TEMPERATURE RESPONSE OF FUNGI AS A STRAIGHT LINE TRANSFORMATION

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(WITH THREE FIGURES)

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The extensive data on the relation of temperature to plant pathogens (15) and other forms of life are largely empirical. When plotted on arithmetic scales, with temperature as the abscissa and growth as the ordinate, the growth data of many if not all organisms yield a modal type of curve skewed to the right (fig. 1). With data of this type it is difficult to express these temperature relations briefly or to compare one organism with another.

This situation is somewhat similar to that which prevailed in toxicological studies through 1933. The responses of many organisms to known dosages of toxins under standardized conditions had been fairly accurately determined, but these responses could be adequately expressed only by giving the entire mortality data over the dosage series. Then in 1934 BLISS (1) showed that mortality data could be expressed as a straight line when

the toxin dosage was plotted on a logarithmic scale against the mortality response on a probit scale. This relation has since been shown to apply to most organisms and toxins which have been studied. When either the LD 95 (or any other LD value) and the slope of the straight line, or two independent LD values are known, an entire set of expected toxicity data for an organism which fits this relation may be derived by interpolation and extrapolation.

The present paper is an initial empirical exploration of the possibility that what has been done to simplify toxicological data may similarly be
done with temperature data, though it is realized that the fundamentals of the two problems are different.

If it is assumed, as shown in figure 1, that temperature-growth response curves for the fungi are basically of the same type, that is, modal and skewed to the right, then their geometric conversion to a straight line relation is readily accomplished. An average curve (fig. 2) may be constructed by averaging horizontally at arbitrary ordinate values the data for the left

![Diagram](https://via.placeholder.com/150)

**Fig. 2.** Straight line geometric transformation of average temperature-growth response curve based on data as plotted in figure 1, in addition to data for two strains of *Corticium vagum* (12), two of *Fusarium oxysporum* (8), *Penicillium italicum* (14), *Polyporus vaporarius* (6), another strain of *Pythium debaryanum* (2), and another strain of *Verticillium albo-atrum* (5).

and right hand arms, respectively, of 16 temperature-growth response curves including those shown in figure 1. A straight line is then drawn from the average minimum temperature point (5.0° C, 0%) through the average optimum point (26.8° C, 100%) of the curve and on to its intersection with a vertical erected at the average maximum temperature point (36.2° C, 0%) on the curve.

A new non-linear scale for per cent. of the growth at the optimum is then derived by projecting a series of verticals from points on the curve to points
on the straight line diagonal, and from these intersections a corresponding series of horizontals to their intersection with the right hand ordinate. These last-mentioned intersections are then numbered to correspond with the left hand ordinate values of the points on the curve from which they were respectively derived. In this way the entire growth scale for the temperature range is transformed from an arithmetic scale in which the points above the optimum temperature overlap those below the optimum temperature to one where the points above the optimum temperature are extended beyond the growth at the optimum temperature.

Since the straight line diagonal covers the whole average temperature range for growth, the temperature-growth response relationship of various organisms can, by means of the empirically derived ordinate scale, be represented by straight line diagonals passing through correspondingly various optimum temperature points with correspondingly various slopes (various temperature ranges).

Temperature-response data plotted for some of the organisms shown in figure 1, in addition to that for a few others, are plotted on the transformed growth scale as figure 3, the points for zero growth being omitted here.

The advantages of the transformed scale should be apparent. The minimum and maximum temperatures stand out as the upper and lower limits of the graph, and the optimum is clearly defined for each organism. Differences between organisms with respect to minimum, optimum, or maximum temperature or temperature range are clearly apparent. More curves can be arranged in the same space without confusion. Inaccuracies or inconsistencies in collected data are more apparent. If this scale or some similar scale is shown to be applicable to all or most organisms, then it might be possible in new studies to determine experimentally only two points (e.g.,

![Figure 3](www.plantphysiol.org)

**Fig. 3.** Extrapolated straight line curves fitted to plotted temperature-growth response data for *Alternaria solani* (10), *Gibberella saubinetti* (4), *Herpotrichia niger* (7), *Schizophyllum commune* (6), *Septoria apii* (3), *Venturia inaequalis* (11), and *Verticillium albo-atrum* (5). Original zero growth values are omitted.
minimum and maximum temperature, or minimum and optimum temperature) and to derive all other values from a graph with a reasonable degree of accuracy.

Two basic weaknesses in the method should be pointed out. First it may be questioned whether the conventional colony diameter measurements of growth as used here represent the true growth, and it may be that if temperature-growth responses were based on dry weight of plant substance, a different curve would result. Not enough temperature-growth responses based on dry weight are available to determine whether the shape of these curves is different from temperature-growth responses based on linear growth. Secondly, most of the data used in this paper were secured in Petri dishes. If this type of container gives a distorted type of temperature-growth curve due to staling and other effects, the transposed straight line scale is correspondingly incorrect. Data for Neurospora crassa (13) might indicate that if fungus growth were measured in long growth tubes the temperature-growth curve would consist essentially of a straight line ascending to and another descending from the optimum temperature. Not enough temperature-growth data secured from such tubes is available to determine whether this principle applies to most organisms. If these weaknesses prove valid, the empirical scale derived here can be readily corrected to meet these inherent errors.

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