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A NEW MODEL FOR ANALYSIS OF DEVELOPMENT RATES OF THE RICE WEEVIL *SITOPHILUS ORYZAE* (L.)

P. TREMATERRA, F. FONTANA AND M. MANCINI
Dipartmento di Scienze Animali, Vegetali e dell'Ambiente,
University of Molise, Via Cavour 50,
I–86100 Campobasso, Italy

ABSTRACT

A way to analyse the experimental data on the comparative developmental rates (at a fixed temperature and relative humidity) of *Sitophilus oryzae* (L.) on five cultivars of wheat (*Triticum aestivum, T. dicoccum, T. durum, T. monoccoccum* and *T. spelta*) is proposed.

A simple exponential model is proposed for the cumulative curves of the development rates. The model accounts for the evolution of a given system from a stable state (no insects at all) to another stable state (complete adult emergence). The main advantage of our approach is that no fitting parameters are required; the only parameters required can be taken directly from the experimental data. Although the model used is the same, different behaviour of *S. oryzae* is manifested according to the food supplied. This corresponds to different survival strategies depending on the food available.

In all the cases examined, the reliability of the simulated data was above the 95% confidence level.

INTRODUCTION

The time required for insect development is influenced mainly by temperature, relative humidity (r.h.), diet and crowding (or population density). For stored-product insects, extensive data on the effects of temperature on developmental times are available. This facilitates predictions of fluctuations in insect life cycles and in the population trends of insect species (Dobie, 1977; Wagner *et al.*, 1984; Hagstrum and Milliken, 1988; Hagstrum and Throne, 1989; Subramanyam and Hagstrum, 1991, 1993; Beckett *et al.*, 1994). In the present study, a way is proposed to analyse and compare experimental data on the development of *Sitophilus oryzae* (L.), at a fixed temperature and r.h., for five different wheat cultivars (*Triticum aestivum, T. dicoccum, T. durum, T. monoccoccum* and *T. spelta*).

MATERIALS AND METHODS

Insect rearing

S. oryzae adults, obtained from the wild, were reared on wheat in the laboratory at 25 ± 1°C and 65 ± 5% r.h.; the photoperiod was natural (approximately 14 h light and 10 h dark). The cereal grains used in the experiments were *Triticum aestivum*, *T. dicoccum*, *T. durum*, *T. monococcum* and *T. spelta*, all obtained from local production in the Molise region of central Italy.

Fifty *S. oryzae* adults of mixed sex and age were released in a 1,700-ml glass jar containing 250 g of grain. They were removed 15 d later. The experiment was conducted at 25 ± 1°C and 65 ± 5% r.h. The number of next-generation adults obtained from the cereal cultivars was recorded every 2–3 d.

Analytical models

Previous models. There is no doubt about the importance of a mathematical/statistical model that permits both description and simulation of individual behaviour under different experimental conditions. As a first step, the data concerning adult emergence must be analysed under firmly established environmental conditions. It is widely acknowledged in the current literature that one must start by carrying out experiments in which all the parameters except time are fixed.

Several attempts have been made during the years to describe experimental data by simple models, using either the cumulative emergence or the daily emergence curves. Both of the most statistically reliable models proposed so far are based on the combination of the exponential function with a suitable choice of fitting parameters and constants (Howe, 1966; Sharpe and De Michele, 1977; Wagner *et al.*, 1984).

Preliminary considerations. Before introducing a new model, some fundamental preliminary considerations should be clarified. Whatever model is presented, it must have as few fitting parameters as possible to ensure that the fitting curves are statistically reliable. The model and its parameters must both have a clear biological interpretation in order to avoid misleading considerations of the behaviour of the individuals described. They must not only be fittable; it must be possible to estimable these parameters, in a straightforward way, on the basis of the data sets. The introduction of dependence on the environmental parameters must be straightforward and must not change the essence of the model.

It is clear from the literature that using the daily emergence data is much more difficult and statistically less reliable than using the cumulative emergence data. Because sampling times influence the data, experimental errors more directly affect both the daily data and the estimation of the fitting parameters. Thus, it is best to restrict the analysis to the cumulative data, leaving the comparison of the model outcomes with the daily or derivated data until a later time.

The simplest way to compare the data for different species or environmental conditions is to deal only with normalised, cumulative data. The underlying assumption is that one need not consider the actual number of adults emerging during each experimental run.

Instead, one should explore the general dynamic of the biological system made up of the species being studied and the fixed environmental conditions in which it is being studied.

The number of adults emerging must in itself be considered a parameter. It is a measure of the efficiency of the interrelationships between the species under examination and the environment in which it is living.

The function $y(t)$, modeling cumulative normalised adult emergence, is characterised by two obvious boundary conditions. As time approaches zero, it becomes zero. As time increases indefinitely, it tends to unity. In simple words, a time ($t = 0$) exists before which no emergence occurs, and a time ($t = \infty$) exists at which the biological cycle of the group of insects has been completed and the maximum possible number of adults has emerged.

When comparing different experimental runs, their synchronisation deserves attention. In order to ensure the clarity of the analysis of the results, the point of first adult emergence must be the same in all experiments. Therefore, during the first days of the experimental run special attention must be paid to carefully recording the first emergence, thus obtaining the zero point of the emergence curve.

The proposed new model. The model here proposed is based on the considerations developed in the previous sections. As far as the cumulative data themselves are concerned, one function describing them is the so called "survival curve" or Boltzmann function:

$$y(t) = -\frac{1}{1 + \exp[(t - t_0)/dt]}$$

This is a well-known formula often used when there is a complex system running from one stable state (in our case, no adult emergence) to another stable state (in our case, complete adult emergence). The daily emergence curve can be obtained as the derivative of the above formula.

Two parameters appear. One (dt) represents the half-width time at the half-height time in the daily emergence curve, while the other (t_0) represents the time at which the daily emergence curve reaches its maximum. Thus, both parameters can be estimated directly from the experimental data. As a consequence, the above expressions are more than fitting curves; they are models with "no free parameters" (Trematerra *et al.*, 1996).

RESULTS

The emergence of *S. oryzae* developing on five different wheat cultivars was analysed in order to validate the above model. Daily emergence (obtained from the experimental data collected as per the test procedure described above) was processed to give cumulative emergences. In all the cases analysed the chi^2 test indicated that the confidence level of the model was over 95%.

The curves obtained from the different sets of data are compared in Fig. 1 to show the actual differences in cumulative emergence for the different culture media. It can be seen

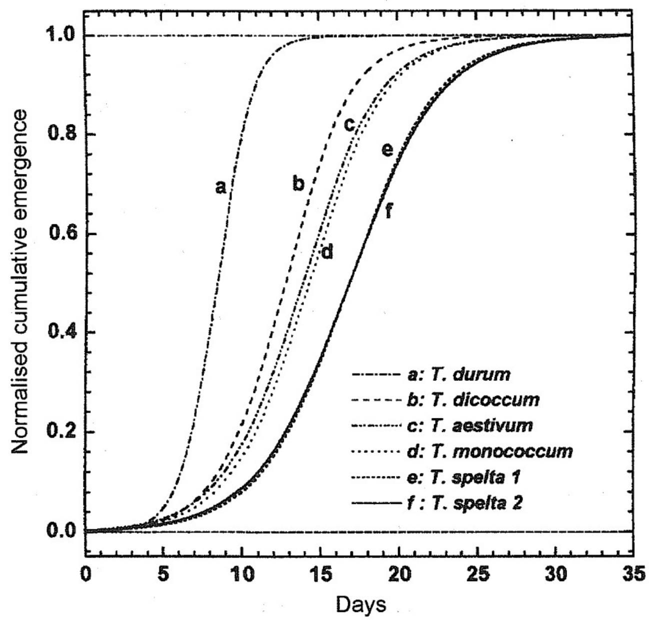

Fig. 1. The normalised cumulative emergence curves for all the experimental cultivars.

that the population dynamics of *S. oryzae* developing on the five wheat cultivars is described by only two parameters.

In some cases, maximum emergence of adults occurs within only a few days, whereas in other cases a long time period is required. In Fig. 2 the actual data (the non-normalised curves) are shown. These curves indicate both the rate and the number of adult progeny emerging during the experiment. Analysis of these curves provides information about the developmental efficiency of the given species for each of the different cereals used.

DISCUSSION

Even though the model presented is quite simple and restricted in the number of parameters, two main features deserve special attention. The model parameters can be estimated by observation of the experimental daily emergence curve because they represent the abscissa at which the maximum occurs and the half-width of the bell-shaped curve itself. Despite the reduced number of parameters, the data from all the culture conditions are fitted at the same level of statistical accuracy, revealing significant differences in development of the *S. oryzae* cultures depending upon the cereal used.

In Fig. 2 it is possible to compare the actual, non-normalised data. This shows that *T. monococcum* and *T. spelta* are the most favourable and *T. durum* and *T. dicoccum* the least favourable hosts in terms of total daily emergence.

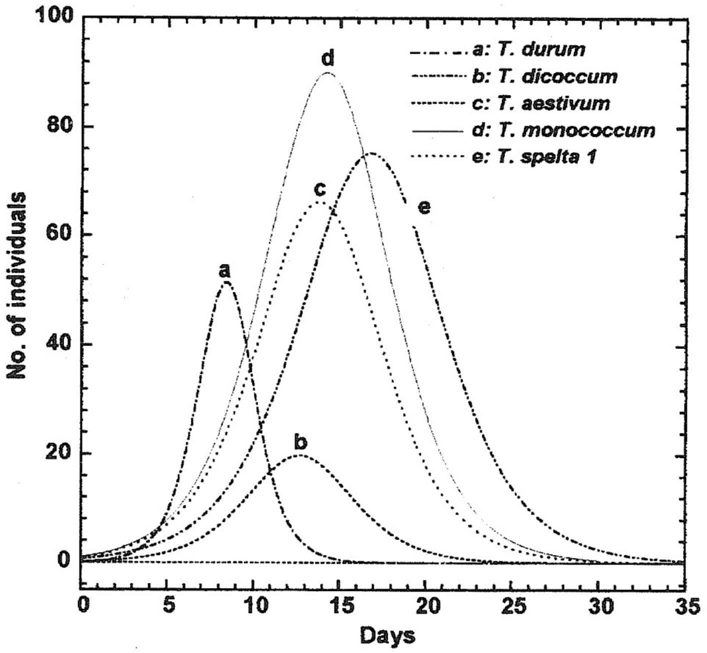

Fig. 2. The actual daily emergence curves for all the experimental cultivars.

The model is of interest in that it illustrates in a simple way, and using only two simple parameters, the inter-dependence between daily emergence of the insect pest and the kind of cereal. Accordingly, it should be possible to analyse the dependence of emergence curve on such other parameters as temperature and humidity.

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