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: Tephritidae), 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 2 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.
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 fruits 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; 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. minax.
were pupae with a few larvae and adults at the time of fruit dissection.

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.

| Grove       | B. minax ± SE | B. dorsalis ± SE | B. minax + B. dorsalis ± SE |
|-------------|---------------|------------------|-----------------------------|
| 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 b    | 0.00 a                      |
| t²          | 0.001 d       | 0.004 d          | NA d                        |

Means followed by the same letter within the same row do not differ significantly (LSD test, P > 0.05).

*Not enough data for LSD test (within the row).

Independent-sample t test within a column.

There is significant difference between GCO-LM and DCO-HM by independent-sample t test (two-tail) (P < 0.05).

Not enough data for independent-sample t test.

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 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 on 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 (Freightostos 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 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 (%) |
|-------------|-------------------------------|----------------|
| GCO-LM      | Culling at harvest (visual inspection) |                |
|             | B. minax (Bm)                 | 82             |
|             | B. dorsalis (Bd)              | 182            |
|             | Spp.‡                         | 2              |
|             | Susp.§                        | 265            |
|             | Fruit fly free (Fff)          | 12,669         |
| DCO-HM      | Culling at harvest (visual inspection) |                |
|             | B. minax (Bm)                 | 4              |
|             | B. dorsalis (Bd)              | 31             |
|             | Spp.‡                         | 0              |
|             | Susp.§                        | 102            |
|             | Fruit fly free (Fff)          | 13,063         |
|             | Fruit dissection (4 wk after culling) |        |
|             | Spp. Bm Bd Fff                |                |
|             | 3 (3.7) 2 (2.4) 31 (37.8)     |                |
|             | Spp. Bm Bd Fff                | 0 1 (50) 1 (50) 0 |
|             | Spp. Bm Bd Fff                | 0 8 (30.0) 19 (7.2) 238 (89.8) |
|             | Spp. Bm Bd Fff                | 3 (0.0) 47 (0.4) 95 (0.8) 12,524 (88.8) |

*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%.

‡Spp. = infested by B. minax and B. dorsalis.

§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.

| Grove       | Spp.† | B. minax | B. dorsalis |
|-------------|-------|----------|-------------|
|             | No. fruits | No. flies | Mean ± SE | No. flies | Mean ± SE | No. fruits | No. flies | Mean ± SE |
| GCO-LM      | 8      | 28       | 3.50 ± 0.96 | 35       | 4.38 ± 0.89 | 106       | 778       | 7.22 ± 0.31 |
|             | L² = 100% | L² = 5.71% | P = 94.29% |         | L² = 98.46% | P = 1.54% |         | L² = 7.32% |
| DCO-HM      | 0      | 0        | 0           | 0        | 0         | 3         | 8         | 2.67 ± 0.88 |

*Both fruits infested by B. minax and B. dorsalis.

†Number of infested fruits.

‡Number of fruit flies inside infested fruits.

§Larva; Pupa; Adult.

*Mean ± SE = The average number (mean ± SE) of fruit flies inside per infested fruit.
One groove 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 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 was 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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