW were also trapped on the pink, red and white sticky traps (Table 2). The individuals caught on blue, green, black, grey, purple and cyan sticky traps were lower than 100, and significant differences were observed among some treatments. For instance, at Huishui's trial site, the attractive effect of green trap was significantly higher than that of blue trap, and the attractive effect of black trap was significantly higher than that of grey trap. But no significant differences were observed among blue, green, black or grey at Fenggang and Guiding (Table 2).

Adult TSW number trapped on 3 yellow sticky traps (ivory, medium, deep-yellow) were analysed in 3 trials sites (Fenggang, test of homogeneity of variances, Levene statistic=0.965; df1=2, df2=9, Sig=0.417; Huishui, test of homogeneity of variances, Levene statistic=0.996; df1=2, df2=9, Sig=0.407; Guiding, test of homogeneity of variances, Levene statistic=0.985; df1=2, df2=9, Sig=0.410) (Table 3). Comparing with ivory yellow trap, the deep-yellow and medium-yellow traps possessed significantly higher attractive effect for adult TSW ($P<0.01$) (Table 3). For instance, individuals caught on deep yellow were 4441.75, 2724.15 and 2800.8225 at the sites of Fenggang, Huishui and Guiding. Nevertheless, no significant difference was observed between deep yellow and medium yellow at 3 trials sites.

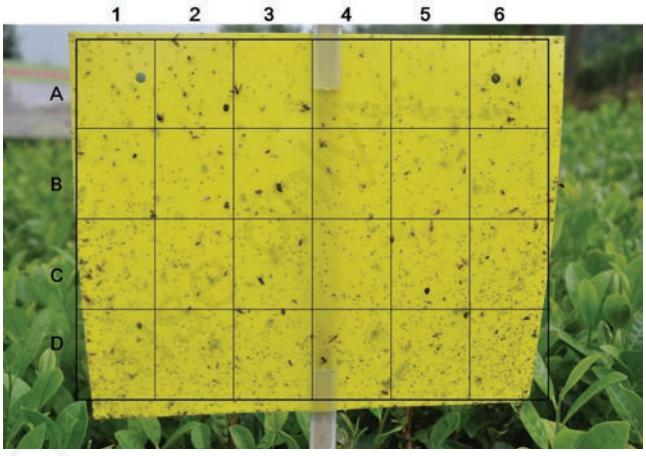

Figure 1. The distribution investigation of adult tea spiny whitefly on yellow sticky traps.

Table 2. Comparison of trapped individuals of adult tea spiny whitefly caught on different coloured traps.

Treatment	Colour				
	Red	Blue	Green	White	Black
Fenggang, 2012	181.8±32.1^{Bb}	73.5±16.0^{Ccd}	87.5±11.4^{Cc}	164.0±37.5^{b}	63.8±18.5^{Ccd}
Huishui, 2014	164.8±37.8^{Bb}	56.5±22.0^{Ccd}	70.5±12.7^{Cc}	147.3±42.8^{Bb}	46.8±22.5^{Ccd}
Guiding, 2014	196.3±32.71^{Bb}	88.0±16.99^{Cc}	102.0±9.80^{Cc}	178.8±36.48^{Bb}	78.3±20.09^{Cc}
Treatment	**Colour**				
	Pink	**Grey**	**Purple**	**Cyan**	**Yellow**
Fenggang, 2012	199.8±58.5^{Bb}	40.3±18.8^{Cd}	68.3±8.4^{Ccd}	89.3±3.9^{Cc}	927.8±49.0^{Aa}
Huishui, 2014	183.0±63.2^{Bb}	23.3±19.6^{Cde}	51.3±12.3^{Ccd}	72.3±8.7^{Cc}	911.8±51.7^{Aa}
Guiding, 2014	214.8±59.2^{Bb}	54.8±22.7^{Cd}	82.8±12.7^{Cc}	103.8±7.4^{Cc}	943.3±51.6^{Aa}

Means±standard deviation in each column followed by different letters are significantly different at the level of 0.05 (lower case) and 0.01 (capital letter).

Table 3. Trapped individuals of adult tea spiny whitefly on yellow coloured traps.

Treatment	Colour		
	Ivory yellow	Medium yellow	Deep yellow
Fenggang, 2012	3131.0±99.0^{Bb}	4422.5±229.1^{Aa}	4441.8±111.0^{Aa}
Huishui, 2014	1878.5±52.4^{Bb}	2659.4±123.4^{Aa}	2724.2±70.4^{Aa}
Guiding, 2014	1975.1±59.9^{Bb}	2788.7±143.1^{Aa}	2800.8±67.8^{Aa}

Means±standard deviation in each column followed by different letters are significantly different at the level of 0.05 (lower case) and 0.01 (capital letter).

Attractive effect of tea spiny whitefly to the sticky traps with different height or number

The treatment of 10 cm height can trapped more adult TSW, with the individuals number reaching at 9607.3 (*10 cm*-treatment *vs* other treatments, P<0.01); the treatments of 20 cm and 0 cm height can also trapped many adult TSW, with the population number reaching at 8125.0 and 7873.5. Nevertheless, the attractive effect of the treatment of 30 cm heights was not ideal, with the individuals' number reaching at 6311.0 (*30 cm*-treatment *vs* other treatments, P<0.01).

For 4 treatments (10, 20, 30 and 40 traps placed in each block), Rdr values of the upper part and the middle/lower-part were 30.2/26.1%, 57.2/47.1%, 53.5/43.9%, and 47.1/41.4%. No significant difference was found between 20 traps and 30 traps treatment at the upper part at the level of 0.05.

Attractive effect of tea spiny whitefly to different time period in the daytime and different area on trap

A time period in which attracted more individuals was 11:00-15:00 in a daytime, and caught individuals reached at 298 (male: 283, female: 15). During another time period of 7:00-11:00, 226 individuals (male: 215, female: 11) were caught on the sticky traps. Relatively few individuals (total: 169, male: 142, female: 27) were attracted during 15:00-19:00. In addition, the investigation of the ratio of female and male adult TSW caught on traps indicated that the active degree about male adult was higher than that of female adult, and the most active time period of male adult was 7:00-11:00 and 11:00-15:00 in a daytime, and the most active time period of female adult was relatively pushed back.

The population number of TSW caught on the rows of *A, B, C, D* was 102.6, 237.1, 468.1 and 842.1. The population number of *D* region was significantly higher than that of other regions (P<0.05), but there was no significant difference between 2 regions of *C* and *D*. In addition, the results also indicated that the population number in column of *1, 6* (individuals: 263.9, 350.3) was significantly higher than that of in columns of *2, 5* (individuals: 277.4, 278.5) and *3, 4* (individuals: 198.6, 181.4) (P<0.01).

Discussion and conclusions

Lin *et al.* (2009) reported that jasmine yellow, pure white, bud green, apple green and peach red can trap more species of tea pests, such as TSW, *Ricania speculum, Empoasca vitis* Göthe, in comparison with orange yellow, sea blue, sky blue, emerald green in tea garden in Shaoxing and Hangzhou in China. Meanwhile, Lin *et al.* (2009) also showed that jasmine yellow, stone yellow, bud green and orange yellow can trap more pest species in the family of *Aleyrodidae* in *Homoptera* in Hangzhou in China, especially with jasmine yellow. Being similar to Lin's results, we also found that the yellow colour can also trap more adult TSW, comparing with other colour (Table 2). Aimed to the attractive effect of yellow with different colour value, Lin *et al.* (2009) had evaluated that the jasmine yellow was the most attractive effect for the family of *Aleyrodidae*, by comparison to tone yellow and orange. In this study, our study noted that deep yellow could trap more adult TSW, comparing with medium yellow and ivory yellow (P<0.05). In addition, the optimisation trial of trap's height indicated that the living range of adult TSW is nearly tree canopy, with poor flight ability to the adult (Jin *et al.*, 2007). Investigation of adult TSW caught on the trap indicated that the colour preference of male adult TSW differed significantly from females adult TSW. The reason may be caused by the difference about spectrum reaction to the two sexes, or the mate mechanism of male adult. This phenomenon may be worth further study in the future because different sex insect represents different reaction to colour or wavelength. For instance, comparing with wavelength preference for the two sexes of *Campoletis perdistinctus* (Viereck), female pest response was consistently higher for all wavelength and intensities (Hollingsworth *et al.*, 1970). The colour preference to male *Trichogramma* spp. was significantly differed from female pest, and yellow and green had more attractive effect than that of white to male pest (Romeis *et al.*, 1998). Nevertheless, no differences were observed in the response of female and male *Pholetesor ornigis* Weed to coloured sticky traps (Trimble & Brach, 1985).

In summary, this study demonstrated that deep yellow trap can trap more adult TSW, and was suitable for the technology of prevention and controlling in tea garden.

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