The Effectiveness of Field Pest Management and Culling at Harvest for Risk Mitigation of Two Fruit Flies Affecting Citrus in China

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The effectiveness of field pest management and culling at harvest for risk mitigation of two fruit flies affecting citrus in China

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Abstract

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephrtitidae), and the Chinese citrus fly, *Bactrocera minax* (Enderlein) (Diptera: Tephritidae), are 2 destructive citrus fruit pests in China. A field study was conducted during Sep to Oct of 2018 in Dongkou County of Hunan Province to assess (1) fruit infestations at the time of harvest under 2 management levels, and (2) the efficacy of culling at harvest (i.e., visual inspection and removal of the infested fruits) on reducing the number of infested fruits. A total of 26,400 fruits of Satsuma mandarins, *Citrus unshiu* (Swingle) Marcov (Rutaceae), were harvested from 2 groves with 1 representing highly managed groves, and the other representing commonly managed groves (low management). Fruit culling was conducted immediately to separate fruits into 5 groups: (1) *B. minax* infested fruits, (2) *B. dorsalis* infested fruits, (3) *B. minax* + *B. dorsalis* infested fruits, (4) suspected fruit fly infested fruits, and (5) fruit fly free fruits. Fruit dissection was conducted 4 wk later to determine the actual number of the infested fruits, and also to act as a check on the accuracy of visual inspection on the reduction of the number of infested fruits. The highly managed grove had 0.02% infested fruits vs. 2.19% in the low managed grove, a 99.09% reduction in infestation rate. Culling reduced the infested rate to 0.0077% in the highly managed grove and 1.14% in the low managed grove, a reduction of 62% and 48%, respectively, compared to that before culling. About 99% and 73% of fruits which were identified as infested actually were pest free in the 2 groves, respectively. The result of this study suggests that field management is highly effective and critical in reducing fruit fly infestation. The efficacy of culling at harvest on reducing the number of infested fruits was moderate. The accuracy of using culling for identifying the infested fruits was unreliable.

Key Words: systems approach; *Bactrocera minax*; *Bactrocera dorsalis*; fruit dissection; phytosanitary measures

Resumo

La mosca oriental de la fruta, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), y la mosca china de los cítricos, *Bactrocera minax* (Enderlein) (Diptera: Tephritidae), son dos plagas destructivas de los cítricos en China. Se realizó un estudio de campo durante septiembre a octubre del 2018 en el condado de Dongkou de la provincia de Hunan para evaluar (1) las infestaciones de frutas en el momento de la cosecha bajo 2 niveles de manejo, y (2) la eficacia de la eliminación selectiva en la cosecha (inspección visual y eliminación de los frutos infestados) sobre la reducción del número de frutos infestados. Un total de 26,400 frutos de mandarinas Satsuma, *Citrus unshiu* (Swingle) Marcov (Rutaceae), fueron recolectados de 2 huertos, con 1 representando huertos sumamente manejados y el otro representando huertos comúnmente manejados (bajo manejo). Se separaron las frutas inmediatamente en 5 grupos: (1) frutas infestadas con *B. minax*, (2) frutas infestadas con *B. dorsalis*, (3) frutas infestadas con *B. minax* + *B. dorsalis*, (4) frutas sospechadas de ser infestadas con moscas de la fruta, y (5) frutas libres de moscas de la fruta. La disección de frutos se realizó 4 semanas después para determinar el número real de frutos infestados y también para actuar como una verificación de la precisión de la inspección visual sobre la reducción del número de frutos infestados. El huerto sumamente manejado tenía un 0.02% de frutos infestados versus un 2.19% en el huerto comúnmente manejado, una reducción del 99.09% en la tasa de infestación. El descarte de frutas dañadas redujo la tasa de infestación al 0,0077% en el huerto sumamente manejado y al 1,14% en el huerto comúnmente manejado, una reducción del 62% y 48%, respectivamente, en comparación con los niveles antes del descarte de las frutas dañadas. Aproximadamente el 99% y el 73% de las frutas que se identificaron como infestadas en realidad estaban libres de plagas en los 2 huertos, respectivamente. El resultado de este estudio sugiere que el manejo de campo es altamente efectivo y crítico para reducir la infestación de moscas de la fruta. La eficacia del descarte de las frutas dañadas para reducir el número de frutos infestados fue moderada. La precisión de utilizar la selección para identificar las frutas infestadas no fue confiable.

Palabras Clave: enfoque de sistemas; *Bactrocera minax*; *Bactrocera dorsalis*; disección de frutos; medidas fitosanitarias

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Pestiferous tephritid fruit flies such as *Bactrocera dorsalis* (Hendel), the oriental fruit fly, and *Bactrocera minax* (Enderlein), the Chinese citrus fly (both Diptera: Tephritidae), are economically significant citrus pests in China (Zhang & Zhao 1994; Wang & Luo 1995) and important quarantine pests in many other countries (EPPO 2001, 2002). Effective phytosanitary measures are essential in preventing the pests from spreading to other citrus growing regions of the world through international citrus trade activities. Although phytosanitary treatment options for control of *B. dorsalis* have been developed (Dohino et al. 2017), there is no single treatment option available for *B. minax* so far (Xia et al. 2018). It is unlikely that either cold or irradiation treatment, the 2 most commonly used phytosanitary options for global citrus trade, can be developed as a single mitigation measure in the near future. The larvae of *B. minax*, especially third instars, appear very cold tolerant; therefore, developing a practical cold treatment schedule for this pest is challenging (Wei X. pers communication; Luo & Chen 1987; Fan et al. 1994). The use of irradiation as a phytosanitary treatment for the fresh fruit trade faces regulatory hurdles in China (Zhan 2013).

A systems approach uses 2 or more independent measures to achieve the requirements for pest risk mitigation (FAO/IPPC 2017). A systems approach starts with low pest prevalence; field pest management which keeps the pest population at a low level is the critical first measure in a systems approach (FAO/IAEA 2010). Area-wide pest management and integrated pest management are effective in managing field fruit fly populations (Vargas et al. 2010). However, due to small-scale production and many other challenges in Asia, the approach seldomly is adopted (Alwang et al. 2019). Pest management practice in China and other developing countries varies greatly from grove to grove. It is difficult to develop an effective systems approach without knowledge of the actual field fruit infestations at harvest. A common assumption is that good grove management results in low pest population. However, there is little quantitative data available, especially for different grove management levels. The relationship between the field management level and fruit infestation has been studied rarely. This information is critical in developing an effective systems approach (Quinlan & Ikin 2009; FAO/IAEA 2010).

Our previous work in China indicated that packinghouse culling and fruit bagging were effective in reducing the number of fruit fly infested citrus fruits (Xia et al. 2019). Packinghouse culling consists of 1 or more procedures involving visual inspection and removal of the suspected infested fruits from the packing line. Fruit bagging is a production measure where fruits were completely covered with paper bags for a certain period of time during the production season. Expanding on this earlier work, 2 independent pest risk management measures, i.e., field pest management as mentioned above and culling at harvest, were evaluated for their effectiveness in reducing the risk. Field pest management of fruit flies in China generally uses 3 major measures: (1) trapping for monitoring field population, (2) picking up and destroying the fallen fruits to reduce the overwintering populations, and (3) pesticide applications during the production season. Culling at harvest is a process of visual inspection and removal of the suspected infested fruits during field harvest or field purchase based on certain fruit damage features (the term “visual inspection” or “culling at harvest” will be used interchangeably hereafter). Culling at harvest is used widely in China. However, there are no data available regarding the effectiveness of the measure in reducing the phytosanitary risk of fruit flies in China or elsewhere. The objectives of this study were to assess fruit fly infestation at harvest under 2 field management levels, and to evaluate the efficacy of culling at harvest on the reduction of infested fruits. These quantitative data are supportive in developing a systems approach for fruit fly risk mitigation associated with the citrus trade in China.

Materials and Methods

STUDY GROVES, FRUIT HARVESTING, CULLING (VISUAL INSPECTION)

This study was conducted in two 13 to 17 yr old Satsuma mandarin, *Citrus unshiu* (Swingle) Marcov (Rutaceae), groves in Dongkou County, Hunan Province, China, from 25 Sep to 30 Oct 2018. Guangli Citrus Orchard (27.042777°N, 110.571388°E; 340 masl) is a low managed grove, whereas Dongkou Citrus Orchard (27.058611°N, 110.541388°E; 365 masl) is a highly managed grove. Low managed citrus groves in China have the following characteristics: small-size, family-owned operations, no regular fallen fruit pick-up, no active fruit fly trapping, sporadic foliar spraying insecticides as the only way of pest management, and no area-wide fruit fly management program. By contrast, highly managed citrus groves in China usually are middle-to-large size co-operations, conducting regular fallen fruit pick-up (3 or 5-d interval in the fall) and fruit fly trapping, and insecticide sprayings. Trapping and survey records by the Dongkou County Department of Agriculture indicated that *B. dorsalis* and *B. minax* are 2 tephritid citrus pests in the county. The groves are 2.1 km apart from each other, with identical citrus plants and environment, except for the management level.

Each grove was divided into 4 roughly equal size sections, and each section was regarded as a replicate. A total of 3,300 fruits (i.e., 100 fruits per tree, 33 trees per replicate) were harvested per replicate by walking through the plant rows, randomly harvesting 100 fruits from 1 out of every 5 citrus trees until reaching 33 trees. This resulted in 13,200 fruits per grove (i.e., 4 × 33 × 100), a total of 26,400 fruits in the study. Fruit harvesting was completed between 25 to 30 Sep.

Immediately after harvest, each fruit was subject to a visual inspection of fruit fly infestation according to certain fruit damage features (i.e., culling at harvest). These damage features are used commonly by citrus growers and packinghouse for removal of the suspected infested fruits. *Bactrocera dorsalis* infested fruits usually have 2 distinctive features: (1) running liquid at the oviposition punctures in the newly infested fruits, and (2) rotting tissue near the punctures or liquid coming out of the punctures if gently squeezed. *Bactrocera minax* infested fruits usually have 3 distinctive features: (1) dark-colored, hardened, and slightly raised oviposition punctures, (2) skin with yellow or yellow-red spots, and (3) a loose or hollow feeling if gently squeezed. Visual inspection categorized a fruit into 1 of the following 5 groups: (1) *B. minax* infested fruit, (2) *B. dorsalis* infested fruit, (3) *B. minax* + *B. dorsalis* infested fruit, (4) suspected fruit fly infested fruit (i.e., uncertain whether these fruits were infested or not), and (5) fruit fly free fruit.

FRUIT DISSECTION

Fruit dissection serves 2 purposes, as a check on the efficacy of visual inspection (culling at harvest) on the reduction of infested fruits, and for assessing the actual fruit infestations by fruit flies at the time of harvest. After the visual inspection, the fruits were individually bagged in lightweight mesh bags, labeled, and stored in a storage house for 4 wk to allow the eggs and larvae inside fruits to grow larger for better visual inspection. To provide air movement and to maintain appropriate temperature for larval development, 2 fans with heaters were placed inside the storage house running 8 h per d. Temperatures varied between 15 to 21 °C during this period. Four wk later (24–25 Oct 2018), the bags were opened and inspected for any insects inside the bag. Fruits were then dissected, and further inspected, recording the number and species, and the developmental stage of fruit flies inside the bag and the fruit. Larvae, pupae, and adults of fruit flies were identified morphologically on site by an expert of the Guangdong Institute of Applied Biological Resources.

STATISTICAL ANALYSIS

The Pearson Chi-square test was used to test the null hypotheses that the total numbers of infested fruits by visual inspection at harvest and fruit dissection 4 wk postharvest were not different between the 2 groves. The mean numbers of infested fruits per replicate within a grove were subjected to 1-way ANOVA, and Fisher's least significant difference (LSD) was used to separate the means. The mean numbers of infested fruits per replicate between the 2 groves were subjected to independent-sample *t* test. The false positive rate of visual inspection was calculated as FP/(FP + TN), where FP is the number of false positives, i.e., the fruits which were identified as infested fruits by visual inspection that actually were not infested, and TN is the number of true negatives (FP + TN being the total number of negatives). The false negative rate of visual inspection was calculated as FN/(FN + TP), where FN is the number of false negatives, i.e., the fruits which were identified as fruit fly free by visual inspection that actually were infested, and TP is the number of true positives (FN + TP being the total number of positives). All analyses were performed using SPSS v. 22 (SPSS Inc., Chicago, Illinois, USA).

Results

Visual inspection at harvest suggested a total of 531 (4.02%) and 137 (1.04%) infested fruits in Guangli Citrus Orchard-low management and Dongkou Citrus Orchard-high management, respectively (Table 1, left side). Later fruit dissection revealed that the total number of infested fruits was 289 (2.19%) and 3 (0.02%) in the 2 groves (Table 1, right side), respectively, suggesting that Dongkou Citrus Orchard-high management had a 99.09% reduction of fruit fly infestation compared to Guangli Citrus Orchard-low management (Fig. 1). The number of infested fruits by *B. minax*, *B. dorsalis*, *B. minax* + *B. dorsalis*, or the total number of the infested fruits in Guangli Citrus Orchard-low management were significantly higher than in Dongkou Citrus Orchard-high management (Table 1, bottom 2 rows right side). The overall false positive rate by visual inspection was 1.9% (i.e., [531–289]/12,911 × 100%) and 1.0% in Guangli Citrus Orchard-low management and Dongkou Citrus Orchard-high management, respectively (Table 1). There were significant differences in the mean numbers of infested fruited by *B. minax* (F = 13.500; df = 6; t = 0.001), and *B. dorsalis* (F = 4.222; df = 6; t = 0.004) between the 2 groves (Table 2). There were also significant differences among the mean numbers of *B. dorsalis*, *B. minax*, and *B. dorsalis* + *B. minax* infested fruits (F = 25.154; df = 2,9; P < 0.0001) in Guangli Citrus Orchard-low management (Table 2). Table 3 is a further breakdown of fruit fly infestation data found in Table 1.

DATA OF GUANGLI CITRUS ORCHARD-LOW MANAGEMENT

Of the 82 fruits which were identified by visual inspection as *B. minax* infested fruits, 46 (56.1%) fruits were *B. minax* infested; the remaining 3, 2, and 31 (3.7, 2.4, and 37.8%) fruits were infested by *B. minax* + *B. dorsalis*, *B. dorsalis*, or were fruit fly free fruits, respectively. Of the 182 fruits which were identified by visual inspection as *B. dorsalis* infested fruits, 58 (31.9%) fruits were infested by *B. dorsalis*, the remaining 2, 4, and 118 (1.1, 2.2, and 64.8%) fruits were actually infested by *B. minax* + *B. dorsalis*, *B. dorsalis*, or were fruit fly free fruits, respectively. Of the 2 fruits which were identified by visual inspection as *B. minax* + *B. dorsalis* infested fruits, 1 was infested by *B. minax*, and another by *B. dorsalis*. Of the 265 fruits which were identified by visual inspection as suspected infested fruits, 8, 19, and 238 (3.0, 7.2, and 89.9%) fruits were infested by *B. minax*, *B. dorsalis,* or fruit fly free fruits, respectively. Of the 12,669 fruits which were identified by visual inspection as fruit fly free fruits, 3 fruits (0.02%) were infested by *B.*

Table 1. Summary of fruit fly infestations in Guangli Citrus Orchard-low management (GCO-LM) and Dongkou Citrus Orchard-high management (DCO-HM) (visual inspection at harvest and fruit dissection 4 wk postharvest).

	No. fruits (%[a])										
	Visual inspection at harvest						Fruit dissection 4 wk postharvest				
	Infested & susp[b]						Infested & susp				
Grove (ha)	*B. minax*	*B. dorsalis*	Spp.[c]	susp	Total	Fruit fly free	*B. minax*	*B. dorsalis*	Spp.	Total	Fruit fly free
GCO-LM (8)	82 (0.62)	182 (1.38)	2 (0.02)	265 (2.01)	531 (4.02)	12,669 (95.98)	106 (0.80)	175 (1.33)	8 (0.06)	289 (2.19)	12,911 (97.81)
DCO-HM (140)	4 (0.03)	31 (0.24)	0	102 (0.77)	137 (1.04)	13,063 (98.96)	0	3 (0.03)	0	3 (0.03)	13,197 (99.97)
P	<0.0001	<0.0001	NA[e]	0.0001	<0.0001		<0.0001	<0.0001	0.013	<0.0001	
χ^2 tests[d]	70.975	107.918	NA	73.416	238.422		106.427	167.330	6.127	283.256	

[a]The number of fruit in the cell / 13,200 × 100%.
[b]Susp = suspected infested fruits.
[c]Spp. = *B. minax* and *B. dorsalis*.
[d]Chi-square test testing the null hypotheses that the number of infested fruits was not different between the 2 groves.
[e]There were not enough data for Chi-square test.

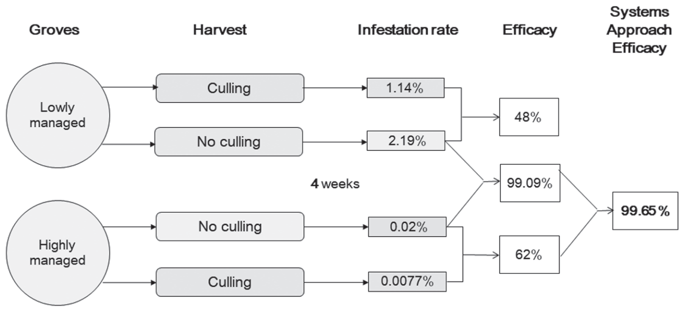

Fig. 1. A logic chart illustrating work flow and calculating efficacies of pest management and culling at harvest (systems approach efficacy = the efficacy of the 2 measures together).

minax + *B. dorsalis*, 47 fruits (0.37%, but rounded to 0.4 in Table 3) were infested by *B. minax*, and 95 (0.75%, but rounded to 0.8 in Table 3) fruits were infested *B. dorsalis*, respectively, resulting in 1.14% infested and 98.86% fruit fly free fruits. In commercial production, the 12,669 fruits which were considered pest free were shipped to packinghouse for the next processing step. Therefore, culling at harvest (visual inspection) reduced fruit infestation rate from 2.19 to 1.14%, a 48% reduction (Fig. 1).

DATA OF DONGKOU CITRUS ORCHARD-HIGH MANAGEMENT

Four and 31 fruits which were identified by visual inspection as *B. minax*, *B. dorsalis* infested fruits actually were fruit fly free. Of the 102 fruits which were identified as suspected infested fruits, 2 fruits (2%) were infested by *B. dorsalis*; the remaining 100 fruits (98%) were fruit fly free. Of the 13,063 fruits which were considered fruit fly free by visual inspection, 1 fruit (0.0077%) was infested. Culling at harvest reduced the fruit infestation rate from 0.03 to 0.0077%, a 62% reduction (Fig. 1).

In summary, the combination of the 2 risk mitigation measures, grove management and culling at harvest (visual inspection at harvest), had a 99.65% reduction of fruit fly infestation (1-[0.0077%/2.19%]) × 100%) (Fig. 1).

Table 4 presents data of fruit flies inside of the infested fruits. The average number of *B. minax* per infested fruit appeared higher than that in *B. dorsalis* infested fruits, i.e., 7.22 ± 0.31 vs. 3.33 ± 0.19. Almost all *B. minax* were larvae, whereas the overwhelming number of *B. dorsalis* were pupae with a few larvae and adults at the time of fruit dissection.

Discussion

One of the major issues in adopting a systems approach for pest risk mitigation in agricultural commodity trade is lack of efficacy data of the independent measures (Quinlan & Ikin 2009). This study provides efficacy data for 2 measures, i.e., field pest management and culling at harvest. The highly managed grove resulted in 99.09% reduction of fruit infestation compared to the low managed grove. The results strongly support that a systems approach has to begin with good field pest management (FAO/IPPC 2017). Citrus fruits from low managed groves like Guangli Citrus Orchard has a high fruit fly infested rate, so it would be very challenging and expensive to develop a systems approach program for the fruits.

Culling at harvest is a common measure for reducing infested fruits in well-managed packinghouses and citrus groves in China (Xia et al. 2019). The measure also is listed as an option of systems approach by FAO/IPPC (2017). However, there is no data available regarding the effectiveness of this measure on the reduction of infested fruits at harvest. The results of this study suggest that the efficacy is moderate and disputable, especially with heavy infestations such as Guangli Citrus Orchard-low management. There were still 1.14% infested fruits after culling the fruits. About 73% in Guangli Citrus Orchard-low management and 99% fruits in Dongkou Citrus Orchard-high management which were identified as infested fruits were actually pest free fruits. The results suggest that culling is not a good measure for identifying the infested fruits, because the fruit damage features currently used for culling in China are not reliable. A better approach of culling needs to be developed.

Fruit dissection was used as a check to assess the accuracy of culling in the study. One major issue with fruit dissection is the sensitivity of the technique in detecting fruit flies inside of fruits. The probability of detecting larvae of the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), by fruit cutting ranged from 1 to 36% (Gould 1995). It is especially challenging to detect eggs and first instar larvae inside citrus fruits. Our previous work in China suggests that fruit flies inside the freshly harvested fruits were predominantly eggs and early instar larvae (Xia et al. 2019). To improve the probability of detection, these fruits were individually bagged for 4 wk before fruit cutting in this study. This allowed eggs and first instars to reach third instars or pupae, which could be detected visually. The 4-wk wait time is based the fact that *B. dorsalis* and *B. minax* need about 5 and 10 wk, respectively, to complete pre-adult stages at room temperature (Yang et al. 1994; Wang & Luo 1995). One potential issue in this approach is that fruit fly mortality may occur during the wait period; it may impact the number of infested fruits or the number of fruit flies inside fruits. However, the issue is not necessarily a concern in terms of fruit fly risk mitigation. Cargo shipping time from China to the US or Europe takes longer than 4 wk (Freightos 2020). Fruit fly mortality during the shipping, if it occurs, will be no less than that during the 4-wk wait time. In other words, the actual fruit infestation at the arrival port will be no more than that found after culling at harvest, assuming no additional phytosanitary measure were applied to the fruits after culling.

Table 2. The numbers of infested fruits per replicate (3,300 fruits) by fruit dissection. GCO-LM = Guangli Citrus Orchard-low management, DCO-HM = Dongkou Citrus Orchard-high management.

	Mean infested fruits ± SE		
Grove	*B. minax*	*B. dorsalis*	*B. minax* + *B. dorsalis*
GCO-LM	26.50 ± 4.79 b	44.00 ± 5.43 c	2.00 ± 0.82 a
DCO-HM	0.00[a]	0.75 ± 0.48[a]	0.00[a]
t[b]	0.001[c]	0.004[c]	NA[d]

Means followed by the same letter within the top row do not differ significantly (LSD test, $P > 0.05$).
[a]Not enough data for LSD test (within the row).
[b]Independent-sample t test within a column.
[c]There is significant difference between GCO-LM and DCO-HM by independent-sample t test (two-tail) ($P < 0.05$).
[d]Not enough data for independent-sample t test.

Table 3. Breakdown of fruit fly infestations in Guangli Citrus Orchard-low management (GCO-LM) and Dongkou Citrus Orchard-high management (DCO-HM) (visual inspection at harvest and fruit dissection 4 wk postharvest).

Grove	Method	No. fruits (%[a])																			
GCO-LM	Culling at harvest (visual inspection)	*B. minax* (Bm)				*B. dorsalis* (Bd)				Spp.[b]				Susp[c]				Fruit fly free (Fff)			
		82				182				2				265				12,669			
	Fruit dissection (4 wk after culling)	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff
		3 (3.7)	46 (56.1)	2 (2.4)	31 (37.8)	2 (1.1)	4 (2.2)	58 (31.9)	118 (64.8)	0	1 (50)	1 (50)	0	0	8 (3.0)	19 (7.2)	238 (89.8)	3 (0.0)	47 (0.4)	95 (0.8)	12,524(98.8)
DCO-HM	Culling at harvest (visual inspection)	*B. minax* (Bm)				*B. dorsalis* (Bd)				Spp.				Susp				Fruit fly free			
		4				31				0				102				13,063			
	Fruit dissection (4 wk after culling)	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff	Spp.	Bm	Bd	Fff
		0	0	0	4 (100)	0	0	0	31 (100)	0	0	0	0	0	0	2 (2)	100 (98)	0	0	1 (0)	13,062 (100)

[a]In the row "Fruit Dissection (4 wk after culling)," number in the cell / number in the big cell above (Culling at harvest) × 100%. For example, 3/82 × 100% = 3.7%.
[b]Spp. = infested by *B. minax* and *B. dorsalis*.
[c]Susp = suspected infested fruits.

Table 4. The number of fruit flies and developmental stages inside the infested fruits. GCO-LM = Guangli Citrus Orchard-low management, DCO-HM = Dongkou Citrus Orchard-high management.

	Spp.[a]					*B. minax*			*B. dorsalis*		
		B. minax		*B. dorsalis*							
Grove	No. fruits[b]	No. flies[c]	Mean ± SE[d]	No. flies[b]	Mean ± SE[d]	No. fruits[b]	No. flies[c]	Mean ± SE[d]	No. fruits[b]	No. flies[c]	Mean ± SE[d]
GCO-LM	8	28 L[e] = 100%	3.50 ± 0.96	35 L[e] = 5.71% *P*[f] = 94.29%	4.38 ± 0.89	106	778 L[e] = 98.46% *P*[f] = 1.54%	7.22 ± 0.31	175	574 L[e] = 7.32% *P*[f] = 90.94% A[g] = 1.74%	3.33 ± 0.19
DCO-HM	0	0		0		0	0		3	8 L[e] = 50.00% P[f] = 50.00%	2.67 ± 0.88

[a]Both fruits infested by *B. minax* and *B. dorsalis.*
[b]Number of infested fruits.
[c]Number of fruit flies inside infested fruits.
[e]Larva; [f]Pupa; [g]Adult
[g]Mean ± SE = The average number (mean ± SE) of fruit flies inside per infested fruit.

One grove only was used in each of the 2 field management levels in this study. The result would be more convincing if 4 or 5 replicate groves were used in each level. Citrus groves in China are overwhelmingly small-scale, and usually are worked using a multiple cropping production environment. It would be challenging to manage and analyze the impacts of many other variables such as citrus variety, the surrounding crops, and discrepancies in field management practice in each of the replicate groves if multiple groves were used in the study. The 2 groves chosen for the study were close to each other (2.1 km apart), with similar citrus plants and surroundings, except for the management level. Satsuma mandarins, which were planted in both Guangli Citrus Orchard-low management and Dongkou Citrus Orchard-high management, has thin skin and is considered a suitable host of tephritid fruit flies, including *B. dorsalis* and *B. minax* (Liquido et al. 2017; Xia et al. 2018). Nevertheless, the results of this study gave us a first look at the scale of difference in fruit fly infestations in differently managed citrus groves in China.

There were 2 additional anecdotal observations from this study. First, *B. minax* infested fruits appeared to be more attractive to *B. dorsalis*. There were a total of 8 fruits from Guangli Citrus Orchard-low management with the infestations of both species together (Table 1). Females of *B. minax* lay eggs earlier in small green fruits, whereas females of *B. dorsalis* lay eggs later in the mature fruits. Accordingly, these 8 fruits were infested already with the larvae of *B. minax* by the time *B. dorsalis* laid its eggs. According to the data, the overall *B. dorsalis* fruit infestation rate in the grove was 1.386% vs. 7.018% for *B. minax* infested fruits. *Bactrocera minax* infested fruits usually ripen prematurely, resulting in early changes in skin color and hardness. This might explain the apparently higher *B. dorsalis* infestation in *B. minax* infested fruits. Since the sample size in this study is relatively small, this observation needs further verification in the future. Second, there appeared to be a higher number of *B. minax* than *B. dorsalis* per infested fruit (Table 4). This result was unexpected for several reasons: (1) larvae of *B. dorsalis* are much smaller than those of *B. minax*; (2) a *B. dorsalis* female can lay up to 1,500 eggs (Weems et al. 2012) vs. about 200 by a *B. minax* female (Wang & Luo 1995); (3) our previous study indicated a much higher number of *B. dorsalis* larvae per fruit (Xia et al. 2019). These observations need to be investigated further in a future study.

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