More than 47,000 mature fruits of nine different varieties of rambutan (Nephelium lappaceum L.) were harvested from orchards in Hawaii to assess natural levels of infestation by tephritid fruit flies and other internal feeding pests. Additionally, harvested, mature fruits of seven different rambutan varieties were artificially infested with eggs or first-instar Mediterranean fruit fly, Ceratitis capitata (Wiedemann), or oriental fruit fly, Bactrocera dorsalis (Hendel) (Diptera: Tephritidae) to assess host suitability. When all varieties were combined over two field seasons of sampling, fruit infestation rates were 0.021% for oriental fruit fly, 0.097% for Cryptophlebia spp. (Lepidoptera: Tortricidae), and 0.85% for pyralids (Lepidoptera). Species of Cryptophlebia included both C. illepida (Butler), the native Hawaiian species, and C. ombrodelta (Lower), an introduced species from Australia. Cryptophlebia spp. had not previously been known to attack rambutan. The pyralid infestation was mainly attributable to Cryptoblabes gnidiella (Milliere), a species also not previously recorded on rambutan in Hawaii. Overall infestation rate for other moths in the families Blastobasidae, Gracillariidae, Tineidae, and Tortricidae was 0.061%. In artificially infested fruits, both species of fruit fly showed moderately high survivorship for all varieties tested. Because rambutan has such low rates of infestation by oriental fruit fly and Cryptophlebia spp., the two primary internal-feeding regulatory pests of rambutan in Hawaii, it may be amenable to the alternative treatment efficacy approach to postharvest quarantine treatment.
consisted of removing pupating larvae and pupae from the sand and fruit in each bag, and transferring them to small plastic cups (0.25 liter) containing a small amount of sand for pupation, with tissue paper added for any recovered caterpillars. After emergence and the death of any adults, dead larvae were sifted from the sand and transferred to 70% alcohol, and dead pupae and emerged adults were transferred to (dry) vials for subsequent identification.

**Artificial Infestation.** *Insects.* Mediterranean and oriental fruit flies used for infestation studies were obtained as pupae from a continuous laboratory colony at the USDA-ARS Tropical Fruit, Vegetable and Ornamental Crop Research Laboratory in Honolulu, HI, now part of the U.S. Pacific Basin Agricultural Research Center. Fruit flies used in our tests were kept in an insectary at 24–27°C, 65–70% RH, and a photoperiod of 12:12 (L:D) h. Adults were fed water and a diet consisting of three parts sucrose, one part protein yeast hydrolysate (Enzymatic, United States Biochemical, Cleveland, OH), and 0.5 part torula yeast (Lake States Division, Rhinelander Paper, Rhinelander, WI). Oriental fruit fly adults were at least 8 d old and Mediterranean fruit fly adults were at least 7 d old when eggs were collected.

**General Methods.** Four varieties of rambutan were used in 1995 ('Binjai', 'R-156 Yellow', 'R-162', and 'R-167'), and three varieties in 1996 ('R-7', 'R-9', and 'Rongrien') for artificial infestation trials. Peaches, which were mature but firm, were obtained from a local grocery store and used in 1995 as a control fruit. Papayas were used in 1995 as a control fruit and were collected at a mature green or color break stage from a local packing house and held in containers that excluded fruit flies until they were fully ripe. In 1995, rambutan and peaches were artificially infested with (1) 20 Mediterranean fruit fly eggs, (2) 20 oriental fruit fly eggs, (3) 20 Mediterranean fruit fly first instars (<2 h old), and (4) 20 oriental fruit fly first instars. For each of these treatments, 24 fruits of each rambutan variety and 24 peaches were artificially infested. In 1996, 28 fruits of each rambutan variety and 29 papayas were used for each of the same egg and first-instar infestations. Before artificial infestation, fruits were all soaked for 2 min in a 5% bleach solution to reduce surface pathogens, allowed to air dry, and then weighed.

**Egg Infestation.** Eggs were handled with a fine-tip paint brush and placed onto pieces of moist, presoaked blotter paper in petri dishes. Eggs were precounted in sets of 20 eggs on blotter paper, which facilitated transfer from blotter paper to fruit. For rambutan, a small flap of skin (pericarp) was sliced open and eggs were inserted on top of the flesh (aril) toward the back edge of the flap. The flap was then closed and fruits were placed in a plastic cup (7 cm diameter by 7 cm high) with 10 ml of clean sand and covered with a screened lid. For peaches and papayas, eggs were inserted into a 3.0- to 6.0-mm deep incision in the flesh. Fruits were then placed on hardware cloth stands over 100 ml clean sand in 1-liter plastic buckets with screened plastic lids. Four days after the Mediterranean fruit fly eggs were inserted, subsamples of five fruits of each variety of rambutan and five of the peach/papaya controls were opened to determine percentage egg hatch. Egg hatch was similarly determined for fruits artificially infested with oriental fruit fly eggs.

**First-Instar Infestation.** Eggs were placed on moist, presoaked blotter paper and held in petri dishes sealed in Ziplock bags and placed in an environmental chamber. Oriental fruit fly eggs were held at 26°C for 32 h. Mediterranean fruit fly eggs were held at 24°C for 48 h. Before egg hatch, a small piece of rambutan fruit (1995, variety 'R-167'; 1996, variety 'Rongrien') was added to the blotter paper to provide a food source for larvae from egg hatch until the time of their insertion into the rambutan fruits. First instars were precounted in sets of 20 on separate pieces of blotter paper in petri dishes before placement in fruits as described for egg infestation. All fruits artificially infested by eggs or first instars were placed in an environmental chamber held at 26°C and 70% RH and held for at least 3 wk before assessment of survivorship.

**Statistical Analysis.** Data on percent adult survival after artificial infestation were arcsine transformed and then subjected to analysis of variance (ANOVA) with mean separations conducted using the Waller—Duncan K-ratio t-test (SAS Institute 1990).

**Results**

**Field Census.** A total of 47,188 rambutan fruits was collected over the two field seasons to assess levels of infestation of internal pests. Average fruit weights (+SEM) by variety are presented in Table 1. When all varieties were combined over both field seasons, fruit infestation rates were 0.021% for *B. dorsalis*, 0.097% for *Cryptophlebia* spp. (Lepidoptera: Tortricidae), and 0.85% for pyralids (Lepidoptera). Infestation rates by cultivar for *B. dorsalis*, *Cryptophlebia* spp., and pyralids are presented in Table 1. Mediterranean fruit fly was not recovered from any of the fruit collections. Species of *Cryptophlebia* included both *C. illepida* (Butler), the native Hawaiian species, and *C. ombrodelta* (Lower), an introduced species from Australia. Twenty-one fruits overall (0.04%) (Table 1) were infested by *Cryptophlebia* spp. However, in addition to that observed infestation, 26 bags were found to have a hole in the bag (and were dropped from our analysis, overall) as would be produced by *Cryptophlebia* spp. larvae chewing through the bag. Although no *Cryptophlebia* spp. were found in these bags, the propensity of these species to chew through plastic bags, combined with a concern not to under-represent infestation levels by these species, commends us to list these additional bags as having *Cryptophlebia* spp. infestation (Gula Batu [4]; 'R-156 Red' [2]; 'R-156 Yellow' [3]; 'R-162' [1]; 'R-167' [2]; 'Rongrien' [3]; Unknown [11]). This would give a total of 47 fruits infested by *Cryptophlebia* spp. out of 48,214 fruits, or an infestation rate of 0.097%. A subset of 34 pyralids, which included observed morphological variation as well as specimens recovered from each of the rambutan varieties, from
Table 1. Summary of infestation of rambutan varieties by *Bactrocera dorsalis*, *Cryptophlebia* spp., and by pyralid species

<table>
<thead>
<tr>
<th>Variety</th>
<th>No. fruit collected</th>
<th>Weight, gm</th>
<th>Mean ± SEM</th>
<th>No. infested fruit</th>
<th>% fruit infested</th>
<th>No. larvae</th>
<th>Mean no. larvae per infested fruit</th>
<th>No. infested fruit</th>
<th>% fruit infested</th>
<th>No. larvae</th>
<th>Mean no. larvae per infested fruit</th>
<th>No. infested fruit</th>
<th>% fruit infested</th>
<th>No. larvae</th>
<th>Mean no. larvae per infested fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Season</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binjai</td>
<td>425</td>
<td>6,000</td>
<td>6,425</td>
<td>36.69 ± 0.10</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>7 0.10</td>
<td>10 1.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cokku Batu (R-3)</td>
<td>45</td>
<td>1,797</td>
<td>1,842</td>
<td>35.34 ± 0.13</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>73 3.96</td>
<td>129 1.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-7</td>
<td>2,000</td>
<td>2,000</td>
<td>36.10</td>
<td>0.13</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>6 0.300</td>
<td>6 1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-156 Red</td>
<td>5,998</td>
<td>5,998</td>
<td>42.94</td>
<td>0.17</td>
<td>24 3.43</td>
<td>1 0.10</td>
<td>1.00</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>8 0.133</td>
<td>8 1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-156 Yellow</td>
<td>3,997</td>
<td>3,997</td>
<td>27.33</td>
<td>0.16</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>41 1.028</td>
<td>55 1.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-162</td>
<td>3,064</td>
<td>3,064</td>
<td>36.10</td>
<td>0.13</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>13 0.424</td>
<td>14 1.06</td>
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<tr>
<td>R-162 Red</td>
<td>9,997</td>
<td>9,997</td>
<td>38.26</td>
<td>0.08</td>
<td>8 4.00</td>
<td>2 0.02</td>
<td>1.00</td>
<td>2 0.00</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>25 0.250</td>
<td>26 1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rongrien</td>
<td>4,997</td>
<td>4,997</td>
<td>35.36</td>
<td>0.10</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>88 1.763</td>
<td>104 1.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seelengkeng</td>
<td>4,983</td>
<td>4,983</td>
<td>30.20</td>
<td>0.11</td>
<td>0 0.0 0 0.0</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>9 0.181</td>
<td>9 1.00</td>
<td>0 0.0</td>
<td>0.0 0.0</td>
<td>32 1.044</td>
<td>59 1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>1,394</td>
<td>2,491</td>
<td>3,885</td>
<td>0.14</td>
<td>7 1.75</td>
<td>4 0.14</td>
<td>1.00</td>
<td>7 0.181</td>
<td>7 1.00</td>
<td>3 0.05</td>
<td>0.0 0.0</td>
<td>90 2.317</td>
<td>143 1.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>19,908</td>
<td>27,280</td>
<td>47,188</td>
<td>0.02</td>
<td>33 3.30</td>
<td>21 0.044</td>
<td>1.14</td>
<td>403 0.854</td>
<td>554 1.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*a* Totals for *Bactrocera dorsalis* include two fruits (R-156 and R-162 each variety) infested by *Biotera longicaudata*, a tephritid fruit fly parasite. Only one parasite was found in each of these fruits.

*b* Overall infestation rate by *Cryptophlebia* spp. would be 0.097% (47 fruits infested out of 48,214 fruits) if one includes the 26 bags found to have a hole in the bag. See text for discussion.

*c* Most, if not all of the pyralids are *Cryptoblabes gnidiella* (Milliere).
significant differences in infestation among varieties tested in 1995 ($F = 6.62; \text{df} = 4, 115; P < 0.0001$) and also among varieties tested in 1996 ($F = 6.12; \text{df} = 3, 108; P = 0.0007$). Percentage survival to adults among rambutan varieties tested in 1995 ranged from 47.1% ($\pm 4.7%$; R-167) to 64.2% ($\pm 3.7%$; R-162) compared with 37.1% ($\pm 4.7%$) in peach. Percentage survival to adults among rambutan varieties tested in 1996 ranged from 40.9% ($\pm 3.3%$; R-7) to 61.4% ($\pm 2.9%$; R-9) compared with 57.5% ($\pm 5.0%$) in papaya.

For fruits infested with first-instar oriental fruit flies (Fig. 2B), there were significant differences in infestation between rambutan varieties and the control, but not among varieties, tested in 1995 ($F = 16.15; \text{df} = 4, 115; P < 0.0001$) and no significant differences among varieties tested in 1996 ($F = 1.20; \text{df} = 3, 108; P = 0.3119$). Percentage survival to adults in 1995 averaged 64.1% ($\pm 2.8%$) among rambutan varieties tested and 32.3% ($\pm 4.2%$) in peach. Percentage survival to adults in 1996 averaged 45.1% ($\pm 3.2%$) among rambutan varieties tested and 48.8% ($\pm 4.1%$) in papaya.

Fig. 1. Percentage survival (mean ± SEM) to adult stage of tephritid fruit fly eggs artificially infested in different varieties of rambutan fruits, relative to control fruits (1995, peach; 1996, papaya). Letters at the top of the bars refer to results of ANOVAs performed by year. Percentage survival was not significantly different where adjacent columns have the same letter. (A) Mediterranean fruit fly egg infestation. (B) Oriental fruit fly egg infestation.

Fig. 2. Percentage survival (mean ± SEM) to adult stage of tephritid fruit fly first instars artificially infested in different varieties of rambutan fruits, relative to control fruits (1995, peach; 1996, papaya). Letters at the top of the bars refer to results of ANOVAs performed by year. Percentage survival was not significantly different where adjacent columns have the same letter. (A) Mediterranean fruit fly first-instar infestation. (B) Oriental fruit fly first-instar infestation.
Discussion

The low infestation rates in the field make it difficult to draw conclusions about the relative infestability of different rambutan varieties by various insect pests. Therefore, infestation results are discussed in terms of all varieties combined. Field infestation rate of rambutan by oriental fruit fly in this study was low (0.021%). This finding agrees with assessments of B. dorsalis on rambutan fruits in Southeast Asia (Osman Mohd and Chettanachitra 1987, Tindall 1994). The spinternes on the fruit are thought to interfere with B. dorsalis oviposition (Osman Mohd and Chettanachitra 1987). Our data showing low tephritid fruit fly infestation in the field but moderately high survival of Mediterranean fruit fly and oriental fruit fly on artificially infested rambutan fruits in the laboratory support this hypothesis. However, other properties of the pericarp, such as thickness, may also be important.

Cryptophlebia illepida (Butler) and C. ombrodelta (Lower) were found attacking rambutan for the first time. Cryptophlebia spp. are internal feeders and therefore pose a quarantine threat similar to fruit flies. Cryptophlebia spp. are federally regulated pests previously known to attack two other sapindaceous fruits, lychee (Litchi chinensis Sonn.) and longan (Dimocarpus longan Lour.). Eggs are laid singly on the fruit surface and newborn larvae bore through the skin and feed at the skin/pulp interface. Typically, only one larva is found feeding in a fruit. Export of lychee fruits from Hawaii requires a hot water immersion or irradiation treatment with a minimum absorbed dose of 250 Gy for disinfection of tephritid fruit flies (Anonymous 1997). This treatment can also disinfest rambutan fruits of any Cryptophlebia spp. (P.A.F., unpublished data).

Cryptoblabes gnidiella also was not previously recorded from rambutan in Hawaii. The infestation rate by C. gnidiella (up to 0.85%, overall) was higher than both B. dorsalis and Cryptophlebia spp. This pyralid was first recorded in Hawaii on Oahu in 1905 and was initially identified as Cryptoblabes aliena Swezy (Zimmerman 1958), although it was subsequently determined to be synonymous with Cryptoblabes gnidiella (Milliere) (Zimmerman 1972). C. gnidiella was first described from France but is now widely distributed throughout the warmer parts of the world and has been reported from Eurasia, Africa, Malaysia, and Bermuda (Zimmerman 1972). It is a pest of grapes, citrus, loquat, pomegranates, and avocado in Israel (Avidov and Gothilf 1960, Ascher et al. 1983, Yehuda et al. 1991–1992). C. gnidiella often infests fruits as a secondary pest, feeding on honeydew and refuse produced by Homoptera, but it can also be a primary pest (Wysoki et al. 1993). It is capable of developing on mealybug refuse alone, and on some fruits (e.g., grapefruit) larval survival is dependent on the presence of mealybugs or their refuse. However, on other fruits (e.g., grapes) there is no difference in development of larvae on mealybug-infested versus noninfested fruits (Avidov and Gothilf 1960). The significant association of C. gnidiella and Homoptera in this study suggests C. gnidiella may be primarily a secondary pest. Further research is needed to assess the pest status of this species on rambutan.

In addition to Cryptophlebia spp. and Cryptoblabes gnidiella, several other moths were recorded infesting rambutan at very low levels. A number of lepidopterous pest species have been recorded in other areas where rambutan is cultivated. The primary fruit borer in Southeast Asia is the gracillariid, Conopomorpha cramerella (Snellen). Conopomorpha cramerella oviposits on young fruits, which often show no external symptoms of infestation because the larvae feed beneath the fruit skin (Osman Mohd and Chettanachitra 1987, Tindall 1994, Yaacob and Subhadrambhandhu 1995). The gracillariid found in our collections was not identified to species, but C. cramerella is not reported to occur in Hawaii. Additional lepidopterous pests of rambutan fruits in Southeast Asia include Deudorix epijarbas cinnabaris Fruh. (Lycaenidae), Dichocrocis punctiferalis Guen. (Pyraustidae), Dichomeris indiserta Meyr. (Gelchiidae), Eublemma versicolora Walk. (Noctuidae), and Tirathala ruficena Walk. (Pyralidae) (Ahmad and Ho 1980, Osman Mohd and Chettanachitra 1987). None of these species have been recorded in Hawaii, although two other species of Dichomeris [D. acuminata (Standing) (alfalfa leafcutter) and D. aenigmatica (Clarke)] and one other species of Eublemma [E. acedens (Felder & Rogenhofer)] have been recorded.

The methodology employed in this study was designed to detect insect species that penetrate and subsequently feed inside rambutan fruits. Although some surface pests, such as mealybugs, were noted we did not attempt to summarize infestation by surface-feeding pests. Rambutan can be attacked by five other surface-feeding regulatory pests: red wax scale, Cereostigmus rubiens Maskell; green scale, Coccus viridis (Green); gray pineapple mealybug, Dysmicoccus neobrevipes Beardsley; yellow flower thrips, Frankliniella schultzei (Trybom); and pink hibiscus mealybug, Macrosiphum hirsutum (Green) (USDA 1996). Infestation rates of mealybugs and other surface pests need further attention because they may contribute to infestation by Cryptoblabes gnidiella and are, themselves, also regulatory pests whose presence potentially could interrupt fruit shipments.

The quarantine treatments currently available (irradiation) or proposed (high-temperature-forced-air) for rambutan from Hawaii were developed by treating hundreds of thousands of insects to meet the probit 9 efficacy standard. The probit 9 standard (99.9968% treatment efficacy or a maximum of 32 survivors in a million treated individuals) was initially recommended with fruit flies and heavily infested fruit in mind (Baker 1939), and has been the guiding principle in quarantine research. However, this standard may be too stringent for quarantine pests in commodities that
are poor, or rarely infested hosts (Landolt et al. 1984, Vail et al. 1993). The “alternative treatment efficacy” approach measures risk as the probability of a mating pair, gravid female, or parthenogenic individual surviving in a shipment (Liquido et al. 1997). This approach may be more appropriate than probit 9 level quarantine treatment for commodities with low infestation rates. Because rambutan is a poor host for its main regulatory pests, *B. dorsalis* and *Cryptophlebia* spp., it may be amenable to the alternative treatment efficacy approach to development of postharvest quarantine treatments.

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