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Effect of Day and Night Temperature Variation and of High Temperature on Devernalization in Radish[1]

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Abstract: Ta-Mei-Fua radish must be exposed to a temperature of 5°C for a period of 20 days to achieve complete vernalization. Exposure to 5°C for only 10 days resulted in incomplete vernalization. When temperatures varied from day to night during vernalization, the higher daytime temperature erased the vernalizing effect of low night temperature. It was shown that the higher daytime temperature of 20 or 30.3 °C eliminated the sugar formed during the cooler nights.

After an uninterrupted period of vernalization, neither subsequent high temperature nor alternating high day/low night temperature could reverse the complete vernalization. It was also shown that a completely vernalized plant maintains a stable high sugar content which neither high temperature nor day/night temperature variation could reduce. Thus, a high sugar level in vernalized plants might account for the hastening of flower initiation and development.

High temperature following vernalization has been reported to erase the effect of low temperature treatment (Gregory and Purvis 1945, 1952; Lang and Melchers 1947; Suzuki 1980). Gregory and Purvis (1952) found that vernalization in winter rye could be reversed if followed immediately by exposure to temperature above 25 °C—35° C. Suzuki (1980) investigated the effect of day-night temperature variation on the flowering of radish and showed that when plants were exposed to 4°C at night and 30°C during the day, the effect of vernalization was erased by the high day-time temperature.

In temperate countries, plastic is used as a mulching material to prevent premature bolting during the winter season. Seyama (1981) indicated that radish planted with mulching had a maximum day temperature higher than that planted under natural field conditions. The higher day temperature could nullify the effect of night vernalization. In the tropics, the degree and duration of low temperature conditions are not enough to slow down bolting in flowering varieties. However, it is not known whether variation in day-night temperature, especially higher day time temperature, is the factor that prevents bolting, or the effect of high temperature causing devernalization following a continuous

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period of vernalization. Devernalization constraints may be more serious in the tropics than in temperate areas. This study addresses these problems.

Material and Methods

Radish cultivar Ta-Mei-Fua was used as the experimental material and the following two experiments were carried out from September 1982 to April 1983 :

(1) Effect of alternating high day/low night temperature on bolting during vernalization.

The first group of seeds was sown in Jiffy-7 (peat pellet) on September 14, 1982. The group was divided into three parts which received the following treatments for 20 days starting on September 22 : A) temperature treatment of 5°C at night (20 : 00 to 8 : 00 in a cool room) and 30.3°C in the daytime (8 : 00 to 20 : 00 in the green house) (Table 1) ; B) 5°C at night and 20°C in the day-time ; C) constant temperature of 5°C (check). A second group of seeds was sown on September 24, 1982 and received the same treatments for 10 days beginning on October 2. On October 12, all seedlings were planted in the field for flowering investigation (Figure 1).

Table 1. Day temperature in the greenhouse (8 : 00—20 : 00)

Date	9/23	9/24	9/25	9/26	9/27	9/28	9/29	9/30	10/1	10/2
Maximum	31	31	33	32.5	32	33	32	32	33	33
Minimum	27.5	28	28	28	29	29	28	28	29	29
Mean	29.3	30	30.5	30.3	30.5	31	30	30	31	31

Date	10/3	10/4	10/5	10/6	10/7	10/8	10/9	10/10	10/11	10/12	mean
Maximum	31.5	32.5	33.0	31.5	33	32	32	32	32.5	31.5	32.3
Minimum	28.5	29	29	28	29	28	29	28	28	27	28.3
Mean	30	20.8	31	29.8	30.5	30	30.5	30	30.3	29.3	30.3

(2) Effect of high temperature following an uninterrupted period of vernalization on bolting.

Two groups of seeds were sown in Jiffy-7 (peat pellet) on December 21 and December 31. Ten days after planting, they received cold treatment of 5°C for 20 and 10 days, respectively. After vernalization, each group was divided into three parts which received the following treatments for 10 days : A) 30°C ; B) 20°C ; C) alternating day temperature of 30° C and night temperature of 20° C. On January 29, all treated radish were planted in 4.5 inch pots and placed in the greenhouse

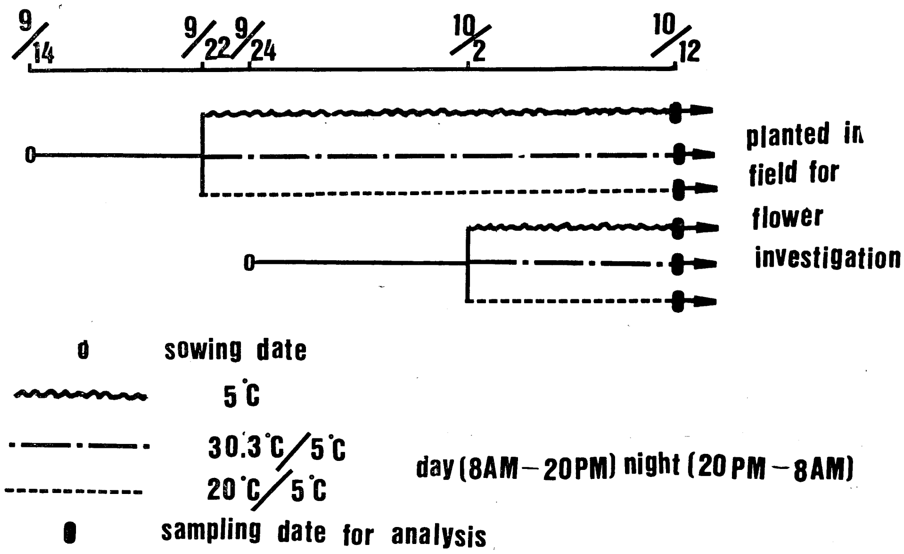

Fig. 1. Plan for effect of alternating day/night temperature on flowering of radish seedling

for bolting investigation (Figure 2).

After high temperature treatments, samples from both experiments were taken for analysis of carbohydrate contents.

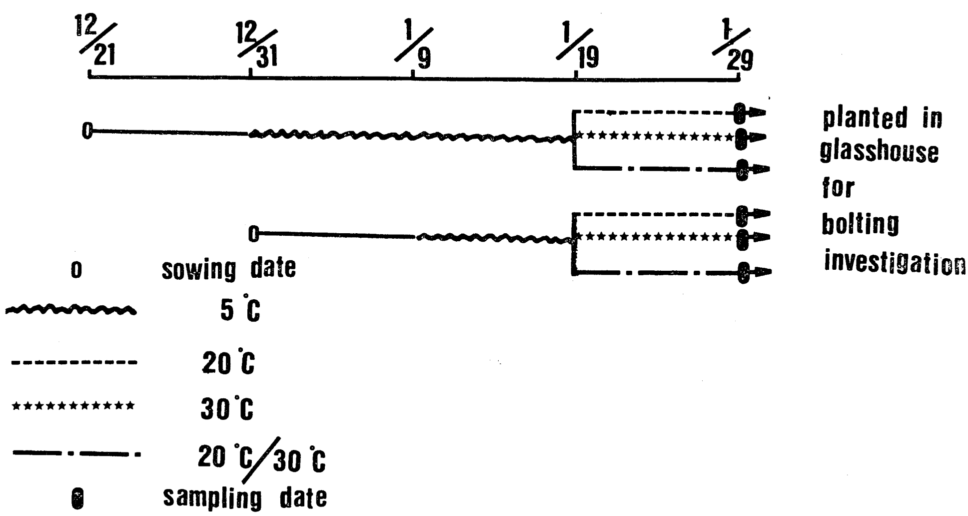

Fig. 2. Plan for effect of high temperature and alternating day/night temperature after an uninterrupted period of vernalization on bolting

Results and Discussions

(1) Effect of alternating high day/low night temperature on flowering

The check maintained at 5°C for 20 days showed complete vernalization whereas 5°C for 10 days was not enough to induce vernalization completely in radish. The number of flowering plants was lower and flowering dates were later for the 10-day treatment than for the 20-day treatment. Alternating day/night temperatures of 20°/5°C and 30.3°/5°C for 10 days did not induce flowering until the end of the experiment, whereas 2 and 1 plants flowering in alternating day/night temperature of 20°/5°C and 30.3°/5°C for 20 days respectively (Table 2). Apparently, high daytime temperatures of 30.3°C during vernalization could certainly erase the effects of cold night temperatures. Even a relatively high daytime temperature around 20°C during the period of vernalization can nullify the effect of vernalization.

Table 2. Effect of alternating day/night temperature on flowering of radish

Temperature (night/day)	Days of treatment	No. of plants treated	No. of flowering plants								
			11/18	11/23	11/28	12/3	12/8	12/13	12/18	12/23	12/28
5°C / 5°C	20	30	14	18	26	28	30	—	—	—	—
5°C / 30.3°C	20	30	0	0	0	0	0	0	0	0	1
5°C / 20°C	20	30	0	0	0	0	0	0	0	0	2
5°C / 5°C	10	30	0	0	2	4	8	8	9	9	9
5°C / 30.3°C	10	30	0	0	0	0	0	0	0	0	0
5°C / 20°C	10	30	0	0	0	0	0	0	0	0	0

Suzuki (1981) indicated that day/night temperature variation plays an important role in inducing flowering in radish. Under the condition of 30°C day/4°C night, the effect of vernalization was erased by the higher day temperature. Seyama (1981) also showed that the bolting effect of low temperature on radish could be annulled by 30°/5°C day/night temperature treatment. He indicated that mulching could prevent premature bolting by raising temperatures. In winter rye, Gregory and Purvis (1938) showed that six weeks of cold treatment (1°C), could induce flowering, whereas alternating temperatures at 1°C with aerobic and 20°C with anaerobic conditions for six weeks, winter rye remained unvernalized. All of these results suggest that high temperature during the day could erase the effect of low temperature during the vernalization process.

Patterns of the carbohydrate contents during vernalization are shown in Table 3. The sugar contents of radish treated with 5°C for 10 days and 20 days are higher compared with those grown under alternating day/night temperature treatmets of 20°C/5°C and 30.3°C/5°C. Among these, seedlings treated with 5°C for 20 days had the highest non-reducing sugar, total sugar, and total carbohydrate con-

Table 3. Carbohydrate contents (% dry matter) of radishs seedlings under various day/night temperature treatment

Temperature (night/day)	Days of treatment	Reducing sugar	Non-reducing sugar	Total sugar	Starch	Total carbohydrate
5°C / 5°C	20	1.77	3.66	6.43	6.33	12.76
5°C / 30.3°C	20	0.98	1.06	2.04	5.19	7.23
5°C / 20°C	20	0.98	1.48	2.46	7.05	9.51
5°C / 5°C	10	2.52	0.64	3.16	4.87	8.03
5°C / 30.3°C	10	0.94	1.07	2.01	5.30	7.31
5°C / 20°C	10	1.46	1.28	2.74	5.23	7.97

tents, whereas treatment of 5°C for 10 days gave the highest reducing sugar contents of all treatments. The alternating of high day temperature with low night temperature resulted in low sugar contents. Although day temperatures of 30.3°C and 20°C for 10 or 20 days did not show much difference in sugar contents, the non-reducing sugar content of the 20°C day temperature treatment was a little higher than that of the 30.3°C treatment.

Sugar content in the alternating day/night temperature treatment did not increase during the treatment period. In other words, the high day temperature of 20°C or 30.3°C could eliminate the sugar that had accumulated as a result of low night temperature.

(2) Effect of high temperature and alternating day/night temperature following vernalization on bolting.

By the time of the final observation on April 9, 1983, it was seen that when plants had been treated with cold temperature (5°C) for 20 days, percentage of bolting plants was a little lower during the early stage when cold treatment was followed by a continuous temperature of 30°C or 30°C day/20°C night than when cold was followed with only 20°C (Table 4). However, on April 9, end of experiment all treatments were 100% or nearly 100% of plants bolted. It means that although heat treatments caused a delay in flowering implying unfavorable flower development conditions, the prolonged 5°C for 20 days treatment had caused complete vernalization and neither subsequent 30°C nor 30°C day/20°C night treatments could reverse the effect.

Bolting was later and percentage of bolting plants was lower for plants treated with cold temperature for 10 days than for plants treated with cold for 20 days when cold treatment was followed by 20°C. When cold temperature treatment of only 10 days was followed by the other two heat treatments (30°C or 30°C day/20°C night), percentage of bolting plants was lower. Evidently the period of cold treatment was too brief for complete vernalization to take place. Thus reversal of vernalization is possible when high temperatures follow an incomplete vernalization.

Table 4. Effect of high temperature and alternating day/night temperature following cold temperature treatment on bolting

Treatments	No. of plants treated	% of bolting plants*						
		3/10	3/15	3/20	3/25	3/30	4/4	4/9**
5°C (20 days) →20°C	30	26.7	50	63.3	83.3	93.3	100	100
5°C (20 days) →30°C	36	22.2	30.6	52.8	66.7	72.2	88.9	97.2
5°C (20 days) →20°C/30°C	30	23.3	26.6	60.0	66.7	73.3	90.0	100
5°C (10 days) →20°C	39	0	0	5.1	12.8	15.4	25.6	43.6
5°C (10 days) →30°C	52	0	0	0	3.8	19.2	19.2	23.1
5°C (10 days) →20°C/30°C	28	0	0	0	3.6	17.9	21.4	28.6

*Mean temperature during planted in glasshouse : 20.9°C.

**Plants which had flower initiation included (checked by microscope).

Suzuki (1981) indicated that alternating day/night temperature (30°C/20°C or 30°C/15°C) after a complete vernalization in radish could not cause devernalization. Purvis and Gregory (1952) pointed out that in winter rye, with increasing duration of vernalization, the reversal becomes progressively less. The vernalized condition thus becomes increasingly stable. After 12 weeks of vernalization, heat treatment at 35°C had no effect, even when given for 5 days ; no devernalization could occur.

Vernalizing and devernalizing temperatures are different. Temperatures for devernalization, usually range from 25 to 40°C but for some plants made neutral temperatures can have this effect. For example, devernalization can occur at 17°C in winter rye (Purvis and Gregory 1952), 17 to 18°C in sugabreet (Owen etc. 1940), and 20°C in *Hyoscyamus*, *Arabidopsis* (Melchers and Lang 1947), and radish (Suzuki 1980). It is interesting to note that the potential for devernalization by heat varies inversely with the completeness of the preceding vernalization treatment. If the vernalization process has been completed reversal by heat becomes impossible.

The carbohydrate contents of radish after complete vernalization subsequent high temperature or alternating day/night temperature treatment showed that high levels of total sugar and non-reducing sugar remained, but no significant difference was found among the 20°C, 30°C, or 30°/20°C treatment. (Table 5). Plants treated with 20°C temperature seemed to have higher non-reducing sugar content. High temperature following incomplete vernalization gave low levels of total sugar, non-reducing sugar and reducing sugar content as well as a higher starch content.

The results show clearly that the thermo induced vernalized state, if completely established, has a high level of non-reducing sugar and total sugar content and maintains stability even when subsequently subjected to high temperature or alternating day/night temperatures. In other words, stability of thermo induction

Table 5. Carbohydrate contents (% dry matter) of radish seedlings under various temperature treatments

Treatments	Reducing sugar	Non-reducing sugar	Total sugar	Starch	Total carbohydrate
5°C (20 days) →20°C	0.27	4.78	5.05	5.89	10.94
5°C (20 days) →30°C	1.99	3.46	5.45	5.01	10.46
5°C (20 days) →20°C/30°C	0.27	5.77	6.04	4.99	11.03
5°C (10 days) →20°C	0.09	1.91	2.00	5.29	6.29
5°C (10 days) →30°C	0.98	1.61	1.70	5.22	6.92
5°C (10 days) →20°C/30°C	0.09	1.69	1.78	5.26	8.04

depends upon the continous maintenance of the level of total sugar content during the subsequent high temperature treatment. The high sugar content is stabilized after complete vernalization, and will not be reversed even under subsequent high temperatures. These conditions might imply that high sugar content is necessary for promoting flower initiation and development. When the sugar level is too low for flower development, high temperature can convert this low level of sugar into starch, and devernalization thus occurs.

The results of the experiments show the possibility of reversing vernalization by high temperature treatment. The effect of alternating high day/low night temperature during the course of vernalization, and the effect of high temperature or alternating day/night temperature following vernalization must be clearly distinguished.

First, the test alternating high day temperature with low night temperature during vernalization showed that temperature as low as 20°C in the daytime will reverse the effect of the low night temperature. Second, the stability of the vernalized condition appears to vary according to the degree of vernalization. A completely vernalized condition will not be reversed by subsequent high temperature of 30.3°C or alternating day/night temperature of 20°C/30°C, but an incompletely vernalized condition can certainly be annulled by subsequent high temperature or alternating day/night temperature, and an increase in vegetative development occurs as well.

The following carbohydrate metablic changes associated with devernalization treatment were observed : First, the level of sugar contents increased with the duration of vernalization. However, when low night temperatures were alternated with higher day temperatures during the course of vernalization, even the optimal growth temperature of 20°C could nullify the sugar raising of effect lower night temperature. Accordingly, the accumulation of sugar contents could not reach the level required for flower initiation and development. In the subtropics, the relatively high day temperature during the winter season is one of the major factors preventing bolting in plants that require cold, Second, it was clear that the stability of vernalization depends upon the degree of vernalization. A complete vernalization requires a stable high level of sugar contents which cannot be annulled by subsequent high temperature or alternating day/night temperatures. Thus the high level of sugar contents might be responsible for the initiation and development of flowering. Incomplete , unstable vernalization in the tropics is mainly due to insufficient accumulation of sugars in plants tissues. The subtropical environment does not provide a continuously low enough temperature for complete vernalization to take place, especially as winter temperatures fluctuate.

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Literature cited

1. Chroboczek, E., 1934. A study of some ecological factors influencing seed-stalk development in beet (*Beta vulgaris* L.) Men. Corn. Univ. Agr. Exp. Sta. No. 154.
2. Georges, B., Jean-Marie, K. and Roy M. S. 1981. The physiology of flowering. CRC Press, Vol. 1 : 69-80.
3. Georges, B., Jean-Marie, K and Roy M. S. 1981. The physiology of flowering. CRC Press. Vol. 2 : 163-170.
4. Gregory, F. K. and Purvis, O. N. 1938. Studies in vernalization of cereals. II. The vernalization of excised mature embryos and of developing grains. Ann. Bot. 2 : 237-251.
5. Gregory F. K., and Purvis O. N. 1938. Studies in vernalization of cereals. III. The use of anaerobic condition in the analysis of vernalizing effect of low temperature during germination. Ann. Bot. 2 : 753-764.
6. Gregory F. K., and Purvis O. N. 1954. Devernalization by high temperatuer. Nature 153 : 113-114.
7. Gregory F. K., and Purvis O. N. 1948. Reversal of vernalization by high temperature. Nature clxi. 589.
8. Gregory F. G. and O. N. Purvis. 1952 Studies in vernalization of cereals. XII. The revesibility by high temperature of the vernalized condition in winter rye. Ann. Bot. 16 : 1-21.
9. Lang, A, and Melchers, G. 1947. Vernalization und devernalization bei einer zweijahrigen Phflanze. Zeit. Naturforsch, 2B : 444-449.
10. Owen, F. V., Carsner, E. and Stout, M. 1940. Photothermol induction of flowering in sugar beet. J. Agr. Res. 1xi. 101-124.
11. Platenius, H. 1932. Carbohydrate and nitrogen metabolism in the celery plant as related to premature seeding. Cornell Univ. Agr. Expt. Sta. Memoir 140.
12. Purvis, O. N. 1934. An analysis of the influence of temperature during germination on subsequent development of certain winter cereals and its relation to the effect of length of day. Ann. Bot. (London) 40 : 919-955.
13. Sadik, S. and J. L. Ozbun. 1968. The association of carbohydrate changes in the shoot tip of cauliflower with flowering. Plant Physiol. 43 : 1696-1698.
14. Sheen T. F. 1981. Low temperature treatment and flower development in Ta-Mei-Fua radish. Jour.

Agric. Res. China 30(4) : 369-377.

15. Sen, B. and Chakravarti S. C. 1946. Effect of high temperature on vernalized mustard seed. Nature. Clvii. 266.
16. Seyama N. and L. Takai 1981. Studies in bolting of Daikon. (In Japanese). Annual Res. Report Moriok Branch 74-81.
17. Seyama N. and T. Masaki 1982. Studies in bolting of Daikon(In Japanese). Ann. Res. Rep. Moriok Branch, Jap. 64-66.
18. Suzuki, Y. 1972. Studies on vernalization in some cole root vegetables, especially on the transition of low temperature sensitivity and the metabolic change during vernalization. (In Japanese with English summary). Fac. Agr. Tokyo Uni. of Eduction 18 : 27-92.
19. Suzuki, Y. Y., Shinohara and K. Ishii, 1980. Effect of alternating day-night temperature on flower inducing of Minowase-Daikon (In Japanese). Res. ab. Autumn, 1980. Jap. Soc. Hort. Sci. 144-145.
20. Suzuki, Y., and Y. Shinohara, 1981. Effect of vernalized degree and alternating day-night temperature on bolting of Minowase-Daikon (In Japanese). Res. ab. Autumn. 1981. The Jap. Soc. Hort. Sci. 190-191.

日夜温度變化和高温對蘿蔔離春化之影響[1]

沈 再 發[2]

大梅花蘿蔔行 5°C20日之低溫處理，可達完全春化作用，而 5°C10日之低溫則爲不完全春化作用。於春化期間日夜溫度變化時，白天之高溫消除了夜間的低溫效果。由試驗結果顯示，白天溫度20°C至 30°C 減少了夜間低溫期的糖類形成。

連續的春化期於達到完全春化作用後，隨之高溫或高日夜溫度變化，皆不能產生離春化。同時顯示出具完全春化處理之植物體，保持有隱定的糖類含量，此含量既不因高溫也不因高日夜溫度變化而減少。因此春化後植物體的高糖類含量，爲促進花芽分化及發育之理由。

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