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# Development of rusty wave (*Idaea inquinata*) at constant temperatures, relative humidities and photoperiods

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## Abstract

The development of larvae and pupae of *Idaea inquinata* (Scopoli) was studied at two different temperatures, relative humidities and photoperiods. Tests were carried out at 26 ± 1 °C and 29 ± 1 °C, 50 ± 5% RH and 70 ± 5% RH, photoperiod 16L:8D and 0L:24D. The highest mortality was observed at 29 °C, with 50 and 70% RH and 16L:8D. The larval development was longest (64 days) at 26 and 29 ± 1 °C, 50 ± 5% RH and 16L:8D, and shortest (23 days) at 29 ± 1 °C, 50 and 70 ± 5% RH, and 0L:24D. The analysis of the mean lengths of the development of larvae at different temperatures and relative humidity with the 16L:8D showed that the developmental time of larvae decreases with increasing relative humidity. This factor was significant, while the effect of the increase of temperature and the interaction between the temperature and relative humidity was not significant. At 0L:24D a decrease of the developmental time of larvae was observed when temperature was increased, both at 50 and at 70% RH. The developmental time of pupae was between 4 and 15 days, the shortest mean developmental time with a highest number of alive individuals was observed at 29 ± 1 °C, and 0L:24D, and both levels of relative humidity. The pupal developmental time showed small differences at the two relative humidities, with the exception of 26 ± 1 °C and 16L:8D at 50 ± 5 % RH where the mean development time was 10.7 days (± 1.3 SD), and at 70 ± 5 % RH with mean duration of 9.1 days (± 1.6 SD). The photoperiod influenced the length of development in *I. inquinata* as the shortest mean development periods were observed in the tests carried out with 0L:24D.

**Key words:** temperature, relative humidity, photoperiod, Lepidoptera Geometridae, *Idaea inquinata*.

## Introduction

*Idaea inquinata* (Scopoli) (Lepidoptera Geometridae) commonly known as rusty wave, is distributed over the European-Mediterranean-Macaronesian region (Skinner, 1984; Naves, 1995; Hausmann, 1997; Flamigni and Bastia, 1998; Gianti, 2001), develops on hay and several medicinal plants (Candura, 1931a; 1931b; Tempel, 1941; Kratochvil, 1948; Locatelli *et al*., 2005), and can spread with the trade of dried aromatic plants (Naves, 1995).

The biology and behaviour of this moth in warehouses in Southern Italy was described by Candura (1931a; 1931b). In this area, adults of *I. inquinata* were observed from the end of April to the end of October. *I. inquinata* showed a great ability for development on dried plants with a preference for medicinal plants. Eggs are laid on dried plants, such as medicinal plants and hay, preferring leguminous plant to grass. Larvae choose apical leaves and flowers, characterized by a higher nutritional value. Mature larvae pupate in the lower layer of the substrate, showing negative phototropism. Locatelli *et al*. (2005), in laboratory tests, observed the highest number of emerged adults on whole fruits of *Foeniculum vulgare* L., squeezed fruit of *Silybum marianum* Gaertner, flower heads of *Crataegus monogyna* Jacq., and roots of *Angelica archangelica* L., but *I. inquinata* developed also on bran, maize flour and wheat kernels, rich in fibre, proteins, lipids, mineral salts and vitamins. Medicinal plants can be heavily damaged and become unusable to essence extraction (Candura, 1931a).

The purpose of this research was to study the influence of the photoperiod at two temperatures and two relative humidities, that can be found in warehouses not conditioned during the summer. The influence was studied on the development of larvae and pupae. A more detailed knowledge of the biology is important for integrated pest management in warehouses.

## Materials and methods

### Rearing

*I. inquinata* was collected on medicinal plants in a warehouse in Milano, and reared for 5 years on an artificial diet in a thermostatic chamber at 26 ± 1 °C, 70 ± 5% RH, and a photoperiod of 16L:8D. Ingredients of the artificial diet: 30 g bran, 15 g corn flour, 15 g wheat flour, 3 g wheat germ, 2 g dried yeast, 20 g glycerine, 15 g honey.

### Development tests

The development of *I. inquinata* at different environmental conditions was studied in glass jars (diameter 3.8 cm; height 2.5 cm), closed with a gauze net to allow gaseous exchange. Eggs, 24-48 hours old, were placed in a Petri dish (diameter 6 cm) and put at the constant conditions of 26 ± 1 °C, 70 ± 5% RH and 16L:8D. Emerged first instar larvae, 12-24 hours old, were individually placed in glass jar with 0.1 g of artificial diet. More food was gradually added when necessary. Tests were carried out at four environmental conditions at each of two photoperiods, 16L:8D and 0L:24D. The conditions were 26 ± 1 °C at 50 and 70 ± 5% RH; 29 ± 1 °C at 50 and 70 ± 5% RH. The development of one hundred eggs for each test was observed.

Until adult emergence, the individuals were observed daily and mortality as well as the development stage was assessed. Developmental time data were submitted to Student's t-test and two-way ANOVA (SPSS 17.0).

## Results

The mortality of one hundred larvae of *I. inquinata* reared at different temperatures, relative humidity, and photoperiod is reported in figure 1. The highest mortality was observed at 29 °C with 50 and 70% RH and 16L:8D, while, at the same temperature and humidities, but with 0L:24D, the observed mortalities were similar to those observed at 26 °C.

Table 1 reports the mean (± SD) developmental time (days) of larvae reared at different temperature, relative humidity and photoperiod.

Larvae reared at 0L:24D developed faster than larvae reared at 16L:8D. In fact, larval development was longer (64 days) at 26 and 29 ± 1 °C, 50 ± 5% RH, 16L:8D but shorter (23 days) at 29 ± 1 °C, 50 and 70 ± 5% RH, 0L:24D. Also standard deviation values were highest at 16L:8D.

The developmental time of pupae lasted between 4 and 15 days (table 2), and the shortest mean time (days) with a higher number of surviving individuals was observed at 29 ± 1 °C, 0L:24D, and both considered levels of relative humidity. The mean development time of pupae observed with the different conditions were similar but standard deviation was higher at 29 °C and the 16L:8D with both relative humidities.

The length of postembryonic development was subdivided into classes (table 3). The durations were more widely distributed among the classes at 16L:8D, while the range was more limited and the developmental time was shorter at 0L:24D.

### Influence of the single parameters

First of all, we considered the influence on the development of the different parameters regardless of the other variables, i.e. the developmental time (days) of larvae and pupae at 29 °C, both at 50 and 70% RH and 16L:8D and 0L:24D. The effect of different temperatures, then of relative humidity, and finally of photoperiods on the postembryonic development of *I. inquinata* are shown in table 4.

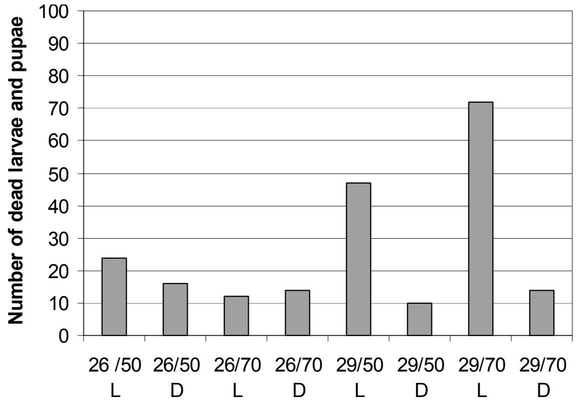


**Figure 1.** Number of larvae and pupae of *I. inquinata* dead at the different conditions of temperature, relative humidity and photoperiod. 26/50 = 26 °C/50% RH (etc.); L = 16L:8D; D = 0L:24D.

The increase of temperature, from 26 °C to 29 °C, the increase of relative humidity from 50% to 70%, and the different photoperiods, 16L:8D and 0L:24D, resulted in a significant decrease of larval and of pupal development time.

### Influence of temperature and relative humidities with two different photoperiods

Data (tables 1, 2) show an influence of the photoperiod on the length of development. The effect of temperature and relative humidity with the two photoperiods was submitted to two-way ANOVA.

#### Larvae

The developmental time of larvae at the 16L:8D significantly decreased with an increase of relative humidity but not with an increase of temperature. The interaction of the two variables was not significant (table 5). At 0L:24D the developmental time of larvae decreased when temperature was increased, both at 50 and at 70% RH (table 1). Results of two-way ANOVA showed that the influence of temperature, relative humidity and the interaction of the two factors were highly significant (table 5).

**Table 1.** Mean (± SD) developmental time (days) of *I. inquinata* larvae reared at 26 and 29 ± 1 °C, 50 and 70 ± 5% RH, 16L:8D and 0L:24D (n=sample size).

| Temperature ± 1°C | Photoperiod | 50 ± 5% RH | | | 70 ± 5% RH | | |
|---|---|---|---|---|---|---|---|
| | light:dark | n | Mean ± SD | Min-max | n | Mean ± SD | Min-max |
| 26 | 16:8 | 76 | 63.9 ± 19.4 | 31-93 | 88 | 38.6 ± 7.8 | 21-65 |
| 26 | 0:24 | 84 | 36.5 ± 6.8 | 27-57 | 86 | 33.5 ± 3.1 | 27-41 |
| 29 | 16:8 | 53 | 64.7 ± 15.6 | 34-88 | 28 | 41.8 ± 11.2 | 19-68 |
| 29 | 0:24 | 90 | 23.7 ± 3.2 | 19-36 | 86 | 23.9 ± 2.5 | 22-32 |

**Table 2.** Mean (± SD) (days) developmental times of *I. inquinata* pupae reared at 26 and 29 ± 1°C, 50 and 70 ± 5% RH, 16L:8D and 0L:24D (n=sample size).

| Temperature ± 1°C | Photoperiod | 50 ± 5% RH | | | 70 ± 5% RH | | |
|---|---|---|---|---|---|---|---|
| | light:dark | n | Mean ± SD | Min-max | n | Mean ± SD | Min-max |
| 26 | 16:8 | 76 | 10.7 ± 1.3 | 8-14 | 88 | 9.1 ± 1.6 | 4-15 |
| 26 | 0:24 | 84 | 10.1 ± 1.4 | 6-13 | 86 | 9.3 ± 1.6 | 4-14 |
| 29 | 16:8 | 53 | 10.5 ± 2.1 | 5-15 | 28 | 10.4 ± 2.2 | 5-14 |
| 29 | 0:24 | 90 | 8.6 ± 0.8 | 6-11 | 86 | 7.8 ± 1.1 | 5-10 |

**Table 3.** Frequency (%) of the length (days) of the postembryonic development of *I. inquinata* at 26 and 29 ± 1 °C, 50 and 70 ± 5% RH, 16L:8D and 0L:24D, assigned to different classes.

| Days | 26 °C | | | | 29 °C | | | |
|---|---|---|---|---|---|---|---|---|
| | 50 ± 5% RH | | 70 ± 5% RH | | 50 ± 5% RH | | 70 ± 5% RH | |
| | 16:8 | 0:24 | 16:8 | 0:24 | 16:8 | 0:24 | 16:8 | 0:24 |
| <20 | | | | | | 10 | 4 | |
| 21-30 | | 29 | 12 | 12 | | 88 | 11 | 96 |
| 31-40 | 16 | 44 | 60 | 80 | 1 | 2 | 28 | 4 |
| 41-50 | 14 | 24 | 22 | 8 | 25 | | 39 | |
| 51-60 | 18 | 3 | 2 | | 11 | | 14 | |
| 61-70 | 7 | | 4 | | 17 | | 4 | |
| 71-80 | 12 | | | | 30 | | | |
| 81-90 | 30 | | | | 15 | | | |
| >90 | 3 | | | | | | | |

**Table 4.** Mean (± SD) and Student's t-test value of the developmental time (days) of larvae and pupae of *I. inquinata* reared at 26 and 29 ± 1 °C, 50 and 70 ± 5% RH, 16L:8D and 0L:24D. (n=sample size).

| Conditions | Larvae | | | Pupae | | |
|---|---|---|---|---|---|---|
| | n | Mean ± SD | Min-max | n | Mean ± SD | Min-max |
| 26°C | 334 | 42.5 ± 15.9 | 21-93 | 334 | 9.8 ± 1.6 | 4-15 |
| 29°C | 257 | 34.2 ± 18.5 | 19-88 | 249 | 8.9 ± 1.8 | 5-15 |
| | df 505 | t-value 5.74 | P < 0.001 | df 502 | t-value 6.02 | P < 0.001 |
| 50% RH | 303 | 44.5 ± 21.5 | 19-93 | 208 | 10.4 ± 1.6 | 5-15 |
| 70% RH | 288 | 32.9 ± 8.8 | 19-68 | 285 | 8.9 ± 1.7 | 4-15 |
| | df 403 | t-value 8.58 | P < 0.001 | df 465 | t-value 10.14 | P < 0.001 |
| 16L:8D | 245 | 52.4 ± 18.9 | 19-93 | 237 | 10.1 ± 1.8 | 4-15 |
| 0L:24D | 346 | 29.3 ± 7.1 | 19-57 | 346 | 8.9 ± 1.5 | 4-14 |
| | df 293 | t-value 18.24 | P < 0.001 | df 440 | t-value7.59 | P < 0.001 |

**Table 5.** Output of two-way ANOVA for developmental times of *I. inquinata* larvae at 16L:8D and 0L:24D.

| Factor | Photoperiod 16L:8D | | | Photoperiod 0L:24D | | |
|---|---|---|---|---|---|---|
| | d.f. | F-ratio | P-value | d.f. | F-ratio | P-value |
| Temperature | 1 | 1.021 | 0.313 | 1 | 603.207 | 0.000 |
| Relative humidity | 1 | 143.430 | 0.000 | 1 | 9.296 | 0.002 |
| Interaction | 1 | 0.344 | 0.558 | 1 | 12.269 | 0.001 |
| Error | 241 | | | 342 | | |
| Total | 245 | | | 346 | | |

**Table 6.** Output of two-way ANOVA for developmental times of *I. inquinata* pupae at 16L:8D and 0L:24D.

| Factor | Photoperiod 16L:8D | | | Photoperiod 0L:24D | | |
|---|---|---|---|---|---|---|
| | d.f. | F-ratio | P-value | d.f. | F-ratio | P-value |
| Temperature | 1 | 5.744 | 0.017 | 1 | 118.388 | 0.000 |
| Relative humidity | 1 | 12.127 | 0.001 | 1 | 35.517 | 0.000 |
| Interaction | 1 | 7.100 | 0.008 | 1 | 0.094 | 0.759 |
| Error | 233 | | | 342 | | |
| Total | 237 | | | 346 | | |

P u p a e

The mean developmental time of pupae was similar at the different temperatures and levels of relative humidity (table 2) but at 29 °C standard deviation was twice the standard deviation at 26 °C. A two-way ANOVA showed that each factor effect and their interactions were significant with 16L:8D (table 6) even if relative humidity had a stronger effect than temperature. With 0L:24D the two-way ANOVA showed that each factor significantly affects the pupal time, but their interaction was not significant.

## Conclusions

Postembryonic development of *I. inquinata*, in the range of temperature, relative humidity and photoperiod studied, lasted between 20 and 90 days. Candura (1931a; 1931b) studied the development of *I. inquinata* in a warehouse in South Italy. The length of larval development, observed by this author, varied between 60 to 333 days, according to the dried plants used. In our work, however, the development was shorter probably because we used a rearing diet that contained a high quantity of nutritive ingredients.

Photoperiod influences the mortality and development time in *I. inquinata*. During postembryonic development, a higher mortality was observed at 16L:8D and 29 °C, both with 50% and 70% RH. Fields *et al*. (1990) found that larval mortality of the Geometrid *Anaitis plagiata* L. was positively correlated with light intensity. *I. inquinata* larvae penetrate the substrate and this can explain the shorter development period observed with 0L:24D.

At 16L:8D the length of larval development was significantly influenced by relative humidity but not by temperature, as both temperatures tested are suitable for development. Instead at 0L:24D the temperature showed a significant influence. There was an influence of photoperiod as temperature and relative humidity exert different effects with the two different lengths of the photoperiod.

At 0L:24D the development time was shorter at all the temperatures and relative humidity levels tested. In fact, Geometrid larvae start feeding at dusk (Gruys, 1970; Fields *et al*., 1990). At 0L:24D we observed that larvae eat more and ingest a higher quantity of nutritive substance and hence, the developmental time was shorter. Tyshchenko and Ba (1986) observed that short day regimes speeds up larval growth, while larval developmental rates were more reduced at continuous light than at 12 h day length.

Postembryonic development was shorter with a low mortality with 0L:24D at 29 °C, 50 and 70 RH. With these environmental conditions, found during summer in not conditioned warehouses, larval development is completed in 24 days. The period is shorter than the one observed on medicinal plants, as the rearing media has a higher nutritive value. Pyralid moths, important food pests, have a similar developmental period on the same rearing media (Bell, 1975).

At all conditions under study, the mean development time of pupae of *I. inquinata* lasted 8-10 days. Tyshchenko and Ba (1986) observed that the duration of the pupal stage of *Tenebrio molitor* L. (Coleoptera Tenebrionidae) does not differ significantly under different photoperiodic regimes. Pupae do not feed and this can explain the lack of influence of photoperiod.

It is important to improve the knowledge on the biology of this moth because it develops not only on medicinal plants but also on stored products (Locatelli *et al*., 2005) and has the potential of becoming a serious pest. The related species *Idaea bonifata* (Hulst) was accidentally introduced in France. There is a concern that also this species may become a serious pest (Martinez and Coutin, 1985).

With suitable environmental conditions, such as dark, high value of temperature and of relative humidity, *I. inquinata* can be an important pest in not conditioned warehouses where dried plants and cereal products are stored together. Since larvae are hidden in the substrate and adults are little active, it is more difficult to detect infestations of *I. inquinata* than of other pests.

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