Growth of Radishes as Influenced by the High Temperatures above the Optimum Range

Shigetoshi Suzuki

College of Agriculture, Meijo University, Tempaku, Nagoya 468

Summary

The effect of temperature on radish growth was examined under controlled conditions. In radishes grown at the higher temperatures of 20—25°C (night-day), dry weight of leaves was increased and that of fleshy organs was reduced. Distribution pattern of dry matter was also affected by higher temperatures; the ratio of leaf weight to total weight became larger at higher temperatures. Hypocotyl elongated during the period of 8 days after germination, being stimulated by the higher temperature. As hypocotyl was longer under such conditions, the thickening of radishes became insufficient. The pronounced effects of the higher temperature on hypocotyl elongation and thickening were observed especially when radishes were subjected to higher temperatures during the early stage of their growth.

Introduction

Although radishes may be cultivated throughout the year by the proper selection of varieties, in general, radish plants grow best in rather cool weather. According to Putt (10), thickening in hypocotyl and fleshy root was good at lower temperatures, whereas it was poor at higher temperatures. In the latter case, the hypocotyl tended to take a procumbent position and also the foliage was relatively large. In the Japanese radish cv. Minowase Daikon, higher temperatures as well as the other environmental stresses during the early stage of growth causes reduction in growth and yield (11). The influence of temperature on vegetative growth of radishes was also investigated in relation to pithiness (2, 3, 13). However, the detailed observation on the response of radish plants to higher temperatures has not yet been made adequately.

From a cultural standpoint, it is essential to discover the best environmental conditions for radish growth. On the other hand, it is also of importance to understand the plant response to unfavorable conditions, e.g., higher temperatures. Needless to say, the thickening growth of radishes is influenced

Materials and Methods

The seeds of Raphanus sativus L. cv. Rapid Red were sterilized with 0.1% Usulun for 30 min. After they were washed in running tap water for 2 hr, they were placed on a wet filter paper in the dark at 25°C for a 24 hr period. The germinated seeds were selected for uniformity before being planted in black plastic pots (9 cm in diameter) filled with vermiculite. Potted plants were transferred into the phytotron of Nagoya University and grown during the experiment at three different temperatures, i.e., 20—25°C (night—day, high temperature), 13—18°C (medium temperature), and 8—12°C (low temperature). Plants were grown during the season of short daylength, and light conditions, such as light intensity and daylength, were not controlled. Plants were watered daily with a nutrient solution (1g/l of Hypox). Ten to twenty plants were used in one treatment. In the experiment shown in Fig. 6, plants were divided into 6 groups and each of them was exposed to 20—25°C (high temperature) for 5 days at different growth
Results

1. Effect of temperature on dry weight growth.

Dry weight growth of radishes was markedly influenced by the temperature at which plants were grown (Fig. 1). Total dry weight was greater at the medium than at the low or high temperature. In foliage leaves, dry weight growth was stimulated by higher temperatures. The growth of cotyledons was, however, reduced by higher temperatures; their dry weight began to decrease earlier than at lower temperatures and maximum dry weight obtained was also reduced. The greatest dry weight of hypocotyl, thickened organ in this cultivar, was obtained at the medium temperature. In roots, although dry weight was the greatest at the high temperature in the final measurement, a definite tendency was not exhibited during the stages of growth among different temperatures.

Distribution pattern expressed in the ratio of dry weight of each organ to total dry
The ratio of foliage leaves in the plants grown at the medium or low temperature reached the maximum value 19 or 24 days after germination, and thereafter that of hypocotyl increased. On the 29th day after germination, the ratio of foliage leaves was less than 40% in the plants grown at the medium or low temperature, while it was 72% at the high temperature. The ratio of cotyledons or hypocotyl was reduced at higher temperatures. No significant difference among treatments was observed in roots.

2. Effect of temperature on hypocotyl elongation and thickening.

Hypocotyl elongation was also influenced by the temperature and stimulated by higher temperatures (Fig. 3). Furthermore, in all temperature regimes, the elongation progressed during the period of 8 days after germination and thereafter any elongation was not observed. That is, hypocotyl length was determined at the early stage of growth, being increased by the high temperature. A reduction in thickening of hypocotyl was marked at the high temperature (Fig. 4). Hypocotyl diameter of plants grown at the high temperature was almost one third of that
of plants grown at the medium temperature.

The relationship between hypocotyl diameter and hypocotyl length is shown in Fig. 5. The increase in hypocotyl diameter was manifest in the plants with short hypocotyl.

3. Effect of high temperature on hypocotyl thickening at different stages of growth

Hypocotyl diameter and length of plants exposed to the high temperature for 5 days of various growing stages were measured (Fig. 6). The inhibition of thickening and stimulation of elongation were caused by the high temperature, especially in the plants exposed to high temperature during 0–5 and

![Diagram](image-url)
The influence of high temperature on the growth of radish plants was marked in hypocotyl elongation (Fig. 3), distribution pattern of dry matter (Fig. 2), and thickening of hypocotyl (Fig. 4).

Although a tendency of progressive increase in hypocotyl elongation was observed in the preceding study for 24 days of experiment (12), it became evident from the detailed measurement that hypocotyl elongation progressed during the period of 8 days after germination (Fig. 3). In plants with epigeal cotyledons, hypocotyls elongate in soil after germination of seeds and then cotyledons emerge above ground. It seems, therefore, to be reasonable to consider that hypocotyl elongation is a phenomenon observed only at the early stage of radish growth. The fact that high temperature stimulated hypocotyl elongation of radish seedlings in the dark was reported also by Kadota (6). High temperature, however, did not affect the duration of hypocotyl elongation (Fig. 3). In plants with epigeal cotyledons, hypocotyls elongate in soil after germination of seeds and then cotyledons emerge above ground. It seems, therefore, to be reasonable to consider that hypocotyl elongation is a phenomenon observed only at the early stage of radish growth.

The species of plants has its own pattern of dry matter distribution and represents the allometric growth during the respective growing stage. However, the pattern varies with environmental conditions and its control becomes an important problem in horticultural production. In radishes cv. Rapid Red, two growth phases, i.e., phase 1 and 2, could be discriminated (12). The ratio of foliage leaves to the total dry weight was less than 50% in phase 2. At higher temperatures, however, growth of leaves was accelerated; the ratio of leaves became higher (72.2%), and, consequently, that of hypocotyl was smaller than at lower temperatures. Plitt (10) also obtained the similar results in radishes. In ryegrass seedlings, shoot/root ratio became larger at a high temperature than at a low temperature (1). Noggle and Fritz (8) suggested that one of the major effects of temperature was related to processes concerned with the apportionment of photosynthates into the different organs. From these results it is probable that excess distribution of dry matter to the leaves at the actively thickening stage at the high temperature, i.e., in phase 2, resulted in insufficient thickening growth.

Thickening growth of radishes is determined by the activity of cambium. From the preliminary anatomical observation, xylem formation and meristematic activity of xylem parenchymatous cells of fleshy parts of radish plants were reduced by high temperatures. Temperature is probably most important as a limiting factor for cambial activity. Further, reduction in cambial activity at high temperatures seems to be partly due to indirect effect (9); a shortage of available water and sugars, or disturbance in hormonal balance...
or in hormonal production due to high temperature may be involved in the reduction of cambial activity. According to Loomis and Torrey (7), auxins and cytokinins play important roles in thickening of radish roots cultured aseptically. Since effect of cytokinins is lowered at high temperatures (5), the reduction in thickening growth at high temperatures may be partly due to the lowered activity or production of cytokinins. Furthermore, sugars are also reported to be important (7). Reduction in apportioning of dry matter to hypocotyl may be one of factors reducing the activity of xylem differentiation.

The optimum temperature for radish growth lies at 24°C (average temperature of 3 weeks after seeding) in cv. Minowase Daikon (11) and near 20°C in cv. Rapid Red (2). In cv. Minowase Daikon, Saito (11) conducted the experiment in which seeding was done every 8th day from July to September and described that growth and yield were reduced when the plants were subjected to higher temperatures within a week after seeding. From his results, it seems likely that there is a sensitive stage to high temperature in the early stage of radish growth. Using cv. Rapid Red in this experiment, the author observed that thickening was reduced in plants exposed to high temperature at the early stage of growth, i.e., during 0—5 or 5—10 days after germination. Thus, evidently, high temperature has the most inhibitory effect on thickening growth at the early stage, that is, 0—10 days after germination, when active formation of secondary xylem begins and hypocotyl elongates.

By the control of hypocotyl elongation during the early stage of growth to the normal level and the inhibition of the growth of leaves to a limited extent, sufficiently thickened and normally shaped radishes may be obtained even at high temperatures. For example, the utilization of growth retarding chemicals are expected to be effective.

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Literature Cited

高温条件下におけるハッカダイコンの生長

鈴木 茂敏
（名城大学農学部）

摘 要

ハッカダイコンの肥大は、高温条件下で不良になることが知られている。そこで、本研究では、ハッカダイコンの発育におよぼす温度、特に比較的高温な条件（20〜25℃、夜温〜昼温）の影響について調べた。その結果、高温条件は、下胚軸の伸長および本葉の生長を促進し、下胚軸の肥大を著しく抑制することが明らかになった。

下胚軸の肥大は、その伸長が促進されたものでは不良である傾向が認められ、また、特に発育後期における本葉の生長促進は下胚軸の肥大を抑制することが認められた。また、肥大に対する高温の影響は、特に発育初期（発芽後10日間）において最も著しいことが明らかになった。