

Research Article

Performance of *Tomicus yunnanensis* and *Tomicus minor* (Col., Scolytinae) on *Pinus yunnanensis* and *Pinus armandii* in Yunnan, Southwestern China

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Pine shoot beetles, *Tomicus yunnanensis* Kirkendall and Faccoli and *Tomicus minor* Hartig (Col., Scolytinae), have been causing substantial mortality to Yunnan pine (*Pinus yunnanensis* Franch) in Yunnan, southwestern China, whereas only a few Armand pine (*Pinus armandii* Franch) were attacked by the beetles. In order to evaluate the suitability of *P. armandii* as host material for the two *Tomicus*, adults of both *Tomicus* were caged on living branches and felled logs of the two pines during shoot feeding and trunk attack phase, respectively. More beetles survived on the living branches of *P. yunnanensis* than on *P. armandii*. *Tomicus yunnanensis* and *T. minor* produced similar progeny in the logs of the two pines. The sex ratio and developmental period were not affected by host species, but the brood beetles emerging from Armand pine weighed less than those from Yunnan pine, suggesting that *P. armandii* are less suitable to be host of *T. yunnanensis* and *T. minor*.

1. Introduction

As the most important forest pests in southwestern China, pine shoot beetles, *Tomicus yunnanensis* Kirkendall and Faccoli and *Tomicus minor* Hartig (Col., Scolytinae), have killed more than 200 000 ha of Yunnan pine (*Pinus yunnanensis* Franch) in Yunnan province since early 1980s [1], of which *T. yunnanensis* is considered as a more serious species [2–4]. Since the morphology and gallery system of *T. yunnanensis* are very similar to *Tomicus piniperda* L., *T. yunnanensis* had long been confused with *T. piniperda*. Molecular and taxonomic studies have, however, demonstrated that *T. piniperda* is absent in Yunnan [3, 4]. Thus, the aggressive *Tomicus* species in Yunnan was a new undescribed species, and consequently *T. yunnanensis* was finally described and named in 2008 [3].

Like the pine shoot beetles in Europe, the life cycle of *T. yunnanensis* and *T. minor* is univoltine and contains two phases, a reproduction phase and a maturation feeding

phase [5–7]. In Yunnan, adults of the two *Tomicus* species mate and lay eggs in the inner bark of trunks and large branches of living trees from November to May [6–8]. Larvae and pupae subsequently complete their development there. After emergence, the young adults fly to the crowns of host pine trees where they feed in the shoots and become sexually mature [2, 5, 9]. The main shoot-feeding phase lasts from May to November in Yunnan [5–7]. However, *T. minor* usually initiates its flight one or two weeks later than *T. yunnanensis* [1, 2]. Since *T. minor* usually attack trees that previously have been attacked by *T. yunnanensis*, it is regarded as a more secondary species in Yunnan [1–3].

P. yunnanensis and Armand pine (*Pinus armandii* Franch) are distributed at similar elevations. Armand pine often grows together with *P. yunnanensis* in Yunnan province, but *P. armandii* has rarely been attacked by *T. piniperda* and *T. minor* [7]. The reason for this is poorly understood, but it would be valuable to know if *P. armandii* really is more resistant to pine shoot beetle damage. In this study, we

compared the suitability of *P. armandii* and *P. yunnanensis* for maturation feeding and breeding of the two *Tomicus* species.

2. Materials and Methods

2.1. Origins of Pine Shoot Beetles. The pine shoot beetles were collected from Yunnan pine forests in Yiliang or Shilin County. We recognized the shoots containing maturation feeding beetles by their yellowish needles and then cut off the shoots 5–10 cm below the entrance holes by scissors. The shoots with beetles were collected from the forest a few days before the experiment started, and the beetles were peeled out of the shoots and identified to species under a stereoscope (Nikon SMZ). The *Tomicus* population in Shilin consisted of mostly *T. yunnanensis*, but a relatively high proportion of *T. minor* was found in Yiliang.

2.2. Shoot Cage Experiment. In order to assess the effect of tree species on the maturation feeding of pine shoot beetles, the shoot cage experiment was carried out in a mixed stand of *P. yunnanensis* and *P. armandii* in Kunming Tree Garden (25°07' N, 103°00' E, 1953 m above sea level). Most of the trees there were 4–5 m high and exhibited a healthy appearance. No damage history had been recorded. A total of 18 similar trees (nine *P. yunnanensis* and nine *P. armandii*) were selected. For each tree, a mid-crown branch with 20–30 current shoots was enclosed within a 2.0 m × 1.5 m net cage. On July 28, 2000, *T. yunnanensis* adults (10 beetles/cage) were released in six cages for each host species. *T. minor* adults were released in three cages for each pine species in the same way on October 24, 2000. The ends of all the cages were closed and fastened by string. On December 25, 2000, all the cages were cut off the trees and taken to the laboratory. The number of attacked shoots in each cage was counted. The numbers of beetles alive, killed by resin, dead from other reasons or missing were recorded. For each attacked shoot, the shoot diameter at entrance hole, the distance from entrance hole to the shoot tip, as well as the length of feeding tunnel (defined as the length from entrance hole to the end of the tunnel) were measured by ruler.

2.3. Breeding Experiments. On December 26, 2000, three *P. yunnanensis* and three *P. armandii* trees of similar size were felled in a naturally generated mixed stand in Yiliang County. The lower stem section of each tree was cut into four 50 cm-long logs and placed in 80 × 70 cm net cages. A total of 12 cages were used, six of these each contained two logs of *P. yunnanensis* or *P. armandii*, and were divided into two groups, each group containing three *P. yunnanensis* cages and three *P. armandii* cages. On December 27, twenty pairs of unsexed *T. yunnanensis* adults were released to each cage in the first group, and an unsexed mixture of the two *Tomicus*-species (11 pairs of *T. minor* and nine pairs of *T. yunnanensis*) was released to the second group of cages.

After beetles were released, all the logs were checked during the entire experimental period. The new entrance holes were marked and counted twice a week. On Mar. 30, 2001, the new brood adults started emerging. Then the

emerging beetles were collected at different intervals ranging from one day to several days. We measured the diameter of each log on April 20. After measurement, we carefully peeled off the outer bark of each log and counted the number of egg galleries constructed by *T. yunnanensis* and *T. minor*, respectively. For each egg gallery, we measured gallery length and counted the number of larvae, pupae, and adults remaining in the phloem. The brood production was obtained by summing up the number of emerged adults and brood remaining in the galleries. The brood adults from the second group were identified to species under stereoscope. On April 28, the collected beetles of *T. yunnanensis* or *T. minor* were separately dried for each sampling occasion at 60°C for 8 hours, and the dry body weight of the beetles collected at different dates was weighed in 10-beetle samples using an electronic balance.

2.4. Data Analysis. Data were analyzed using the statistics program “StatPac for windows” (StatPac Inc., 1999). All the means were given as mean ± SD (standard deviation) and compared by Student’s *t*-test. The percentage data was compared by Chi-square test.

3. Results

3.1. Maturation Feeding. The status of pine shoot beetles that were caged in the branches of two pine species was identified as alive, killed by resin, dead from other reasons, or missing at the inspection. Although a few beetles of both species survived on both host species (Table 1), the *Tomicus* species performed differently on the two hosts. The survival rate of both *Tomicus* species on *P. yunnanensis* was two-fold higher than on *P. armandii*. Correspondingly, the mortality of *T. yunnanensis* and *T. minor* on *P. armandii* (63% and 73% resp.) was somewhat higher than on *P. yunnanensis* (42% and 50% resp.). Significantly more beetles feeding on *P. armandii* were killed by resin than that feeding on *P. yunnanensis* ($X^2 = 5.44-9.31$, $P < 0.05$). In addition, *T. yunnanensis* excavated twofold more tunnels on *P. yunnanensis* than on *P. armandii* ($t = 4.45$, $P < 0.01$), and the tunnels by both *Tomicus* species on *P. yunnanensis* were longer than on *P. armandii* ($t = 4.28-5.61$, $P < 0.01$) (Table 2), indicating that the beetles were more adapted to their principal host than to *P. armandii* in the shoot feeding phase.

3.2. Oviposition and Brood Production. During reproduction phase, the female adults of either *T. yunnanensis* or *T. minor* excavated similar numbers of egg galleries in the logs of *P. yunnanensis* and *P. armandii* (Table 3). The brood production of the two beetles was also similar in the two hosts. These results suggest that the oviposition and brood production of *T. yunnanensis* and *T. minor* do not differ that much in the logs of the two hosts.

Tomicus minor seemed to be in an inferior position in the competition with *T. yunnanensis*. After the mixture of two beetle species, composed of 55% *T. minor* and 45% *T. yunnanensis*, was released in the cages, the resulting egg galleries of *T. minor* occupied only 24.4% and 19.0% of the

TABLE 1: The performance of *Tomicus yunnanensis* and *T. minor* in the caged shoots of *Pinus armandii* and *P. yunnanensis* in Kunming. 60 *T. yunnanensis* adults were released into the 6 shoot cages on July 28, and 30 *T. minor* adults were released into 3 cages on October 24, for each tree species. The performances of the beetles were checked on December 25, 2000.

<i>Tomicus</i> species	<i>Pinus</i> species	Total	Number of beetles (percentage)			
			Alive	Killed by resin	Dead from other reasons	Missing
<i>T. yunnanensis</i>	<i>P. yunnanensis</i>	60	13 (21.7)	1 (1.7)	24 (40.0)	22 (36.6)
	<i>P. armandii</i>	60	7 (11.7)	12 (20.0)	26 (43.3)	15 (25.0)
Chi-square analysis of 2×4 contingency table				$X^2 = 12.5$, d.f. = 3, $P = 0.006$		
<i>T. minor</i>	<i>P. yunnanensis</i>	30	8 (26.7)	1 (3.3)	14 (46.7)	7 (23.3)
	<i>P. armandii</i>	30	4 (13.3)	8 (26.7)	14 (46.7)	4 (13.3)
Chi-square analysis of 2×4 contingency table				$X^2 = 7.60$, d.f. = 3, $P = 0.055$		

TABLE 2: Feeding tunnels by *Tomicus yunnanensis* and *T. minor* in the caged shoots of *Pinus armandii* and *P. yunnanensis* in Kunming. Ten *T. yunnanensis* adults were released into each cage on July 28, and 10 *T. minor* adults were released into each cage on October 24. The data were collected on December 25, 2000 and are expressed as means \pm 1SD. Means followed by the different letters in a column are significantly different at $P < 0.05$ by *t*-test.

<i>Tomicus</i> species	Cages	<i>Pinus</i> species	Tunnel no cage ⁻¹	Tunnel length (mm) cage ⁻¹
<i>T. yunnanensis</i>	6	<i>P. yunnanensis</i>	16.5 \pm 3.7 a	24.5 \pm 19.5 a
	6	<i>P. armandii</i>	7.5 \pm 3.3 b	7.9 \pm 5.2 b
<i>T. minor</i>	3	<i>P. yunnanensis</i>	12.0 \pm 2.0 a	16.1 \pm 8.7 a
	3	<i>P. armandii</i>	11.0 \pm 6.4 a	9.3 \pm 3.3 b

total attack density in *P. yunnanensis* and *P. armandii*, respectively. Correspondingly, the brood production of *T. minor* was only 18.9% and 13.7% of the total brood production in *P. yunnanensis* and *P. armandii* logs, respectively (Table 3).

3.3. Developmental Period. To investigate the influence of host species on the developmental period of the *Tomicus*, we estimated the speed of brood development of *T. yunnanensis* under laboratory conditions by counting the days from median attacking date to the median date of emergence (Table 4). The developmental period of *T. yunnanensis* was 89 days on *P. yunnanensis*, and 93 days on *P. armandii*, demonstrating that the developmental period of *T. yunnanensis* was nearly similar in the logs of two host species.

3.4. Size of Emerging Beetles. In addition to developmental period, we also investigated the effect of host species on the size of emerging beetles, by comparing the dry weight of *T. yunnanensis* emerging from the logs of the two hosts. The result indicated that *T. yunnanensis* adults reared on *P. yunnanensis* were heavier than those reared on *P. armandii* (data not shown). In addition, the dry weight of *T. yunnanensis* brood adults was strongly related to the date of emergence. The weights of brood adults bred on both *P. yunnanensis* and *P. armandii* decreased with time after the initial brood emergence date, indicating an effect

of intraspecific competition or deteriorating food quality (Figure 1).

4. Discussion

The pine shoot beetles *T. piniperda* and *T. minor* have been reported from a large number of pine species and other conifers as well [10], but the principal host for them in Europe is Scots pine (*Pinus sylvestris* L.). Since the accidental introduction into North America, *T. piniperda* has been reported from a number of North American pines since the 1990s [11–13]. Experiments in Sweden and France have shown successful development in several exotic pine hosts [14]. Although both *T. piniperda* and *T. minor* occur on the exotic host lodgepole pine (*Pinus contorta* Douglas ex Loudon) in Sweden [15], they perform less well in this host [16].

There is another pine shoot beetle species, *Tomicus destruens* Woll., in the Mediterranean area which biologically is more similar to *T. yunnanensis* than *T. piniperda* [3], and this species did better on local maritime than on boreal pine species in northern Italy [17]. In Portugal, Vasconcelos et al. found different host preferences between local populations of *T. piniperda* and *T. destruens*, that is, that northern populations preferred Aleppo pine (*Pinus halepensis* Miller) whereas southern populations preferred Italian stone pine (*Pinus pinea* L.) [18].

The shoot cage experiments showed that *T. yunnanensis* and *T. minor* are capable of feeding in the shoots of *P. armandii*, but more beetles died due to resin and other reasons on *P. armandii* than on *P. yunnanensis*. The resistance of conifers against invaders is mainly based on their ability to produce resin [19–22]. The resin of *P. armandii* was more abundant, and its concretionary speed was slower than *P. yunnanensis* [23]. In addition, the terpene compositions of the two pine species were also different. The shoot piths of *P. armandii* trees contain a lower proportion of α -pinene but a higher proportion of β -pinene than *P. yunnanensis* (Borg-Karlson, A.-K., unpublished data). The observation that more beetles were killed by resin on *P. armandii* might be due to the stronger physical repellency and sticky property of its resin and reflected a higher resistance of *P. armandii* to pine shoot beetles. In addition, the small shoot diameter of *P.*

TABLE 3: Oviposition and brood development of *Tomicus yunnanensis* and *T. minor* in the logs of *Pinus armandii* and *P. yunnanensis* in laboratory condition, after 11 pairs of *T. minor* and 9 pairs of *T. yunnanensis* were introduced to each cage with two logs of *P. yunnanensis* or *P. armandii*. Gallery and brood production data were collected from three replicates. Larval tunnel gallery⁻¹ and gallery length were the mean from all the egg galleries appeared in the logs (number in the bracket). Data are expressed as means \pm 1SD. Means followed by the different letters in a column are significantly different at $P < 0.05$ by *t*-test.

<i>Pinus</i> species	<i>Tomicus</i> species	Galleries m ⁻²	Brood production m ⁻²	Larval tunnel gallery ⁻¹	Gallery length cm
<i>P. yunnanensis</i>	<i>T. yunnanensis</i>	83.4 \pm 12.4 a	1449.9 \pm 96.3 a	29.1 \pm 6.9 a	6.75 \pm 4.2 a (68)
	<i>T. minor</i>	36.80 \pm 14.6 b	338.6 \pm 36.2 b	9.2 \pm 3.1 b	6.18 \pm 3.59 a (30)
<i>P. armandii</i>	<i>T. yunnanensis</i>	86.8 \pm 9.1 a	1693.2 \pm 166.7 a	22.4 \pm 4.5 a	5.02 \pm 2.50 a (68)
	<i>T. minor</i>	20.43 \pm 7.6 b	268.2 \pm 23.2 b	13.1 \pm 2.2 b	4.08 \pm 1.85 a (16)

TABLE 4: Developmental periods of *Tomicus yunnanensis* in logs of *Pinus armandii* and *P. yunnanensis* in laboratory condition. The developmental periods were estimated from the median date of entering (50% entrance holes existed) to the median date of emergence (50% of new generation emerging from brood logs).

Host species	Median date of attack	Median date of emerging	Developmental period, days
<i>P. yunnanensis</i>	Jan. 4	Apr. 3	89
<i>P. armandii</i>	Jan. 8	Apr. 12	93

armandii might also contribute to high mortality of *Tomicus* in this pine species during maturation feeding.

The females of the two *Tomicus*-species accepted *P. armandii* as brood material, and the brood production of the two species was also similar in the two hosts, indicating that *T. yunnanensis* and *T. minor* could reproduce in the logs of *P. armandii* as well. However, *T. yunnanensis* oviposited later, and the brood development was somewhat slower on *P. armandii* than on *P. yunnanensis*, suggesting that this beetle preferred the last host. Similarly, Långström and Hellqvist found no variation on brood production and adult weight between *T. piniperda* beetles reared on lodgepole pine and those reared on Scots pine, but the development time of this beetle was longer on *P. contorta* than on *P. sylvestris* [16]. Führer and Mühlenbrock demonstrated that six-toothed spruce bark beetle (*Pityogenes chalcographus* L.) had similar brood production on its principal and secondary conifer hosts [24]. Differently, Cerezke showed that mountain pine beetle (*Dendroctonus ponderosae* Hopkins) was able to reproduce successfully in some pine species, but with a considerable variation in the brood production [25].

In our experiments the dry weight of *T. yunnanensis* brood adults emerged from Yunnan pine was higher than of those beetles that emerged from Armand pine. This observation might be due to qualitative differences in nutritional value and/or secondary metabolisms in the two hosts or just simply have resulted from the difference in phloem thickness of the two tree species. A similar pattern was found for the spruce bark beetle (*Ips typographus* L.) developing on its native host, Norway spruce [*Picea abies* (L.) Karsten], as compared to beetles emerging from an exotic host, sitka spruce [*Picea sitchensis* (Bong) Carrière] [26]. Since heavier bark beetles survive better than the lighter ones

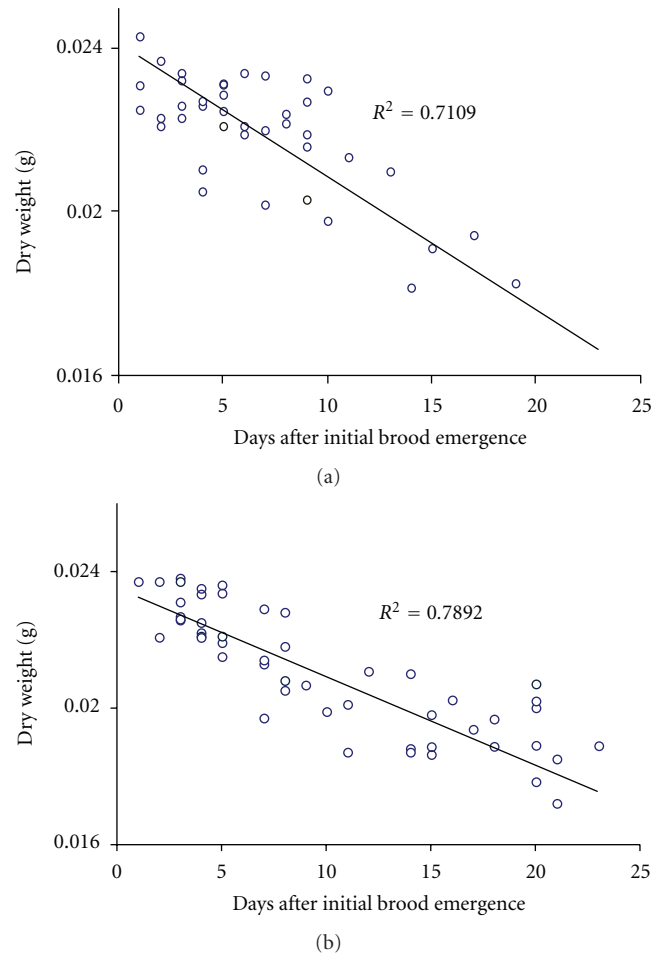


FIGURE 1: Mean dry weight of emerging *Tomicus yunnanensis* reared on *Pinus yunnanensis* (a) and *P. armandii* (b) related to days post the initiation of brood adult emergence. Each dot represents the average adult weight for a 10-beetle sample.

[27], and the fecundity of female bark beetles is related to the fat reserves available [28, 29], the lower body weight for *T. yunnanensis* bred from *P. armandii* could reduce survival of the beetles when they feed in the shoot and lead to less brood production later on. Långström and Hellqvist found that the weights of callow adults bred on both *P. contorta* and *P. sylvestris* decreased over the days following the initiation

of brood emergence [16]. We found the same pattern in the present experiment, both on *P. yunnanensis* and *P. armandii*. This pattern indicates an intraspecific competition and/or a deteriorating food quality.

In conclusion, this study demonstrates that *T. yunnanensis* and *T. minor* can feed in the shoots and reproduce in the logs of *P. armandii*. The performance of the beetle species is, however, somewhat lower in Armand pine than in Yunnan pine, which may explain the beetles' preference for the latter species. We suggest that a stronger defense in Armand pine may be the cause of this difference, and more experiments on host defenses are needed to assess the risk of *T. yunnanensis* and *T. minor* to *P. armandii* forests.

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