

THE GROWTH AND DURATION OF LIFE OF CELOSIA CRISTATA SEEDLINGS AT DIFFERENT TEMPERATURES

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Papers on the temperature relations of seedlings grown in darkness at several constant temperatures may be classified according to the length of the growing period during which measurements were made. Sierp (18), Silberschmidt (19), and Hamada (7) measured the lengths of oat coleoptiles throughout the grand period of growth, obtaining much the same results, although it is to be noted that arithmetical errors in Sierp's table (18, p. 442) apparently led him to erroneous conclusions as to the position of the optimal temperature. Silberschmidt (19) carried out experiments on pea and rice seedlings also; his data and his discussion are the most important recent contribution to this subject. Rudolfs (16) made similar measurements on bean seedlings but unfortunately he did not publish his numerical results. Pearl, Edwards, and Miner (14) reported the results of such tests on *Cucumis melo* seedlings. The data to be presented in this paper fall in the same category. In all these experiments the plotted growth data for each constant temperature fall along S-shaped curves of the logistic type. Both the final heights of the seedlings and the duration of growth, and consequently the time rate of growth, are influenced by temperature. Usually the temperature that induces the most rapid growth at first is somewhat higher than the one which finally yields the tallest seedlings.

Two important experiments extended over only a part of the growth cycle. Lehenbauer's (10) measurements of the growth of maize seedlings were made at nearly thirty constant temperatures and his data were the first to show a change in the optimal temperature as growth progressed. Unlike Lehenbauer's data, which showed an increase in the optimal temperature with time, Talma's (20) experi-

ments on *Lepidium sativum* roots showed a decrease in the optimal temperature with time.

Measurements confined to the first stages of seedling growth were reported by Sachs (17) in 1860 and as a result of his work the papers of de Vries (22), Koeppen (9), and Haberlandt (6) appeared within a few years. All used seedlings of crop plants. Much later Newcombe (12) carried out experiments on the seedlings of fifteen species, mostly cultivated grasses and cereal crop plants. So far as they go, his data for *Lepidium sativum* confirm Talma's work. Leitch (11) and Cerighelli (2) presented data on the temperature relations of pea seedlings; Gericke (4) made tests on the early growth of wheat seedlings, and Fawcett's (3) tests on citrus seedlings belong in this class. Vogt (21) made measurements on the final length of oat coleoptiles grown in darkness at a number of constant temperatures and found an unusually low optimal temperature (12.8°C).

In the later work in this field less attention is paid to the temperature optimum¹ than formerly, principally because it is alleged to change as growth progresses. Sierp (18) and Silberschmidt (19) centered their attention principally on the grand period of growth and more than their predecessors regarded the series of constant temperatures they tested as a convenient means for creating a graded series of environments in which seedling growth could be studied, and this is the treatment to be followed here.

Material and Methods

Celosia cristata is a member of the Amaranthaceae extensively grown in flower gardens under the name of cockscomb. When grown on agar in darkness, as in these experiments, the seedlings develop a primary root which penetrates the agar to a depth of 2–3 cm. and which forms no lateral roots. The hypocotyl is curved at the upper end so that the cotyledon hangs downward for the first few days of growth and then it straightens, so that by the time growth has ceased the long, narrow, and reddish yellow cotyledons point upwards. The epicotyl does not develop under these conditions. The length of the hypocotyl seems to be a satisfactory measure of growth; the hypocotyl is cylindrical,

¹ For a discussion of the sense in which optimum temperature for growth is used in our work in this laboratory, including the present paper, see Pearl, Edwards, and Miner (14).

and since there is very little increase in the diameter of the organ this measurement also may be regarded as proportional to the volume of tissue produced, and may be taken as an index of growth *yield*. The only organ competing with the hypocotyl for the food stored in the cotyledons is the primary root; this runs through a grand cycle of growth just as does the hypocotyl and terminates its growth a little earlier.

The technique used in these experiments was, in general, that which has become standard in many years of seedling work in this laboratory (see Pearl (13), and earlier papers there cited, and also Gould, Pearl, Edwards, and Miner (5)).

Seeds of about the same size were sorted into lots of 22, having a combined weight of about 0.0195 gm., each lot being used for the experiments at one constant temperature. After being soaked in 1:1000 HgCl₂ solution the seeds were rinsed once and soaked for 3 hours in sterile distilled water. For germination and growth they were transferred to individual culture tubes 15 cm. long and about 1.6 cm. in internal diameter and distributed among constant temperature cases maintaining six temperatures between 14.5° and 40.5°C. The tubes were kept in darkness and the hypocotyl length was measured daily in red light.

After the rate of elongation had fallen below an average rate of about 0.1 mm. per day measurements were discontinued but the seedlings were kept at the same temperatures and observed regularly to ascertain the beginning of death of the hypocotyl of each seedling. The first visible signs of death of the hypocotyl were the appearance of a translucent zone or the shrinkage of the upper portion. In some specimens the cotyledons shrunk before the hypocotyls showed any morbid symptoms. At 40° blackening of the seedlings occurred at death and the symptoms in general differed from those of the other cultures so that the recorded data are not quite comparable in this one respect.

RESULTS

Growth

Table I shows the mean lengths of *Celosia* hypocotyls for various intervals after planting at the six constant temperatures tested. The cultures exposed at 14.5°, 20°, 30°, and 40.5° were first examined 12

hours after planting and at 24 hour intervals thereafter. The 25° and 35° cultures were first examined 18 hours after the seeds were placed in the culture tubes and subsequently at 24 hour intervals. Observations were also made 24 hours after planting at 30° and 35°. Besides the main series of tests which was begun in January, 1933,

TABLE I
Mean Heights of Celosia cristata Seedlings at Different Intervals after Planting

Interval after planting	Temperature				Interval after planting	1933 data	1930 data	1933 data	1930 data
	14.5°	20°	30°	40.5°		25°		35°	
days	mm.	mm.	mm.	mm.	days	mm.	mm.	mm.	mm.
1.0	—	—	0.9	—	1.00	—	—	2.0	—
1.5	—	—	3.0	1.5	1.75	1.1	1.1	5.2	5.4
2.5	—	—	11.4	6.2	2.75	6.1	5.7	16.4	11.6
3.5	—	—	21.9	10.1	3.75	13.4	13.7	26.5	25.2
4.5	—	1.3	29.7	11.7	4.75	20.2	21.1	31.5	30.3
5.5	—	4.0	34.0	12.3	5.75	26.0	24.8	33.5	31.9
6.5	—	8.4	35.7	12.7	6.75	29.1	26.5	34.1	32.5
7.5	—	12.8	36.2	—	7.75	30.7	27.1	—	32.7
8.5	0.7	17.0	36.3	—	8.75	31.6	27.7	—	—
9.5	1.7	20.8	—	—	9.75	31.7	—	—	—
10.5	2.6	23.0	—	—	—	—	—	—	—
11.5	3.7	24.6	—	—	—	—	—	—	—
12.5	5.6	26.2	—	—	—	—	—	—	—
13.5	7.3	26.8	—	—	—	—	—	—	—
14.5	9.4	27.4	—	—	—	—	—	—	—
15.5	11.3	27.7	—	—	—	—	—	—	—
16.5	13.9	—	—	—	—	—	—	—	—
17.5	15.3	—	—	—	—	—	—	—	—
18.5	17.0	—	—	—	—	—	—	—	—
19.5	17.7	28.3	—	—	—	—	—	—	—
20.5	18.7	—	—	—	—	—	—	—	—
21.5	19.3	—	—	—	—	—	—	—	—
22.5	19.9	—	—	—	—	—	—	—	—
23.5	20.0	—	—	—	—	—	—	—	—

two temperatures, 25° and 35°, were tested in the spring of 1930; these data are presented in Table I for comparison with the other series but they were not used in the preparation of the graphs. These two sets of data for these temperatures appear to show satisfactory

agreement considering that commercial seed produced in different seasons were used in the two series of tests.

Fig. 1 shows the growth curves that result when these data are plotted, and brings out the considerable differences in height and growth rate associated with different temperatures. For a considerable part of the growth period the seedlings cultured at 35° were taller than at any other temperature and it was not until comparatively late in the growth cycle that they were surpassed by the 30° seedlings. At 25° growth was slower and the final height was a little less than

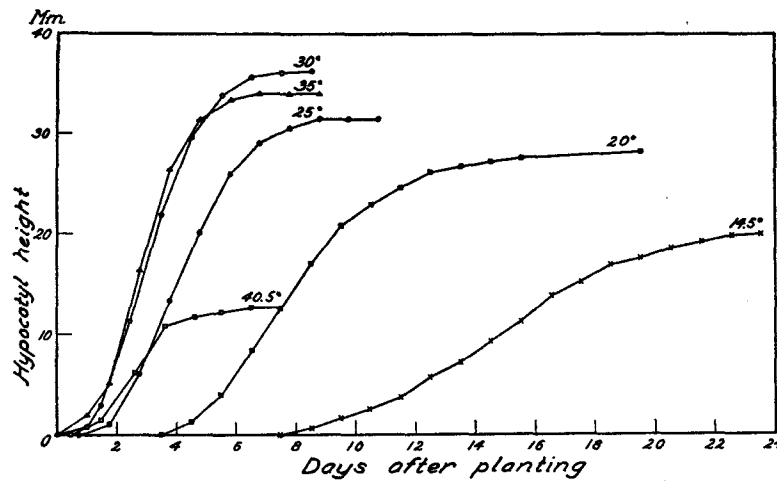


FIG. 1. Growth curve of *Celosia cristata* hypocotyls grown in darkness at six constant temperatures.

at 35°. At 20° the beginning of measurable elongation was delayed and both growth rate and final height were less than at 25°. There is a much longer latent period before growth commences at 14.5° and growth rate and final height are still less. The irregularities of the 14.5° curve are probably due to difficulties of measurement; the curvature of the agar surface tended to conceal the base of the hypocotyl.

In these respects the behavior of *Celosia* is very similar to that of *Cucumis melo* seedlings grown at these temperatures with the same treatment (14).

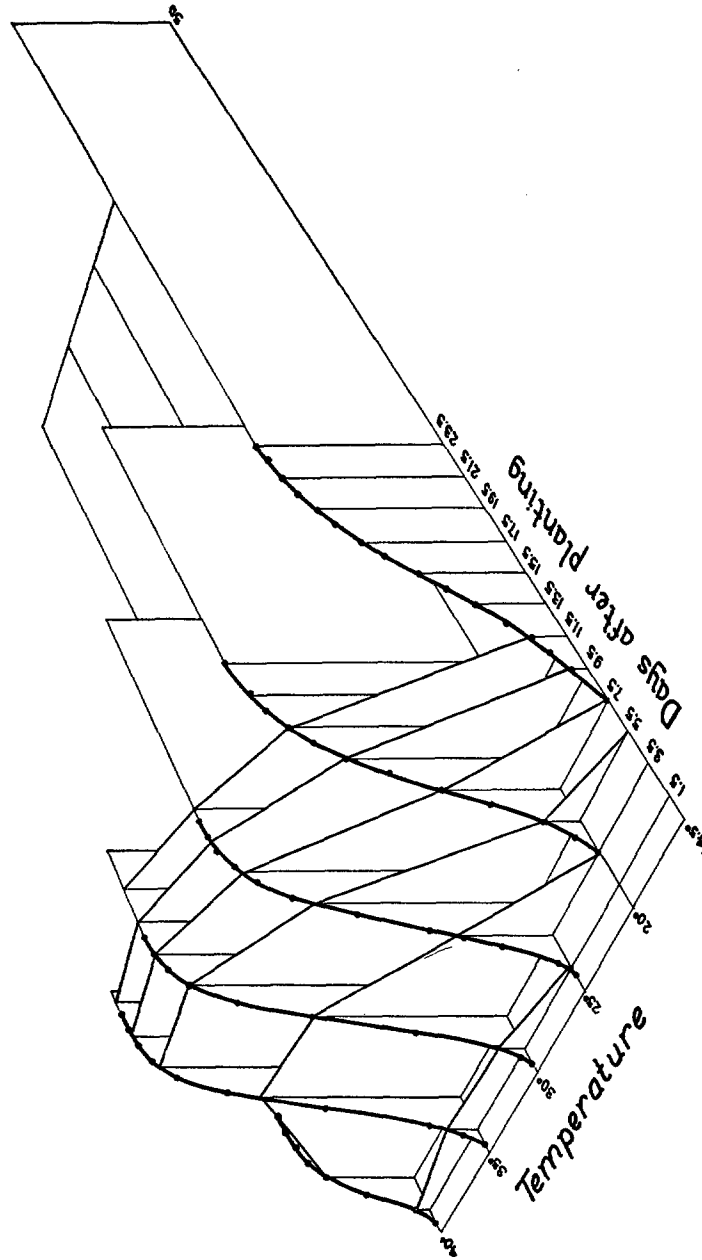


FIG. 2. Three dimensional diagram showing the growth and duration of life of *Celosia cristata* hypocotyls at six constant temperatures. Dots indicate observed heights of hypocotyls.

At 40.5° growth abnormalities were observed; many hypocotyls were bent or twisted and some underwent very little elongation, and the roots, for the most part, either lay on the surface of the agar or penetrated it so shallowly that they provided very little anchorage. Six of the seeds were planted near enough the wall of the tube so that the hypocotyl could obtain mechanical support by resting against the wall and these six were used for growth measurements. It should be emphasized that the appearance of the measured hypocotyls, and of the ones which were so coiled that measurement was impossible, was not greatly different from that of seedlings grown at lower temperatures, apart from their shortness. It appears that the hypocotyls were able to elongate, although at a very low rate compared with the 35° cultures, and to grow upward from whatever position in which they found themselves, but the failure of the roots to function properly left the hypocotyls without any anchorage. Any normal geotropic response of the hypocotyl would alter the center of gravity of the seedling making it fall into another position from which another geotropic response could be made only by altering the direction of growth.

The three dimensional diagram shown in Fig. 2 has been constructed from the data of Table I according to the same plan, and by the same methods, as the corresponding diagram in our *Cucumis* paper (14) except that in the present case the part of the curve which approaches the upper asymptote has been extended to show the total duration of life (Table II).

An inspection of the transverse planes of the diagram, which connect culture periods of the same duration, reveals a gradual apparent shift of the temperature at which growth is temporarily going on at the most rapid rate, from 35° at the beginning of growth to 30° by the time growth ceased. In other words, after a high initial growth rate the 35° seedlings elongated more slowly than the 30° ones. This will appear more clearly as the data are analyzed quantitatively. The same sort of shift of the growth rate with temperature as growth progresses has been found by Lehenbauer (10), Talma (20), Silberschmidt (19), and Pearl, Edwards, and Miner (14).

Having seen graphically the general course of events in the experiments we may now proceed to their analysis along the same lines as were followed in our study of *Cucumis melo* seedlings. If the total

average growth rate at each temperature is computed by dividing the mean total yield (length of hypocotyl) by the time from planting to cessation of growth, it is found that in *Celosia*, just as in *Cucumis*, the relation between temperature and time rate of growth is parabolic over the observed range of these experiments.

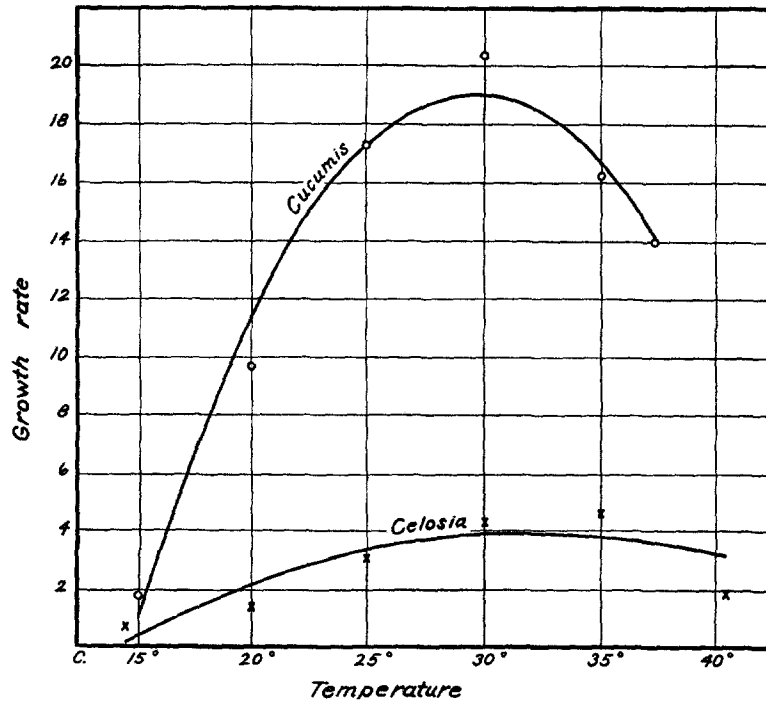


FIG. 3. The relation between temperature and mean total growth rate in the seedlings of (a) *Celosia cristata*, and (b) *Cucumis melo*. The observations are given by crosses in the case of *Celosia* and by circles in the case of *Cucumis*. The smooth curves are the graphs of the respective parabolas, fitted by least squares.

Fitting by least squares, the equation is

$$R = 0.898 T - 0.015T^2 - 9.689, \quad (i)$$

where R denotes mean total growth rate, and T temperature in Centigrade degrees.

In Fig. 3 this curve is plotted against the observations, and it is apparent that it describes the relations with reasonable accuracy, when

the relatively small magnitude of the observational material is taken into account. For the sake of comparison the corresponding curve from our *Cucumis melo* study is plotted on the same diagram.

It is seen from Fig. 3 that while these two species follow the same general rule as regards the relation of growth to temperature under the specified experimental conditions, in that the mean total growth rate is lower as the temperature departs from the optimum in either direction, there is in one respect a striking difference between the two species. *Celosia cristata* seedlings are much less sensitive to a differential influence of temperature upon growth than are *Cucumis melo* seedlings. The *Celosia* curve is much flatter. In the case of *Cucumis* the mean total growth rate at the observed optimum temperature (30°) is roughly ten times as great as it is at 15°. On the other hand, in the case of *Celosia* the mean total growth rate at the observed optimum temperature (30°) is only about five times as great as at 15°, and even less at the probably true optimum temperature (from the fitted curve). In other words, *Celosia* seedlings are much less thermolabile than *Cucumis* seedlings.

While from the gross observations it would appear that the optimum temperature for growth rate was higher for *Celosia* than for *Cucumis*, actually if the differential coefficient for equation (i) is put equal to zero the result is

$$\frac{dR}{dT} = 0.89752 - 0.029444 T = 0, \quad (\text{ii})$$

and

$$T_{\text{opt.}} = 30.48^\circ$$

This value is thus close to that reported in our *Cucumis* study (14), which was 29.74°.

The above analysis of the quantitative relations between temperature and growth follows the same lines as that of our *Cucumis melo* study (14). In the present case, as in that, we tried different postulates as to a single numerical measure of mean growth rate in a given temperature, and as to the separation of visible, measured growth of hypocotyl from the processes of germination. But in *Celosia*, just as in *Cucumis*, it was found that no difference in the essential results or conclusions resulted. For a detailed discussion of this matter the

reader is referred to the *Cucumis* paper (14). There seems no point in repeating it here.

It has been noted above that in these experiments temperature appears to affect growth differently in different parts of the cycle. The observations on the point are given more precisely in Table II. The first set of percentages, given in the left half of Table II, state the approximate percentage of the final mean total yield (hypocotyl length) at each temperature which the plants in that temperature series have achieved at the end of the first quarter, the first half, and the first three-quarters of their own respective total growth periods. Thus at the end of the first half of their growth period the 14.5° plants had made 20.9 per cent of their total yield. The second set of

TABLE II
Approximate Relative Hypocotyl Lengths at Stated Relative Times, and in Proportion to 30° Hypocotyl Lengths at the Same Relative Times

Percentages of total growth period	Percentages of own total growth						Percentages of own growth to 30° growth at same relative times					
	14.5°	20°	25°*	30°	35°*	40.5°	14.5°	20°	25°*	30°	35°*	40.5°
25	0	8.2	14.3	22.7	19.4	16.4	0	28.0	55.0	100	44.2	25.3
50	20.9	75.4	66.0	76.4	66.6	71.9	15.0	76.9	75.4	100	81.8	32.9
75	77.6	96.9	94.6	97.8	94.2	93.9	43.7	77.3	84.5	100	90.5	33.6
100	100	100	100	100	100	100	55.1	78.0	87.3	100	93.9	35.0

* 1933 data.

figures, in the right half of Table II, shows the approximate percentage which the achieved yield in each temperature series was of the yield in the 30° series (30° being the observed optimum temperature for total yield) in one-quarter, one-half, and three-quarters of the total growth period. Thus it appears that the 20° plants at the end of half their growth period had produced only 76.9 per cent as much yield as the 30° plants in the first half of their cycle. The percentages in Table II are approximate because, in interpolating times and yields, we have assumed that growth proceeded at a constant rate between any two recorded observations in Table I. This is not strictly true, but the error is negligible for present purposes. In the computations germination, in respect of time, is counted as a part of growth.

From Table II the following points may be noted.

1. The seedlings in these experiments did not in any case attain as much as 25 per cent of their total growth in the first quarter of their total growth period. Those in the 30° series came nearest to it.

2. When a half of the growing period had been completed the seedlings in all of the temperature series except at 14.5° had achieved 2/3 or more of their final total yields. At the end of the first three quarters of their total growth periods all of the seedlings had achieved more than 75 per cent of their total yields, and all of them except in the 14.5° series well over 90 per cent of the final total yields.

3. In *Celosia cristata*, under the conditions of these experiments, just as we have shown (14) to be the case in *Cucumis melo*, the greatest growth activity was concentrated in the second quarter of the growth cycle, except at the lowest (14.5°) temperature where the greatest growth per unit of time occurred in the third quarter of the cycle.

4. Except in the 14.5° series the amount of growth activity displayed in the fourth (final) quarter of the cycle was extremely small.

5. At all other temperatures tested, and at all parts of the growth cycle, the yield at any given comparable point in the cycle was less than that in the 30° series at the corresponding time. In other words, while, as has already been pointed out, maximum growth activity may occur at different parts of the cycle in different temperatures, the greatest growth of *Celosia cristata* seedlings as measured by yield occurs at 30°, not only in the cycle as a whole, but also in each of its equivalent parts, on a relative time scale. In the face of this fact it would seem to be an error, based upon insufficiently penetrating analysis, to speak of the optimal temperature shifting about during different parts of the cycle, at least in this case. The point in the matter, which is essential and appears to have been sometimes overlooked, is that biologically equivalent points in the growth cycle (and indeed in the life cycle generally) cannot be correctly apprehended or determined in terms solely of absolute (chronological) time units, but require some sort of relative time scale. Essentially the same point is involved in discussions of "physiological" versus "chronological" age.

6. *Celosia cristata* seedlings, under the conditions of the experiments, are generally speaking relatively more rapid growers in the first quarter of the cycle at all temperatures than *Cucumis melo* seedlings.

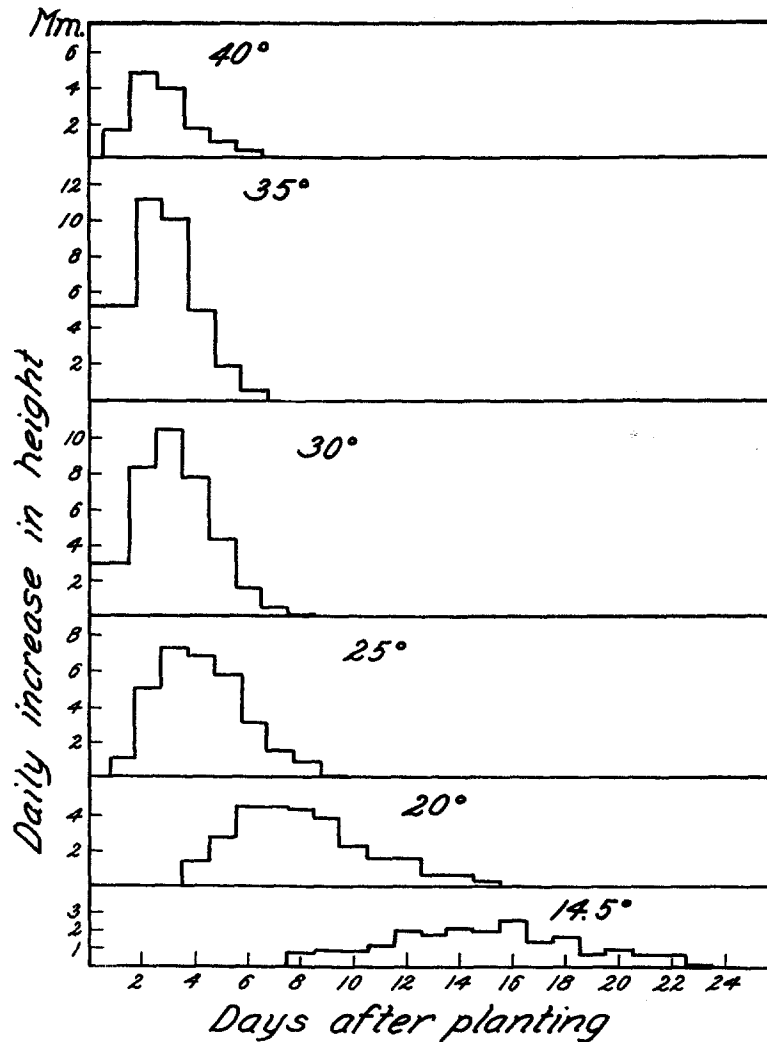


FIG. 4. Increases in height of *Celosia* hypocotyls during 24 hour periods. For 14.5°, however, 48 hour increments were used.

The points just discussed may be looked at in another way by examining the absolute growth increments in absolute (chronological) time in the several series. These are shown graphically in Fig. 4.

As one examines the graphs of the growth increments in turn, begin-

ning with 14.5°, it is seen that there is a tendency for the period of most active elongation to come progressively earlier in chronological time units as higher temperatures are examined until 40.5° is reached where there is a delay, compared with 35°. This statement is true in two senses: (1) If one measures the time of occurrence of the peak of these graphs in terms of days after the time of planting, this relationship stands out clearly, and it is, in fact, the kind of relationship which would be expected on the basis of other work on the temperature relations of biological processes. (2) If the graphs are examined one by one to find when the period of most active elongation fell in relation to the whole growth period a similar kind of trend is encountered. At the lowest temperature the greatest growth rate came relatively late in the growth cycle, at 20° it came a little before the middle point of the period in which measurable growth occurred, and each higher temperature had the effect of inducing a larger and larger proportion of the total growth to occur during the first few days of growth. But in another way, there is a regular change in symmetry as one examines the graphs in turn. Both kinds of relationship have also been observed in *Cucumis melo* seedlings (14).

Fig. 3 shows nothing different from, or additional to, what is brought out in precise numerical terms in Table II. But inasmuch as the analysis of growth in terms of relative time given in Table II and the discussion following it is, so far as we are aware, novel, it has seemed to us advisable to insert Fig. 4 in order to exhibit the results in a form accordant with the conventional procedure in work upon growth in seedlings.

Duration of Life

In considering the durations of life of these seedlings, which are represented in Fig. 2 as extensions of the sigmoid growth curves, the experimental conditions need to be kept in mind. Since the seedlings were grown under aseptic conditions throughout, death was due to failure of the plant to be able to get further food material from the cotyledons, and not because of microbial attack. The only materials that were supplied to the plant during its lifetime were air, distilled water, and agar, and agar has been shown by earlier unpublished work not to be a source of food in sufficient amount to be either physically

or chemically detectable or measurable. Since the seedlings were kept in darkness (except for brief exposure to red light during measurement) no chlorophyll developed and photosynthesis was impossible. Thus the seedlings were entirely dependent upon the food reserves laid down in the cotyledons and embryo, and since the same weight of seeds of a uniform size was used for each culture the six lots of seedlings began on an equal basis. Their durations of life, however, were quite different, as Fig. 2 and Table III show; the seedlings grown at 14.5°, for instance, lived five times as long as those grown at 35°, and disregarding for a moment the 40.5° cultures, the duration of life was inversely proportional to the temperature. Furthermore the data

TABLE III
Final Heights and Durations of Growth and of Life of Celosia cristata Seedlings at Various Temperatures

	Temperature							
	14.5°	20°	25°		30°	35°		40.5°
			1933 data	1930 data		1933 data	1930 data	
Final hypocotyl height, <i>mm</i>	20.0 ±0.5	28.3 ±0.9	31.7 ±0.6	27.7 ±1.3	36.3 ±0.6	34.7 ±0.9	32.5 ±0.7	12.7
Duration of growth, <i>days</i>	23.5	19.5	9.75	8.75	8.5	6.75	7.75	7.75
Duration of intermediate period, <i>days</i>	26.6	13.5	13.4	15.7	5.4	5	3.9	5.7
Duration of life (total), <i>days</i>	50.1	33.0	23.15	24.45	13.9	11.75	11.65	13.45
No. of seedlings	14	18	19	15	20	17	19	6

show that the intermediate period of the life cycle of these seedlings (period from end of growth to beginning of death) is lengthened in temperatures below the growth optimum and shortened in temperatures above the growth optimum. In other words the optimal temperature for duration of life in these experiments was the minimum temperature, within the range of observations. These observations are definitely and significantly confirmatory of the "rate of living" (13) theory of life duration. The rate of living, as manifested by rate of growth for example, is influenced by temperature, as inorganic chemical reactions are, and in consequence the time duration of life is altered in an orderly manner. When the time rate of growth is more rapid not only is the

period of growth shortened, *but so also is the duration of the intermediate period after growth has ceased, and the total duration of life.*

The inverse relation between growth rate and life duration described in the preceding paragraph is shown quantitatively in Table IV and Fig. 5. It is obvious that what we have called the "intermediate" period—that is the time from the end of growth to the beginning of death—is the crucial element in total life duration, from the theoretical point of view. Naturally if the growth period is lengthened, with consequently lowered growth rate, as in the low temperatures, that fact will of itself tend to lengthen total duration of life, which is the sum of growth period + intermediate period. Con-

TABLE IV
Relative Magnitudes at Different Temperatures of Mean Total Growth Rate and the Duration of Various Portions of the Life Cycle in Celosia cristata Seedlings

Temperature	Relative observed growth rate	Relative duration of intermediate period	Relative duration of growth period	Relative total longevity
°C.	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
14.5	26.5	198.5	241.0	216.4
20	45.2	100.7	200.0	142.5
25	100	100	100	100
30	133.0	40.3	87.2	60.0
35	143.6	37.3	69.2	50.8
40.5	60.7	42.5	79.5	58.3

sequently we shall deal separately with duration of intermediate period and total longevity.

In Table IV the performance of the seedlings at 25° in respect of (a) mean total growth rate, (b) duration of intermediate period, (c) duration of growth period, and (d) total longevity, is taken as 100 per cent for each variable and the relative (percentage) values on this basis at each of the other temperatures tested are then set down.

It is evident that both total duration of life and the duration of the crucially important intermediate period, exhibit an inverse relation to the rate of growth. From 15° to 35° inclusive, where the mean total growth rate is increasing with rising temperature, total longevity and duration of the intermediate period decline. At 40.5° where the total growth rate falls, the durations rise. The rise at this high tem-

perature is not, however, in either case anything like proportional to the relative decline in the growth rate, and too much stress should not be laid upon it, particularly in view of the abnormal character of the growth and the dying at this temperature. At 35° and temperatures below, the inverse proportionality between growth rate and duration of life is more precisely and regularly maintained. By slowing the growth rate to roughly a quarter of its value at 25° the total duration of life is about doubled.

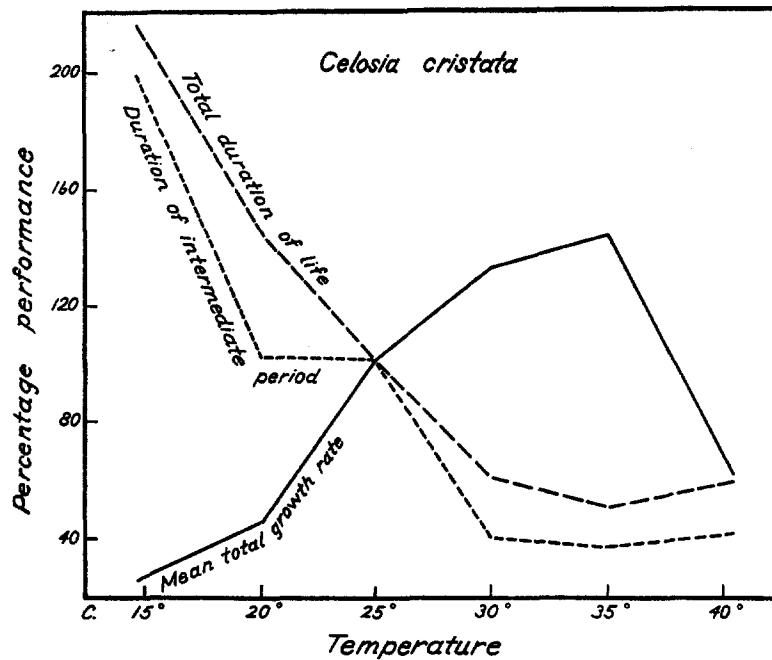


FIG. 5. Showing the inverse relation between mean total rate of growth and total duration of life, and duration of intermediate period of the life cycle.

In 1916 Rahn (15) sought to extend the reasoning of Blackman (1) and of Jost (8) and to account for limitations of size and duration of life on a chemical basis. He assumed: (1) The quantity of material capable of being transformed by a given quantity of enzyme is definitely limited, and this limits the quantity of material which an organism can metabolize during its lifetime. (2) Each enzyme is the product of a chain of reactions, whose links may have different tem-

perature coefficients. Thus according to the temperature at which an organism is grown it may have a large or a small quantity of enzyme at its disposal, and may have a large or a small final size, or a long or a short duration of life. Rahn was careful to state that his speculation was “*ganz unbeweisbar*,” and it does not seem to be particularly helpful in the consideration of the present data.

A complete and precise quantitative analysis of the inverse relationship between rate of growth and subsequent duration of life (and also total duration of life) in these seedlings would require more extensive data, and far finer temperature divisions than the present experiments furnish.

SUMMARY

Daily measurements of hypocotyl length were made on *Celosia cristata* seedlings cultured in darkness under aseptic conditions at six constant temperatures between 14.5° and 40.5°C. At 40.5° roots did not penetrate the agar and only the hypocotyls that were supported by the wall of the test tube could be measured.

The growth curves were of the generalized logistic type, but of different degrees of skewness. The degree of symmetry of the growth curves was influenced by temperature. At the lower temperatures the maximal growth rate came relatively late in the grand period of growth; at successively higher temperatures it came progressively earlier.

The mean total time rate of growth (millimeter *per diem*) was found to be a parabolic function of the temperature.

The maximum rate of growth was found from the curve to be at 30.48°C. The maximum observed rate of growth, and the maximum yield, were found to be at 30°C.

At all temperatures above 14.5° the maximum growth activity fell in the second quarter of the whole growth period. At all temperatures tested other than 30°, and at all parts of the growth cycle, the growth yield as measured by height of hypocotyl at any given equivalent point was less than at 30°.

The total duration of life of the seedlings, and the duration of life after the end of the growth period (intermediate period) were inversely proportional to the mean total growth rate. The observations on

Celosia cristata seedlings are thus in accord with the "rate of living" theory of life duration.

The optimal temperature for life duration is the minimum temperature, within the range of these observations.

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