

Physiological characteristics of the Large Copper butterfly, *Lycaena dispar* (Lepidoptera: Lycaenidae)

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To establish an indoor-rearing system for the Large Copper butterfly, *Lycaena dispar* and the Small Copper butterfly, *Lycaena phlaeas*, the effect of temperature, photoperiod and host plants on larval development was investigated. The larvae of *Lycaena dispar* fed on *Rumex crispus*, whereas the larvae of *Lycaena phlaeas* ate both *Rumex crispus* and *Rumex acetosa*. The duration of the larval period of *Lycaena dispar* was 13.8 days on *R. crispus* and that, of *Lycaena phlaeas* was 15.9 days and 15.2 days on *R. acetosa* and *R. crispus* respectively. Laboratory experiments show that the Large Copper larvae are able to feed on other *Rumex* species without harming their overall survival and can utilize these alternative host plants at least as efficiently as their natural host plant. This result suggests that plant chemistry is not responsible for their lack of utilization of the alternative host plants in the wild. Host plant choice by ovipositing females was measured with the two alternative hosts. *Lycaena dispar* preferred *R. crispus* to *R. acetosa*, whereas *Lycaena phlaeas* preferred *R. acetosa* to *R. crispus*. Temperature has been proposed as an important determinant of developmental rate, lifespan and mortality in invertebrates. As temperature increased, length of the developmental period gradually decreased. The developmental period of the Large Copper larvae was 11.0 days and 28.5 days at 30°C and 17.5°C, respectively.

Keywords: *Lycaena dispar*, *Lycaena phlaeas*, *Rumex* spp., Oviposition, Hostplant

Introduction

The Large Copper (*Lycaena dispar*) usually occurs in natural marsh vegetation along water courses, rivers and marshes, but it may also be found in unimproved, semi-natural grass-lands. The male defends a territory, and the female travels through large wetlands areas to find a male and a plant on which to deposit eggs after mating (Webb and Pullin, 2000). The females are highly mobile and can colonize suitable habitats relatively rapidly over distances of 10 km (Bloemmen, 2004). For this reason, the butterfly adapts very well to mosaics of habitat patches.

The Large Copper has declined significantly in Western Europe, whereas Eastern European populations are generally stable (Duffey, 1977; Higgins and Hargreaves, 1983; Pullin, 1998; Webb and Pullin, 1996). At the northern limit of its range in Estonia and more recently in Finland, this butterfly's habitat is expanding (Pullin, 1997). It is probable that this change is result of global warming over the past decades (Kudrna, 2002). Like most threatened wetland species, the Large Copper has severely declined in recent years and no longer occurs, in many areas due to habitat destruction. It became extinct in the UK in the 1920s due to drainage of its low-land habitat and excessive collecting during that period (Asher *et al.*, 2001; Bretherton, 1966; Chris, 1990; Duffey, 1968; Heath, 1981, 1983; IUCN, 1990). Successive and long term attempts to reintroduce the species to the UK have failed for many reasons including lack of sufficiently extensive habitat, unsuitability of the subspecies selected for reintroduction (the British subspecies of *L. dispar* is extinct) and acclimatization to the greenhouse environment in which the annual supply of "booster" butterflies was held (Pullin, 1995, 1998).

The Small Copper, *Lycaena phlaeas*, is a multi voltine butterfly that emerges from spring through autumn in the

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Republic of Korea. Adults inhabit sunny areas, such as forest margins, clearings, open fields with low vegetation, banks and roadsides (Suzuki, 1976). The primarily holarctic lycaenid butterfly *L. phlaeas* (L.) inhabits a wide range of habitats from sea level to ca. 4,000 m elevation. Various subspecies of *L. phlaeas* in Asia, Europe, and eastern North America are multivoltine, polyphagous (primarily on *Rumex* species) and common at low elevations. Lycaenid butterflies are considered the most beautiful of all insects worldwide. As such, many butterflies function as ideal conservation flagships, selected for their attractiveness, distinctiveness or vulnerability to best engender public support and acknowledgement for broader conservation issues or concerns. For similar reasons, butterflies are particularly useful insects to help promote science literacy, environmental stewardship, and participatory learning, especially in youth. More recently, butterflies are playing an ever increasingly important role in ecotourism, wildlife viewing, and environmental landscaping with the growth of butterfly watching, wildlife-friendly gardening, butterfly farming and live butterfly exhibits. This course provides students with an introduction to the important nontraditional role butterflies can play in public education, sustainable development and ecotourism. This thesis investigates the physiological bases of food plant usage, development and diapause in *L. dispar* by analyzing the species preferences and performance. The analysis includes the host plant *R. crispus* and other commonly-used *Rumex* species, such as *R. japonicus* and *R. obtusifolius*.

Materials and Methods

Experimental insect

Laboratory colonies of *L. dispar* were established from adults collected at their overwintering sites on 15 May 2007 and 15 July 2007 (Goyang; 37°4'N, 127°6'E). Their diet consisted of *Rumex* species prior to the beginning of the experiments. The insects were maintained at 25°C and 65% relative humidity under a photoperiod of LD 16:8 h. Hatched larvae were individually reared in Petri-dishes under the same conditions. The containers used for rearing include a small Petri-dish (35 cm in diameter and 10 cm high) for the 1st stage, a medium Petri dish (60 cm in diameter and 1.5 cm high) for the 2nd and 3rd stages, and a large Petri dish (100 cm in diameter and 40 cm high) for the 4th stage.

Comparison of larval growth and development on different host

The duration of larval growth on the *Rumex* species (*R. crispus*, *R. japonicus*, *R. obtusifolius*) was measured from

hatching to pupation to determine whether growth and survival rates during the larval period differed among *Rumex* species. Hatching larvae were transferred to plants of different *Rumex* species. When feeding ceased in the 4th instar they were placed in separate large Petri-dish (100×40 cm), where they were allowed to pupate. The pupal mass was measured by weighing the surviving pupae 48 h after pupation. Developmental times from hatching to pupation and adult emergence were also recorded.

Oviposition preference and pattern on alternative *Rumex* species

To test for oviposition preference, mated females were presented with a choice between the two *Rumex* species. For this experiment, all larvae were reared to the adult stage under summer light and temperature regimes (LD 16:8 h at 25°C) on their natural host. The rationale for this approach was Hopkins' Host Selection Principle, which suggests that an ovipositing female will preferentially choose the host-plant on which she was reared (Stanton, 1979; Wiklund, 1974). Female butterflies were mated prior to the experiment by releasing two males and one female into a cage, with a natural food source (*Erigeron annuus*, *Chupea hyssopifolia*) for 24 h. The *Rumex* plants were grown in 20 cm pots under green-house conditions. For the experiment, plant of each species, matched for size, were placed in a muslin cage (200 cm×100 cm×100 cm) in a square pattern. The plants were randomly allocated to each of two positions by drawing lots. The arrangement was re-randomised for each individual female. The females were released into the experimental cages and left for 24 h with a food source, as above, in natural day-light and temperatures. After 24 h, the female and the plants were removed from the experimental cage, and the number of eggs present on each plant species was counted.

Effects of temperature on developmental characteristics

The effect of constant rearing temperatures on the developmental of *L. dispar* was tested at 17.5, 20, 22.5, 25, 27.5 and 30°C (LD 14:10 h). *R. crispus* plants were inoculated with hatching larvae. The larval period and the survival rate were determined as follows; Newly hatched larvae were placed on *R. crispus* plants and held at various temperatures. The larvae were examined daily, and food was added as needed. The developmental periods and survival rates at each instar were determined. The pupal mass was measured in each group.

Statistical analysis

Differences in development, reproduction, and diapause

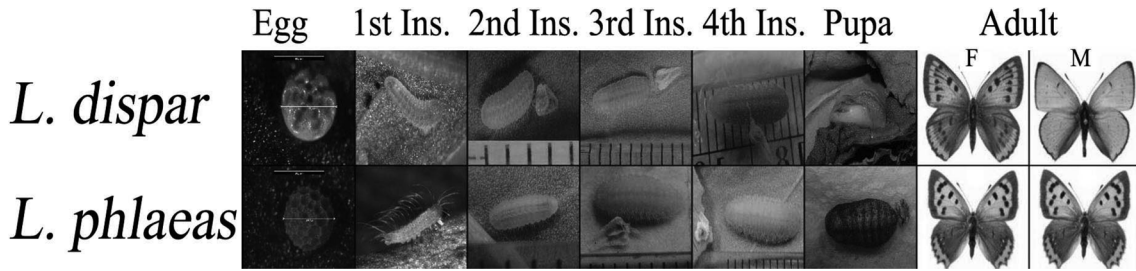


Fig. 1. Life cycle of *Lycaena* spp. (F: female, M: male).

were tested with an analysis of variance (ANOVA). If significant differences were detected, multiple comparisons were performed using Tukey’s HSD multiple range test ($P = 0.05$)

Results and Discussion

Life cycle of *Lycaena* spp.

Newly hatched larvae of *L. dispar* are covered with long hairs and are very pale yellow in color, changing to green after a day. After the third molt under short day lengths and shortly before hibernation, The larvae lose nearly all their greenish color and acquire a reddish- tinge. The larvae of *Lycaena phlaeas* usually have five instars if oviposition occurs during short days (<11 h light) and at low maximum diurnal temperatures (22°C). If oviposition occurs during longer days (>12 h light) and at higher mean diurnal temperatures (33°C), most larvae have four instars (Fig. 1). Although diapause is not obligate, overwintering likely occurs at a larval stage. The larvae, are more cold-resistant than the pupae or adults (Ballmer and Pratt, 1989).

Developmental consequences on different host plants
1. Comparison of larval growth and development of *Lycaena* spp. on different *Rumex* hosts

To study the effects of host plant, Large Copper larvae were reared two host plant species at 25°C, LD 16:8 h. The larval duration of the Large Copper is shown in Fig. 2 and Table 1. The larval duration of the Large Copper on *R. crispus* was 13.8 days, and the survivorship was 97%. However, all larvae died on *R. acetosa*. The larval duration of the Small Copper was 15.9 and 15.1 days on *R. crispus* and *R. acetosa*, respectively. The duration of the larval period in the Small Copper did not differ between the two host plants. The weight of the Large Copper pupae was 204 mg. All Large Copper test larvae pupated when reared on *R. crispus*. The larval survival rate of the Small Copper exceeded 70%, The highest rate, 78.6%, occurred on *R. acetosa*. However, the larval survival rate

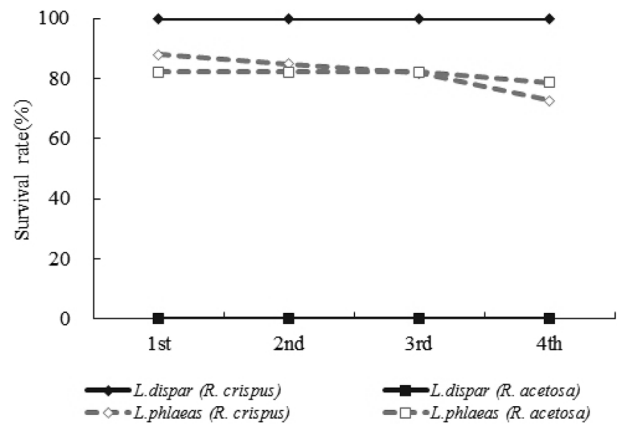


Fig. 2. Survival rate of each instar of *L. dispar* and *L. phlaeas* reared on different host plants.

Table 1. Developmental consequences of *L. dispar* and *L. phlaeas* reared on different host plant

| | Host plant | Pupation rate (%) | Pupal duration (days) | Emergence rate (%) |
|-------------------|-------------------|-------------------|------------------------|--------------------|
| <i>L. dispar</i> | <i>R. crispus</i> | 97.9 | 7.2 ± 0.6 | 95.7 |
| | <i>R. acetosa</i> | - | - | - |
| <i>L. phlaeas</i> | <i>R. acetosa</i> | 78.6 ^a | 9.4 ± 2.4 ^a | 78.6 ^a |
| | <i>R. crispus</i> | 69.7 ^a | 8.6 ± 2.4 ^a | 57.6 ^a |

did not differ significantly between the two host plant species. The emergence rate was higher on *R. acetosa* (78.6%) than on *R. crispus* (57.6%). The growth and development of Small Copper larvae from hatching to adulthood on the two *Rumex* species did not show any significant differences (Fig. 3). The pupal weights of the Small copper on the two *Rumex* species were very similar and did not differ significantly. The pupal duration of the Large Copper was 7.2 days on *R. crispus*. The pupation rate of the Large Copper was 97.9% on *R. crispus*, and emergence rate was 95.7%. The pupal duration of the Small Copper ranged between 9.4 and 9.6 days and did not differ significantly between *R. acetosa* and *R. crispus*.

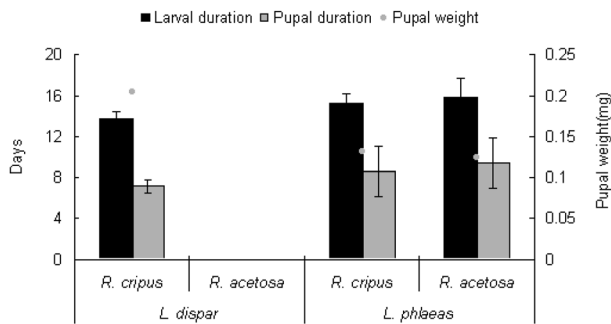


Fig. 3. Development of *L. dispar* and *L. phlaeas* reared on different host plant. Larvae (n=60) were reared at 25°C under LD 16:8 h.

Larval survival did not differ significantly between *R. acetosa* and *R. crispus*. However, the emergence rate of the Small Copper on *R. crispus* was significantly lower than that on *R. acetosa*.

Because the Small Copper larval survival rates were similar for the two *Rumex* species, it is unlikely that interspecific differences in allelochemical concentrations had any effect on the larvae. Secondary plant metabolites can affect larval performance on the host plant. The family Polygonaceae, to which *Rumex* belongs, is reported to contain high levels of oxalates (Libert and Franceschi, 1987). These compounds, can act as a feeding deterrent to many herbivores (Bink, 1970, 1986; Libert and Franceschi, 1987; Yoshida *et al.*, 1997; Yoshihara *et al.*, 1980). Because the final-instar larvae of *L. phlaeas* can use *R. crispus* and *R. acetosa*, it is probable that the oxalates present in these plants have little or no harmful effect on *L. phlaeas* larvae and that allelochemicals may not be the reason that other *Rumex* species are not used as host plants. Because *L. phlaeas* larvae reared on the two plant species survived to pupation and adulthood, it is probable that non-host *Rumex* spp. are able to support these larvae successfully to maturity. However Large Copper larvae were unable to feed on *R. acetosa*. The leaves of *R. acetosa* contain potassium oxalate, tartaric acid, oxalic acid and tannin, and many *Rumex* species have astringent and slightly purgative qualities. *R. acetosa* has substantially higher levels of oxalic acid than other *Rumex* species (Bown, 1995). It is probable that the oxalate present in

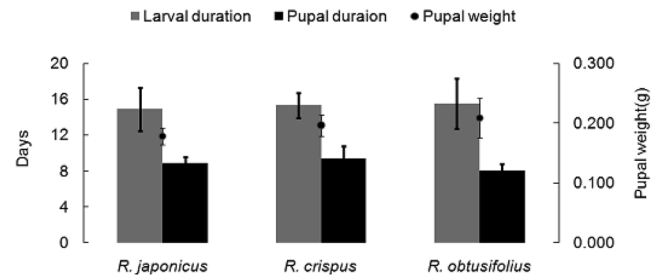


Fig. 4. Developmental consequences of *L. dispar* reared on different host plant. Larvae were reared at 25°C and LD 16:8 h. Sample size (n=60).

this plant species has a deterrent on *L. dispar* larvae and that the allelochemicals present in *R. acetosa* prevent its use as a host plant by *L. dispar*.

2. Comparison of larval growth and development of *L. dispar* on different *Rumex* hosts

All larvae in the early instar experiment, except two in the *R. obtusifolius* treatment and one in the *R. crispus* treatment, commenced feeding and successfully molted to the 2nd instar (Table 2). Early instar larval survival did not differ significantly among the three plant species ($d.f = 2, P > 0.05$). The length of the larval stage showed no significant differences among the three *Rumex* species. Pupal weights did not differ significantly among the host plant species (Fig. 4).

Newly hatched larvae readily accepted all three plant species and commenced feeding. This result indicates that the three *Rumex* species all contain the appropriate feeding stimulants and is consistent with the statement of Whittaker and Feeny (1971) that related plant species typically contain similar chemical profiles. However, in certain cases small larvae of other species cannot detoxify high concentrations of allelochemicals that present no problem to older larvae (Chew and Rodman, 1979; Hatcher *et al.*, 1995, Martin and Pullin 2004a, b) found that *R. crispus* had 20.3% higher oxalate concentrations than *R. obtusifolius* (unfortunately, no comparative information is available for *R. japonicus*). Because final instar *L. d. batavus* larvae are able to utilize *R. crispus* more efficiently than they use *R. obtusifolius*, it is probable that oxalate present in *R. crispus* has little or no harmful effect

Table 2. Survival rate of each stage of *L. dispar* on various host plant

| Host plant | Larval survival rate (%) | | | | Pupal Rate (%) | Emergence rate (%) |
|------------------------|--------------------------|-------|-------|------|----------------|--------------------|
| | 1st | 2nd | 3rd | 4th | | |
| <i>R. japonicus</i> | 100.0 | 100.0 | 100.0 | 93.8 | 93.8 | 87.5 |
| <i>R. crispus</i> | 100.0 | 100.0 | 100.0 | 86.7 | 86.7 | 86.7 |
| <i>R. obtusifolius</i> | 100.0 | 100.0 | 100.0 | 94.9 | 94.9 | 76.9 |

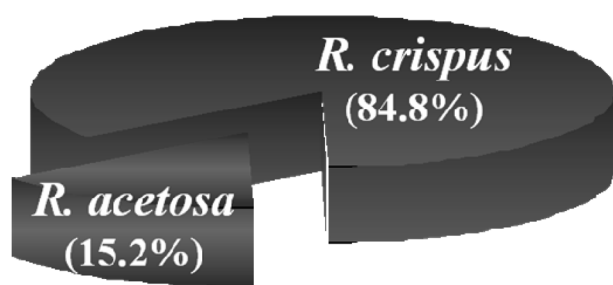


Fig. 5. Oviposition preference of *L. dispar* (N=1,055).

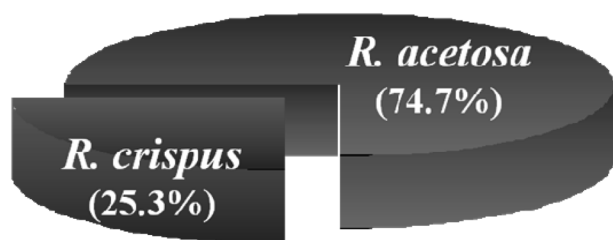


Fig. 6. Oviposition preference of *L. phlaeas* (N=475).

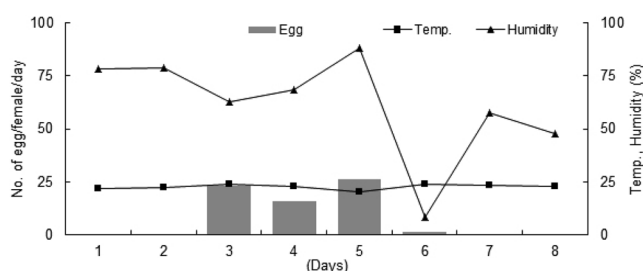


Fig. 7. Daily oviposition by *L. dispar* females under field conditions (*R. obtusifolius*). Cage (200 cm × 100 cm × 100 cm), with plants in a square pattern.

on *L. d. batavus* larvae and that allelochemicals are not the reason that other *Rumex* species are not used as host plants. Because larvae from all three plants survived to pupation and adulthood, it is likely that non-host *Rumex* spp. are able to support larvae successfully to maturity.

Oviposition preference and pattern of laboratory-reared individuals

The Large Copper females exhibited a significant preference for *R. crispus* (Fig. 5). The Large Copper females given *R. crispus* and *R. acetosa* as host plants laid significantly more eggs on *R. crispus* (895 and 160, respectively). The oviposition behaviors of the Small Copper and the Large Copper differed (Fig. 6). *L. phlaeas* preferred *R. acetosa* to *R. crispus*. The oviposition period and post-oviposition period of *L. dispar* were 4-5 and 2 days on *R. crispus* and *R. obtusifolius* respectively (Fig. 7 and 8).

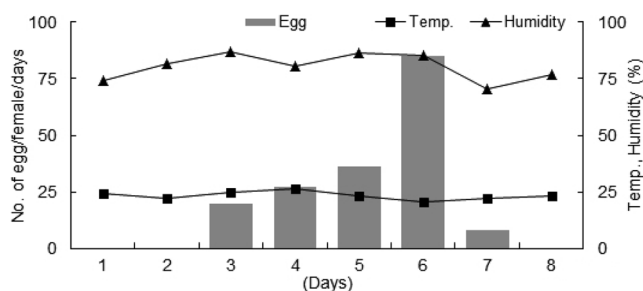


Fig. 8. Daily oviposition by *L. dispar* females under field conditions (*R. crispus*). Cage (200 cm × 100 cm × 100 cm), with plants in a square pattern.

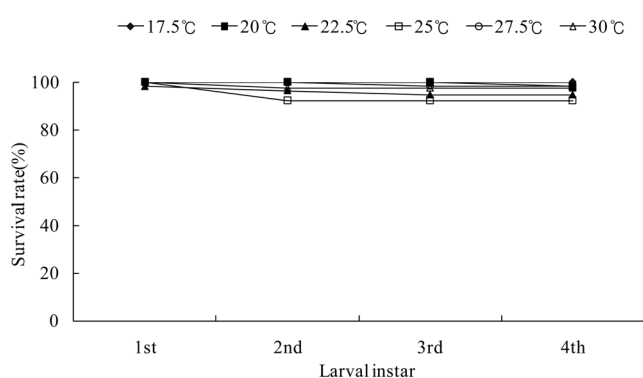


Fig. 9. Survival rate of each instar of *L. dispar* at various rearing temperature. Larvae were reared at LD 14:10 h.

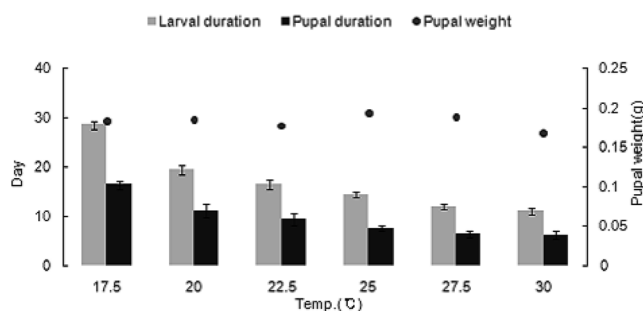


Fig. 10. Development of *L. dispar* reared at different temperatures. Larvae (n=60) were reared at LD 14:10 h. The bar indicates standard deviation; means listed in the same colored bars followed by the same letter are not significantly different by Tukey's HSD multiple range test ($P = 0.05$).

Effect of temperature on the development of L. dispar

L. dispar larvae were reared at various temperatures to determine the effects of temperature variation on development. The survival rates of *L. dispar* at the 6 different temperatures used are shown in Fig. 9. These survival rates were 72.7, 94.2, 82.1, 84.6, 81.4 and 85.0% at 17.5, 20, 22.5, 25, 27.5 and 30°C, respectively. The effect of

Table 3. Developmental consequences of *L. dispar* at different rearing temperatures

| Temp. (°C) | Pupation rate (%) | Pupal duration (day) | Emergence rate (%) |
|------------|-------------------|-------------------------|--------------------|
| 17.5 | 100% | 16.4 ± 0.8 ^c | 72.7 ^b |
| 20 | 98.1 | 11.1 ± 1.3 ^d | 94.2 ^a |
| 22.5 | 94.4 | 9.3 ± 1.1 ^c | 82.1 ^b |
| 25 | 92.3 | 7.7 ± 0.5 ^b | 84.6 ^b |
| 27.5 | 98.1 | 6.6 ± 0.7 ^a | 81.4 ^b |
| 30 | 97.5 | 6.3 ± 0.9 ^a | 85.0 ^b |

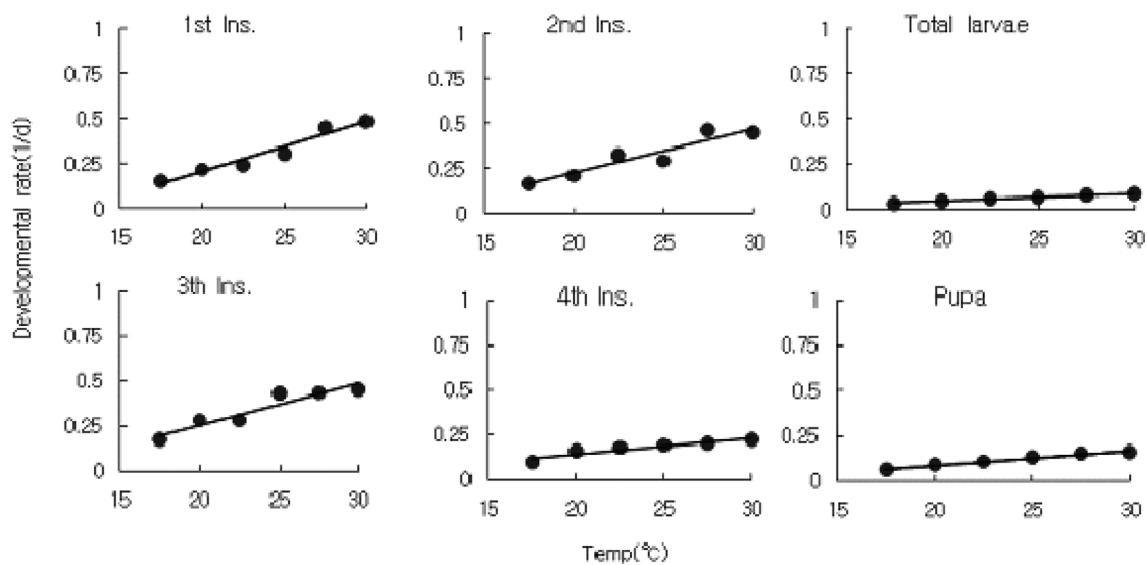
Hatching larvae of *L. dispar* subjected to different temperature (17.5, 20, 22.5, 25, 27.5 and 30°C). Sample size (n = 60)

these constant temperatures on larval developmental time is summarized in Fig. 10 and Table 3. The mean duration of development, 11.0 days, was shortest at 30°C. The

duration of each instar was greater at relatively low temperatures than at higher temperatures. Pupal weight did not differ among the temperature regimes. The developmental rate increased linearly with increasing temperature within the experimental temperature range (Fig. 11), as is generally the case in insects. The lower developmental threshold temperature was estimated to be 8.8°C, and the estimated thermal constant was 230.6 degree-days for the larvae. The pupal threshold temperature was 9.3°C, and the thermal constant was 124.8 degree-days (Table 4).

Acknowledgment

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**Fig. 11.** Developmental rate (1/d) of each growth stage of *L. dispar* at various rearing temperatures.**Table 4.** Development threshold temperatures (DT) and effective temperature (DD) for larval and pupal stages of *L. dispar*

| Developmental stage | Regression Equation ⁽¹⁾ | R ² | DT (°C) | DD (degree day) |
|------------------------|------------------------------------|----------------|---------|-----------------|
| 1 st instar | y = 0.0276x - 0.3446 | 0.95 | 12.5 | 36.8 |
| 2 nd instar | y = 0.0245x - 0.2628 | 0.89 | 10.7 | 42.5 |
| 3 rd instar | y = 0.0231x - 0.2083 | 0.89 | 9.0 | 45.6 |
| 4 th instar | y = 0.0087x - 0.028 | 0.88 | 3.2 | 118.1 |
| larva | y = 0.0044x - 0.0388 | 0.99 | 8.8 | 230.6 |
| pupa | y = 0.0081x - 0.0752 | 0.98 | 9.3 | 124.8 |

¹⁾ Y=ax+b where y is development rate and x is the temperature

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