Summary

A rapid cryoscopic method proposed for drop-size samples consists of freezing a drop of solution and following its temperature during thawing with a thermistor and a potentiometer chart. The method can be used for determining osmotic pressure, the molecular weight of solutes, and the concentration of deuterium in heavy water.

The method is limited to dilute solutions (up to 6 atm osmotic pressure) and is sensitive to better than 0.1 atm.

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EFFECTS OF THERMOPERIODISM ON TUBER FORMATION IN IPOMOEA BATATAS UNDER CONTROLLED CONDITIONS[1]

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Went (9) and Viglierchio and Went (8) found that the night temperature is the most critical factor governing the developmental process in tomato, chili pepper, tobacco, and beans. The importance of night temperature in general to plants was also suggested.

Previous work on *Ipomoea batatas* indicated that tuber formation is a process depending more on the condition of the growing point than on carbohydrate production in the leaf (6). Later a sensitivity to photoperiodism was found (7).

With respect to temperature, only some general effects on tuber formation have been reported.

Thus, Isiguro (5) found that with an average temperature less than 20 C, there was a decrease in yield, and Ido (4), that high temperature favors tuber production. Dogari (2) indicated that tuber production might be adapted in low soil temperature of 19 to 21 C. However, to date, there is no information on the effect of thermoperiodism on tuber formation. The following experiments, therefore, were undertaken under controlled conditions to study the effects of low night temperature, etc., on tuber formation as well as growth.

Materials & Methods

The experiments were conducted in thermoperiodically-controlled rooms, with a photoperiod of 16 hours and 8 hours of darkness in all cases. Incandescent lamps, providing a light intensity of approximately 100 to 150 ft-c were used.

The environmental factors may be divided into two general groups, nutritional and others. Since growth depends on a number of factors, it was possible to obtain undersized plants by restricting several, such as quantity of nutrition and light. This was advantageous for these experiments both from a standpoint of using a large quantity under uniform conditions, as well as easy handling for harvesting, with laboratory scales. Satisfactory tuber formation was obtained under the restricted conditions.

The seed tubers of *Ipomoea batatas* var. Okinawa 100, were sprouted in sand in wooden boxes and grown at the given temperature of each experiment. When the young plants were about 20 cm high, uniform cuttings of 8 to 10 cm, containing four nodes

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or three unfolded leaves, were made for transplanting. These were planted in 15 × 15 cm bamboo boxes filled with thoroughly-washed sand.

To each box was added 45 mg nitrogen, 90 mg phosphorus, and 270 mg potassium, representing approximately one-quarter, one-half, and one-half, respectively, of the standards used for *Ipomoea batatas* by Dogari (2). The moisture content of the sand in the growing boxes was maintained at approximately 60 %, by an automatic supply of water through a concrete block medium. These blocks, containing a ratio of sand to cement of 5: 1, were more satisfactory as a supply medium than was unglazed pottery. However before use, they must be leached with water in order to eliminate all soluble alkaline substances. The bamboo boxes were placed in wooden frames above the water tanks, in which the level of water controlled the water supply; the boxes could be moved freely as desired.

In the first experiment, the effects of low night temperature were studied. A phototemperature of 29 C and a nyctotemperature of 20 C were used, while the controls were kept at constant 29 C.

In the second experiment a comparison of two night temperatures was made. One set of plants was kept at 26 C during the light period, and 14 C during the dark period, while the other was kept at 26 C and 20 C, respectively.

The lowering from high temperature of the light period to low of the night period was achieved quickly. However, the reverse required 2 to 3 hours, so that the temperature of the first few hours of the light period must be considered as transitional.

Results

Effects of Thermoperiodism: The tuber formation of *Ipomoea batatas* was greatly promoted at low nyctotemperature (fig 1).

Thus, at a 29 C photoperiod and 20 C dark period, the tuber weight was about 10 to 16 times greater than at 29 C constant temperature. An increase in the number of tubers per plant was also found at low nyctotemperature, although this was less marked than the increase in weight, being only two to six times of constant high temperature.

Tuber formation appeared to be earlier with low nyctotemperature, lying between 20 and 30 days after planting.

Root growth at low nyctotemperature was also promoted, the proportion of weight of roots to tops being 14 to 26 % at low nyctotemperature and only 4 to 5 % at constant temperature (fig 2).

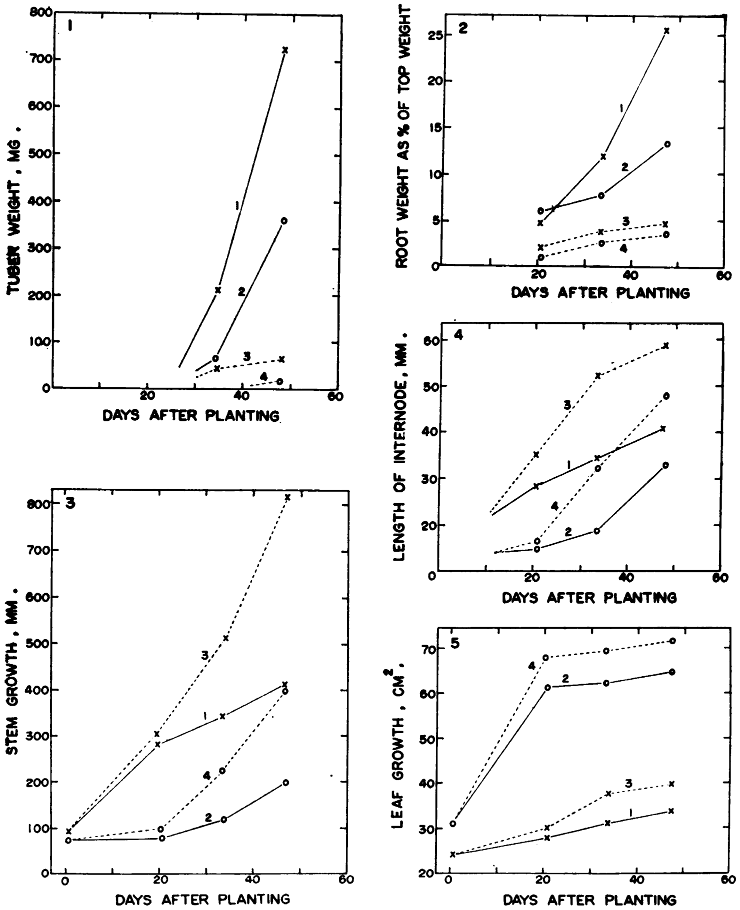

Fig. 1–5. The effects of thermoperiodism and a changed environment on the growth and tuber formation of *Ipomoea batatas*: *Solid line* (1, 2). phototemperature of 29 C and night temperature of 20 C; *broken line* (3, 4), constant temperature of 29 C; × (1, 3), continual environment under the controlled conditions; ○ (2, 4), changed environment from the natural conditions to the controlled conditions.

Fig. 1 (*upper, left*). The fresh weight of tubers (t value of the difference between the low-night temperature of 29 C to 20 C and the constant temperature of 29 C was 27.8 (df. 11) under the continual environment of controlled and 32.3 (df. 11) under the changed environment).

Fig. 2 (*upper, right*). The percentage of root weight (including tuber weight) to top weight.

Fig. 3 (*lower, left*). Stem growth (height of plants).

Fig. 4 (*center, right*). Average length of internodes.

Fig. 5 (*lower, right*). The leaf growth (length × width).

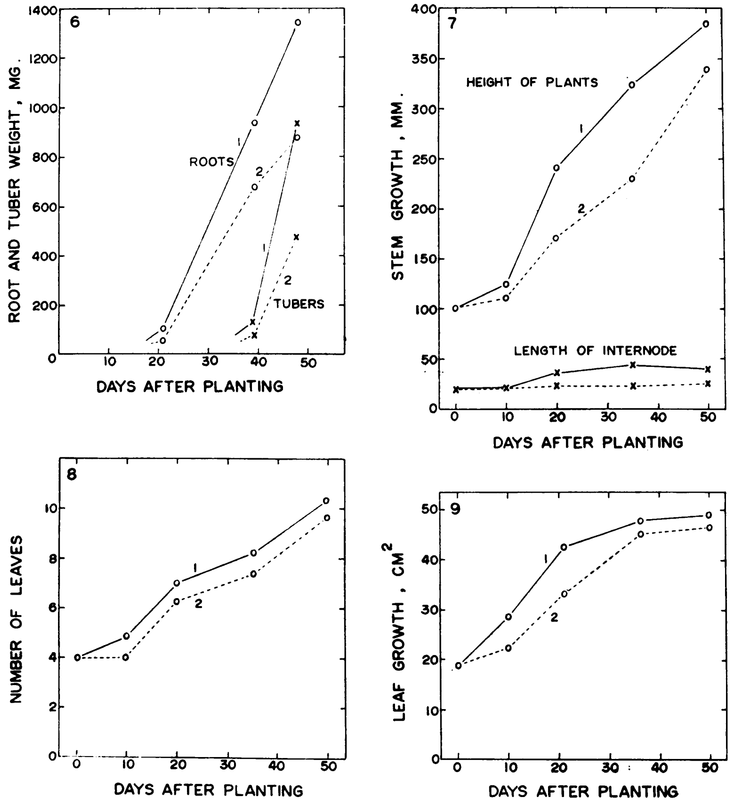

FIG. 6–9. The effects of two regimens of nyctotemperature on the growth of *Ipomoea batatas*: *Solid line* (1), 26 C of phototemperature and 20 C of night temperature; *broken line* (2), 26 C of phototemperature and 14 C of night temperature.

FIG. 6 (*upper left*). Fresh weight of tubers and roots (root weight include both weights of fibrous roots & tubers).

FIG. 7 (*upper, right*). Stem growth.

FIG. 8 (*lower, left*). Number of leaves.

FIG. 9 (*lower, right*). Leaf growth (length $\times$ width).

By contrast to tubers and roots, the top growth was not promoted by low nyctotemperature. On the contrary, stem elongation, number of leaves, length of internodes, leaf elongation, and top weight were enhanced by a constant temperature of 29 C; the greatest increase occurred in stem elongation (figs 3–5). Thus, there seems to be a selective effect of low nyctotemperature between top and underground parts of *Ipomoea batatas* (figs 1–5).

In addition to tuber formation and root development, all the growth of tops such as stem elongation, length of internodes, and number of leaves was greater under a day-night temperature regimen of 26 C to 20 C than when the difference between day and night was larger (26 C–14 C).

The fact may be due to the higher average temperature of the former regimen (26 C–20 C) than the latter (26 C–14 C).

GROWTH UNDER CONTROLLED CONDITIONS: Growth under the given controlled conditions showed a different behavior compared with that of natural conditions. Thus, the total size of the plants under controlled conditions was dimished due to the low light intensity and restricted concentration of nutrients. Leaf expansion and stem diameter in particular were suppressed, but elongation of internodes was promoted. This elongation might possibly be due to the light quality of the incandescent lamps, as has been indicated already by other research (11).

Another outstanding effect of the controlled conditions was the red pigmentation of the stem and leaf veins.

Tuber formation was most sensitive of all to the various conditions. With adequate day length and temperature, tuber formation was greatly promoted even under low light intensity of 70 to 150 ft-c, as well as restricted concentration of nutrients. At a photoperiod of 16 hours at 26 C, and a dark period of 8 hours at 20 C, the proportion of tuber to top weight 48 days after planting was 22 %, while at constant 29 C, it was only 1 %. Under short day conditions no tubers were formed (fig 10) (7).

GROWTH BEHAVIOR UNDER CHANGING ENVIRONMENTAL CONDITIONS: Cuttings grown in the field under natural conditions have larger and thicker leaves, smaller and stouter internodes than those grown in controlled rooms. When young plants from the field were introduced to the culture rooms and then transplanted to controlled conditions of low light intensity of the incandescent lamps, etc., stem growth was entirely suppressed at an early period (fig 3). On the other hand, growth of leaves and petioles was promoted so greatly that the growing point of the stem appeared as an accessory of the petiole or else buried in it (fig 5). This contrary behavior of stem and leaf growth continued for about 20 days after transplanting, regardless of conditions of low nyctotemperature or constant temperature. The

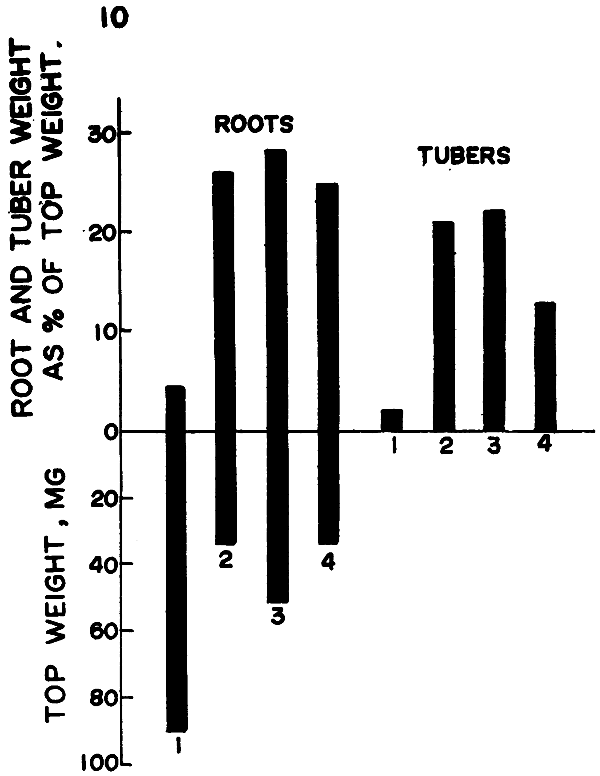

FIG. 10. The effects of thermoperiodism on the ratio of root weight to top weight in *Ipomoea batatas;* 1, Constant temperature of 29 C. 2, Phototemperature of 29 C and night temperature of 20 C. 3, Phototemperature of 26 C and night temperature of 20 C. 4, Phototemperature of 25 C and night temperature of 14 C.

effect of the new conditions became dominant only after 20 to 30 days (fig 3, 5). However, the stem elongation, length of internodes and number of leaves in the plants introduced from the field remained continually less than that of plants started under controlled conditions. Their leaf areas, however, were greater.

Compared with growth of other organs, tuber formation was of a sensitive and non-adaptive character when conditions were changed from field to controlled rooms, or vice-versa. For example, the proportion of tuber to top weight of plants from field cuttings was only 5.5 %, whereas that of plants grown throughout under room conditions, with low nyctotemperature, was 20.6 %. On the other hand, when cuttings from room conditions were planted in the field, the proportion of tuber to top weight was only 1 %, while that of plants grown throughout under field conditions was 21 %. Also, plants transferred from rooms to outdoors had a reduction of stem length and number of leaves in comparison with plants grown continually under natural conditions. The length of internodes remained unchanged.

DISCUSSION

Went (8, 9) found that the night temperature is the most critical factor influencing the developmental process in tomato, chili pepper, and tobacco. In *Ipomoea batatas* there is another remarkable example of the effect of nyctotemperature, especially with reference to tuber formation and root growth. Thus, tuber production is greatly promoted by low night temperature while stem elongation is promoted by high night temperature. Viglierchio and Went (8) showed that stem elongation of Phaseolus increases with higher nyctotemperature during the early stages, but that optimal night temperature shifts with age.

The fact that stem elongation and tuber formation of *Ipomoea batatas* were contrary in their responses to low night temperatures indicates that the low night temperature effect is different by various parts of the plant, whereas those temperature effects concerned only with an average temperature, are not.

It is plausible that the large promotion of tuber development at low nyctotemperature might be due to the greater translocation of sugars from tops to roots, as indicated by Went (10), who showed for tomatoes that the effect of night temperature is due to the translocation of sugar from leaves to other parts of the plant.

Low night temperature together with long day conditions seem to be the most critical factors for tuber formation in *Ipomoea batatas.* The former may be a critical accelerating factor while the latter, a regulative factor, in a similar manner to which, as shown by Gregory (3), the short day condition is

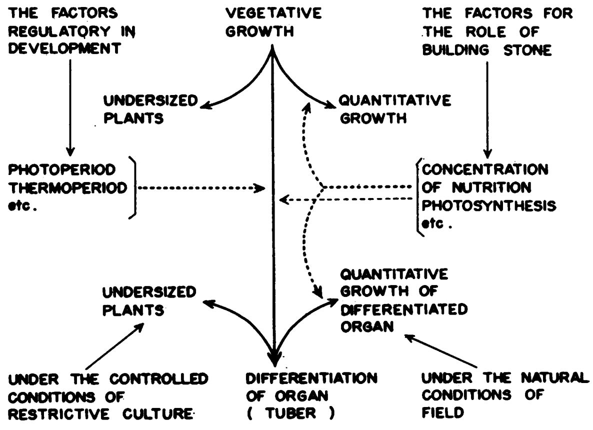

FIG. 11. External factors which give effects in a different way from each other on the growth and organ formation of *Ipomoea batatas*; *Large broken line,* showing the initiative, critical effects on the process of growth or organ formation; *Small broken line,* showing only general effects on the process of growth etc.; *Large solid line,* showing the process of growth and development. A satisfactory tuber formation resulted from controlled conditions by regulating the critical factors such as day length and thermoperiod, though the quantitative growth was suppressed by restricting the factors of light intensity and the concentration of nutrient.

the inducing stimulus for tuber production in the potato.

In the observation of the above-mentioned critical factors, tuber formation was satisfactory despite the limited nutrition due to low concentration as well as the fact that photosynthesis was limited by low light intensity. This indicates that the culture method with restricted nutrients can be useful in studying organ differentiation. It further indicates that the mode of influence of factors on differential or quantitative growth is dissimilar (fig 11).

In an ordinary environment, growth usually is relatively constant; however, in a shifting environment such as changing from field to controlled conditions, the plant shows either a specific growth behavior or an inertia of its previous growing habits, with respect to the new condition.

The fact that stem and leaf growth were quite contrasting when the plant was transferred from natural to room conditions, indicates that the growth of each organ must have an internal and independent mechanism, such as has been hinted at by other research workers on this problem (1). Inasmuch as the suppressed stem growth of transferred plants was opposed by the stimulatory effect of incandescent lamps on stem elongation, indicates that the external factors may exert their effects not directly upon the growth habits of plants but through the internal mechanism of growth. In other words, the growth habits of plants should be considered as the result of a cooperative reaction of external factors and internal mechanisms of growth.

It might further be suggested that the change from one set of conditions to another, such as from natural to controlled, offers a method for distinguishing the specific character of the internal mechanism of growth for each organ.

Summary

A low night temperature of 20 C and day temperature of 29 C greatly promoted tuber formation in *Ipomoea batatas* as compared with constant temperature of 29 C, day and night. Stem elongation, however, was greatest under constant temperature of 29 C.

All growth such as stem elongation, number of leaves, root development, tuber formation, etc., was a little more enhanced by temperature conditions of 26 C day and 20 C night, than with 26 C day and 14 C night.

The experiments were carried out under low light intensity of incandescent lamps (150 ft-c), as well as low concentration of nutrients (¼ or ½ the standard), so that the resulting dwarfed plants could readily be handled in large quantity under uniform conditions, and laboratory scales could be used for obtaining final results.

Even under these restricted conditions, however, tuber formation was satisfactory if appropriate day length and thermoperiod were provided. Thus the proportion of tuber weight to top weight 48 days after planting was about 22 % under low night temperature, as contrasted with only 1 % under constant temperature conditions.

Specific growth responses which varied with different organs were shown to exist under conditions of changing environment; it was suggested that such a conversion of conditions might be useful as a method for distinguishing the specific character of each organ growth.

Acknowledgment

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