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Seed-Insect Fauna in Pre-Dispersal Acorns of *Quercus Variabilis* and *Q. Serrata* and Its Impact on Acorn Production

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Abstract - Seed-insect fauna in pre-dispersal acorns of *Quercus variabilis* Blume and *Q. serrata* Thunb. ex Murray and impact of the insects on acorn production were investigated in broad-leaved forests of central Japan. In *Q. variabilis*, *Curculio robustus* (Roelofs), curculio weevil (unidentified species), *Poecilips cardamomi* (Schaufuss), blastobasid moth (unidentified species), *Pammene nemorosa* Kuznetzov, *Cydia glandicolana* (Danilevsky) and *Characoma ruficirra* (Hampson) attacked pre-dispersal acorns. These insects damaged more than 50% (site A) and less than 25% (site B) of the initial number of female reproductive organs of plants. By contrast, pre-dispersal acorns of *Q. serrata* were attacked by seven insect species: *Mechoris ursulus* (Roelofs), *Curculio sikkimensis* (Heller), *P. cardamomi*, cynipid wasp (unidentified species), *Cydia danilevskyi* (Kuznetzov), *C. glandicolana* and *Cydia amurensis* (Danilevsky). These insects damaged less than 10% of the organs (site A and B). Thus, it is clear from our field data that seed-insect fauna was markedly different between *Q. variabilis* and *Q. serrata*, and the insects had a more serious effect on acorn production in *Q. variabilis* than in *Q. serrata*. A germination test of insect-damaged *Q. variabilis* acorns was carried out in the laboratory. Germination rate of acorns damaged by curculio weevils was significantly lower than that of the sound acorns, particularly when there was a larger endosperm loss of the damaged acorns. Thus, predation by seed insects would have a negative effect on acorn germination.

I. Introduction

The genus *Quercus* is a major tree in secondary forests in warm and cool temperate regions in Japan. *Quercus* acorns are damaged by many herbivorous predators such as insects, birds and mammals before and after dispersal [1, 2, 3]. Of these, insects are considered to be the most important predators. To date, approximately 67 species of phytophagous insects are known to damage acorns of oak trees [4]. They can play a significant role in mortality of pre-dispersal acorns [5, 6]. However, little information is available about seed-insect fauna and effects of insect damage on acorn production and germination in Japan.

The aims of the present study are to investigate 1) seed-insect fauna in two co-occurring oaks, *Q.variabilis* and *Q. serrata*, 2) losses attributable to damage by the insects and 3) germination success of insect-damaged acorns in relation to endosperm loss.

II. Materials and methods

A. Study site

A series of field experiments were carried out in secondary forests on the Nagoya University Campus (site A) and Higashiyama Park (site B), Aichi Prefecture, central Japan. The forest consists mainly of deciduous oaks (*Q. variabilis* and *Q. serrata*) and Japanese red pine (*Pinus densiflora* Sieb. et Zucc). The annual precipitation and annual mean temperature at the Nagoya Weather Station are about 1500 mm and 15.1 ℃, respectively [7].

B. Acorn development of studied tree species

Quercus variabilis and *Q. serrata* belong to section *Cerris* and section *Prinus*, respectively [8]. The time between flowering and fertilization differs markedly between these two sections. In the *Cerris* reproductive cycle, which lasts two years, development of female reproductive organ stops in the early summer of the first year shortly after pollination, and fertilization and acorn maturation occur during the second year ("2nd-year acorn"). In this study, pistillate flowers and tiny unfertilized acorns were referred to as "1st-year acorn". By contrast, in the *Prinus* cycle, pistillate flowers are produced in the spring, and acorns mature in the autumn of the same year. Tiny *Q. serrata* acorns with a cupule width of less than 2 mm were regarded as pistillate flowers [9].

C. Survey of insects attacking acorns of Q. variabilis and Q. serrata (Experiment 1)

To investigate the seed-insect fauna of pre-dispersal acorns of *Q. variabilis* and *Q. serrata*, falling female reproductive organs (pistillate flowers and acorns) were collected using seed traps in 1995 and 1996 in site A. Five trees each of *Q. variabilis* and *Q. serrata*, with no canopy overlap of adjacent conspecific oaks, were selected. Two seed traps, each with a projection area of 0.24 m^2, were set under the canopy of each tree on 1 June 1995. The organs that fall into the traps were collected once a week from June to December in both 1995 and 1996. In the laboratory, 1st-year acorns of *Q. variabilis* and pistillate flowers of *Q. serrata* were eliminated. Collected acorns were dissected, and were classified into sound, aborted, insect-damaged and degenerated. The insect species in damaged acorns were identified.

To identify larvae of seed insects in collected acorns, the insects were reared until the adult stage in the field or laboratory. In this study area (site A), five 2nd-year immature acorns of *Q. variabilis* damaged by moths were sampled from branches of other trees in

August 1996. About 290 2nd-year mature acorns of *Q. variabilis* and about 540 mature acorns of *Q. serrata*, in some of which moths and weevils were hibernating, were collected randomly from the forest floor from October to November in 1995 and 1996. The *Q. variabilis* acorns sampled from the branches were put individually into a plastic tube (φ25 mm × 65 mm), and the moth larvae were reared until adult in the laboratory. About 70 to 140 of each species of the *Quercus* acorns collected from the forest floor were placed in an emergence box (φ210 mm × 170 mm) filled with sterilized soil, and then the boxes were buried in the forest floor. The top of the boxes was covered by nylon-screen to prevent predation by wood mice. Adult moths and weevils that emerged in the boxes were collected every day from April 1996 to October 1997.

D. Annual fall of female reproductive organs and losses to damage by insects (Experiment 2)

We selected five trees each of *Q. variabilis* and *Q. serrata* in site A and five trees of *Q. variabilis* and fourteen trees of *Q. serrata* in site B in order to examine the number of female reproductive organs and their inner conditions from 1997 to 1999. Four seed traps, each with a projection area of 0.25 ㎡, were set under the tree canopy on 24 May 1997 in site A and 15 June 1997 in site B. The organs that fell into the traps were collected twice a month from June to December in 1997 and once every 1 or 2 months from April to December in both 1998 and 1999. The collected organs were classified into 1st-year acorns and 2nd-year acorns for *Q. variabilis* and pistillate flowers and acorns for *Q. serrata*, and then were dissected and classified into sound, aborted, insect-damaged and degenerated.

E. Germination test (Experiment 3)

A germination test was carried out for 2nd-year acorns dispersed by three other trees of *Q. variabilis* in site A. About one hundred mature acorns were collected randomly on 28 September 1998 from the ground beneath the tree canopy. In order to break diapause, all acorns collected were stored in an incubator (EYELATRON FLI-301NH, EYELA, Tokyo) until they were used for the germination test (4 to 6 ℃, 95% relative humidity, 24 h dark).

On 12 December 1998, two acorns were put on two moist filter-papers in a petri dish (90 mm in diameter). Thereafter, the dishes were placed in the incubator under conditions of 25 ℃, 75% relative humidity and 16 h light (2000 lx) and 8 h dark. The number of germinated individuals was recorded once every 3 or 4 days till 16 January 1999. Evidence of acorn germination was considered to be when the radicle protruded through the pericarp [10].

After the germination test, all the acorns were split to record the inner conditions (sound, insect-damaged and degenerated). For insect-damaged acorns, the insect species were identified, and the degree of insect predation was estimated as the proportion of the maximum sectional area of insect-damaged endosperm at the end of the test to the total sectional area of the endosperm, assuming the acorns to be intact. The predation degree was categorized into five groups [10]: 0 for no predation (0%), 1 for slight endosperm loss (>0% <33%), 2 for moderate endosperm loss (>33% <67%), 3 for large endosperm loss (>67% <100%) and 4 for complete endosperm loss (100%). Degenerated acorns showed no evidence of insect predation, and thus scored 0 as well as sound acorns, although they probably were damaged by unidentified fungi.

III. Results and Discussion

A. Seed-insect fauna in Q. variabilis and Q. serrata

Table 1 lists seed insects attacking acorns of *Q. variabilis* and/or *Q. serrata* in Experiment 1, where five coleopteran species, one hymenopteran species and six lepidopteran species were found. Acorns of *Q. variabilis* were damaged by curculio weevils (*Curculio robustus* (Roelofs) and an unidentified species), a scolytid beetle (*Poecilips cardamomi* (Schaufuss)), a blastobasid moth (unidentified species), tortricid moths (*Pammene nemorosa* Kuznetzov and *Cydia glandicolana* (Danilevsky)) and a noctuid moth (*Characoma ruficirra* (Hampson)). Acorns of *Q. serrata* were damaged by a total of seven insect species: a mechoris weevil (*Mechoris ursulus* (Roelofs)), a curculio weevil (*Curculio sikkimensis* (Heller)), a scolytid beetle (*P. cardamomi*), a cynipid wasp (unidentified species) and tortricid moths (*Cydia danilevskyi* (Kuznetzov), *C. glandicolana* and *C. amurensis* (Danilevsky)). In this study area, *P. cardamomi* and *C. glandicolana* were found in both *Q. variabilis* and *Q. serrata* acorns (Table 1).

Table 1
Seed insects attacking pre-dispersal acorns of *Q. variabilis* and/or *Q. serrata* from 1995 to 1997 in central Japan

Order	Family	Species	Damaged acorn
Coleoptera	Attelabidae	*Mechoris ursulus* (Roelofs)	*Q. serrata*
	Curculionidae	*Curculio robustus* (Roelofs)	*Q. variabilis*
		Curculio sikkimensis (Heller)	*Q. serrata*
		Unidentified	*Q. variabilis*
	Scolytidae	*Poecilips cardamomi* (Schaufuss)	*Q. variabilis, Q. serrata*
Hymenoptera	Cynipidae	Unidentified	*Q. serrata*
Lepidoptera	Blastobasidae	Unidentified	*Q. variabilis*
	Tortricidae	*Pammene nemorosa* Kuznetzov	*Q. variabilis*
		Cydia danilevskyi (Kuznetzov)	*Q. serrata*
		Cydia glandicolana (Danilevsky)	*Q. variabilis, Q. serrata*
		Cydia amurensis (Danilevsky)	*Q. serrata*
	Noctuidae	*Characoma ruficirra* (Hampson)	*Q. variabilis*

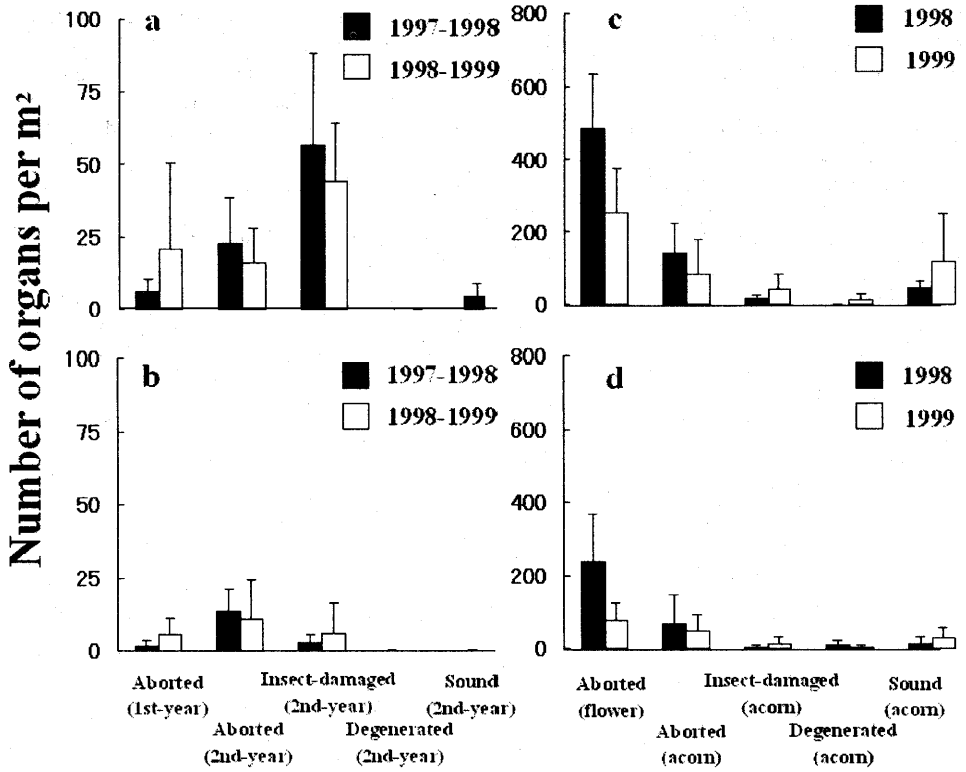

Fig. 1. The number of female reproductive organs with different inner conditions that fell into seed traps.(a) *Q. variabilis* in site A, (b) *Q. variabilis* in site B, (c) *Q. serrata* in site A, (d) *Q. serrata* in site B.

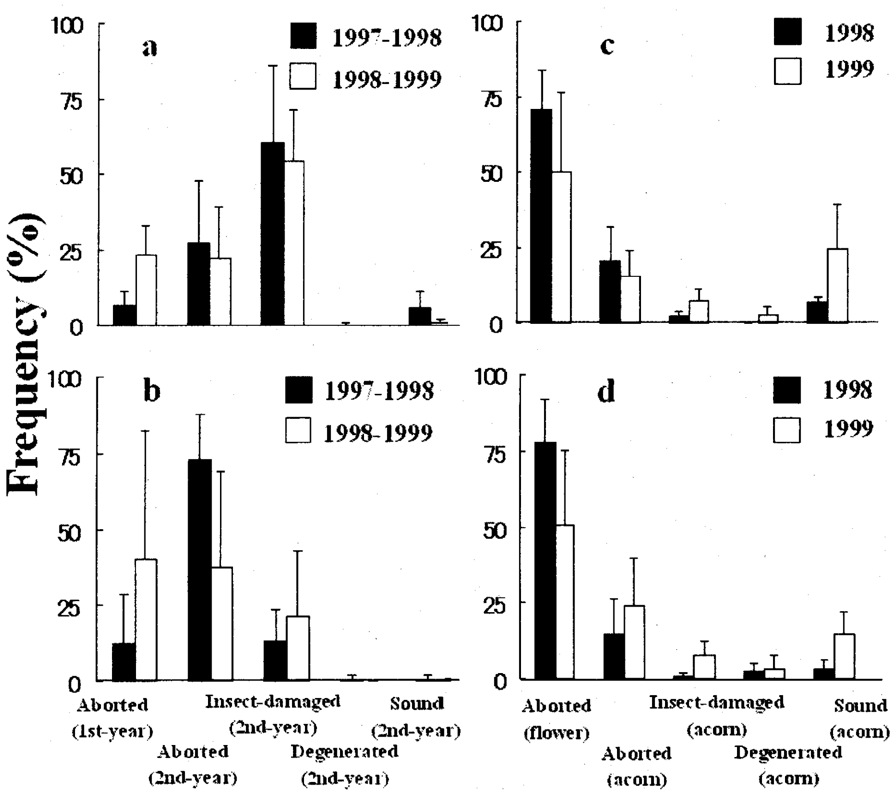

Fig. 2. The proportion of the number of organs in each inner condition to total number of dropped organs, expressed as a percentage. (a) *Q. variabilis* in site A, (b) *Q. variabilis* in site B, (c) *Q. serrata* in site A, (d) *Q. serrata* in site B.

B. Estimation of production of female reproductive organs and their inner conditions

For both *Q. variabilis* and *Q. serrata*, more reproductive organs fell to the ground in site A than in site B (Fig. 1). In *Q. variabilis*, insects damaged more than 50% of the total fall of the organs in site A but less than 25% in site B (Fig. 2). By contrast, insects damaged less than 10% of the *Q. serrata* organs in both sites (Fig. 2). Thus, it is clear from our field data that seed insects had a more serious effect on acorn production in *Q. variabilis* than in *Q. serrata*.

C. Effects of insect predation on acorn germination

In Experiment 3, endosperm loss of *Q. variabilis* acorns was caused mainly by predation by curculio weevils. The percentage of acorn germination (proportion of the number of acorns germinated to total number of acorns tested) in the five damage scores are summarized in Table 2, where the data for the three trees are combined. The germination rates of acorns with scores 2 and 3 tended to be lower than those with score 0 (sound) (Fisher's exact probability test, score 2 *vs.* score 0 (sound), d. f. = 1, $p < 0.05$; score 3 *vs.* score 0 (sound), d. f. = 1, $p = 0.066$). This fact indicates that insect predation could have a negative effect on acorn germination.

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Table 2
Percentages of germination of *Q. variabilis* acorns, in each class of endosperm loss by curculio weevils

	Score of endosperm loss					
	0	0	1	2	3	4
	Sound	Degenerated	Curculio weevils-damaged			
Germination rate of acorns (%)[a]	90.0 (144/160)	54.8*** (17/31)	$94.7^{n.s.}$ (71/75)	64.3* (9/14)	$66.7^{n.s.}$ (6/9)	-

[a] Percentages followed by asterisks within a row are significantly different from that of score 0 (Sound) according to the Fisher's exact probability test (* p<0.05, ** p<0.01, *** p<0.001; $^{n.s.}$ not significant).