TIME AND TEMPERATURE FACTORS FOR THE FLOWER FORMATION IN CABBAGE

TIME AND TEMPERATURE FACTORS FOR THE FLOWER FORMATION IN CABBAGE

By

Hideo ITO and Takasi SAITO

Department of Agronomy, Faculty of Agriculture, Tohoku University, Sendai, Japan

(*Received, October 16, 1961*)

In cabbage culture, sometimes, considerable losses occur as a result of some plants shooting to seed instead of forming heads.

It had been found that a close positive correlation exists between the size of the plant at the time it is forced into dormancy by cold weather and the tendency to shoot to seed in the spring. Under warm conditions, flower formation was almost entirely inhibited. The severity of the winter season has much influence upon the percentage of the seeders formed. The prolonged low temperature appeared to cause the larger plants to shoot to seed.

It is known, on the other hand, that genetic factors play a part in shooting to seed, or "bolting". The tendency to shoot to seed is different among the varieties.

For the interest in the scientific and theoretical aspects and for the practical importance of this problem, efforts were made to determine the range and duration of cold temperature to affect the performance of cabbage plants belonging to various types of varieties.

Experiments

1. Interrelations between range and duration of low temperature to influence the flower bud differentiation.

(1) Range of temperature: 0°, 4° and 9°C

Plants of the variety Watanabe-Seiko with stems of 8.2 mm in diameter were used.

Plants were placed in the greenhouse of 4° or 9°C. Some plants were set in the field. In the field, the average temperature fell to zero.

Below 4°C cabbage plants ceased growing (Fig. 1).

Microscopic observations examined the flower bud differentiation at intervals of ten days as shown in Table 1.

After 50 days, the plants growing in the field were subjected to microscopic observation and it was ascertained that rapid elevation of the surface of the

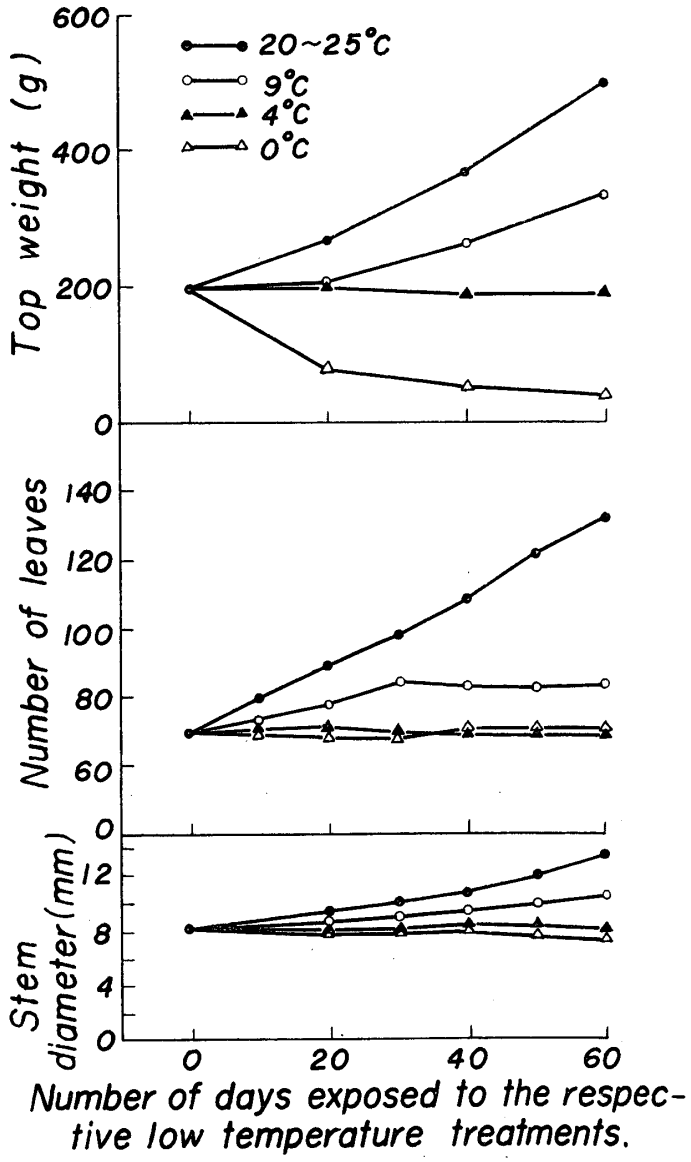

Fig. 1. Growth of the plants exposed to the different range of the low temperature (Watanabe-Seiko).

growing points into a narrow conical form, rounded at the apex took place, and ten days thereafter floral differentiation was ascertained.

Plants placed in the 4°C greenhouse formed flower buds after 50 days temperature treatment and those placed in the 9°C greenhouse formed flower buds after 40 days temperature treatment.

Some of the plants were transferred to the warmer greenhouse after a definite length of time of the low temperature treatment at 0°, 4° and 9°C in the greenhouse (Table 2).

Ten to 20 days treatment of the lower temperature was not adequate. Plants placed in the field for 20 days formed leafy heads completely. Plants

Table 1. Effects of the range of low temperatures on the flower formation (Watanabe-Seiko).

Temperature (°C)	Days after treatments	No. of plants	Mode of the growing point						
			Undifferentiated	Dome shaped	Differentiated		Sepals formed	Petals formed	Stamens formed
					Early stage	Middle stage			
0	10	3	3	—	—	—	—	—	—
	20	3	3	—	—	—	—	—	—
	30	3	3	—	—	—	—	—	—
	40	3	3	—	—	—	—	—	—
	50	3	2	1	—	—	—	—	—
	60	3	1	2	—	—	—	—	—
4	10	3	3	—	—	—	—	—	—
	20	3	3	—	—	—	—	—	—
	30	3	3	—	—	—	—	—	—
	40	3	—	3	—	—	—	—	—
	50	3	—	—	1	2	—	—	—
	60	3	—	—	—	—	3	—	—
9	10	3	3	—	—	—	—	—	—
	20	3	3	—	—	—	—	—	—
	30	3	1	2	—	—	—	—	—
	40	3	—	1	2	—	—	—	—
	50	3	—	—	—	1	2	—	—
	60	3	—	—	—	—	—	3	—

placed in the 4° or 9°C greenhouse for 20 days formed leafy heads with stems beginning to elongate.

Thirty days treatment of the lower temperature proved to be effective. Plants placed in the 9°C greenhouse for 30 days, all shooted and bloomed whereas those under a temperature of 4°C for 30 days, had the vegetative shoots elongating. Plants set in the field for 30 days formed leafy heads with more or less elongated stems.

Plants placed in the 4°C and 9°C greenhouse for 40 days shooted to bloom, whereas those in the field for 40 days shooted to form bracts and a single plant was found having formed the flower bud but ceased to develop to anthesis.

Plants set under the temperature treatment for 50 and 60 days, including those set in the field, all shooted to bloom.

Longer temperature treatment up to 50 days hastened shooting and blooming. Sixty days temperature treatment on the other hand, seemed to suppress shooting and blooming.

Development of the laterals: At each temperature, longer treatment stimulated more laterals to grow and to bear flower buds and flowers. Temperature treatment shorter than 40 days failed to stimulate the laterals. Fifty days temperature treatment caused the lateral growth with flower buds only on the apical parts of the terminal three secondary laterals and those flower buds all dropped before anthesis. Sixty days treatment caused those identical flower buds to bloom and induced flower buds formation, though they

Table 2. Effects of range and duration of low temperatures on the bolting, flowering and fruiting (Watanabe-Seiko).

Temperature (°C)	Number of days exposed to low temperature	Mode of growing point at removing date into the warmer greenhouse	Head formation	Bolting		Flowering		Number of primary lateral branches		
				Date	Number of days after removing into the warmer greenhouse	Date	Number of days after removing into the wermer greenhouse	Flowered & Fruited	Non-flowered	Headed
0	10	Undifferentiated	Yes	—	—	—	—	—	—	—
	20	Undifferentiated	Yes	—	—	—	—	—	—	—
	30	Undifferentiated	Yes	—	—	—	—	—	—	—
	40	Undifferentiated	Yes (2 plants)	Apr. 21	63	—	—	0	1.8	0
	50	Dome shaped	No	Mar. 28	29	May 18	80	0	3.3	3.4
	60	Dome shaped	No	Apr. 5	27	May 9	61	3.1	10.7	4.2
4	10	Undifferentiated	Yes	—	—	—	—	—	—	—
	20	Undifferentiated	Yes	—	—	—	—	—	—	—
	30	Undifferentiated	Stem elongated	—	—	—	—	—	—	—
	40	Dome shaped	No	Apr. 1	43	May 14	86	2.3	4.6	3.8
	50	Floral differentiated	No	Mar. 12	13	Apr, 3	35	9.2	1.3	3.6
	60	Sepals formed	No	Mar. 18	9	Apr, 10	32	11.3	3.7	0
9	10	Undifferentiated	Yes	—	—	—	—	—	—	—
	20	Undifferentiated	Yes	—	—	—	—	—	—	—
	30	Dome shaped	No	Mar, 26	47	May 17	99	0	5.8	3.0
	40	Floral differentiated	No	Mar, 30	41	May 2	74	5.0	2.4	5.1
	50	Sepals formed	No	Mar, 10	11	Apr, 4	36	8.6	1.0	3.4
	60	Petals formed	No	Mar, 16	7	Apr, 8	30	10.8	3.1	0

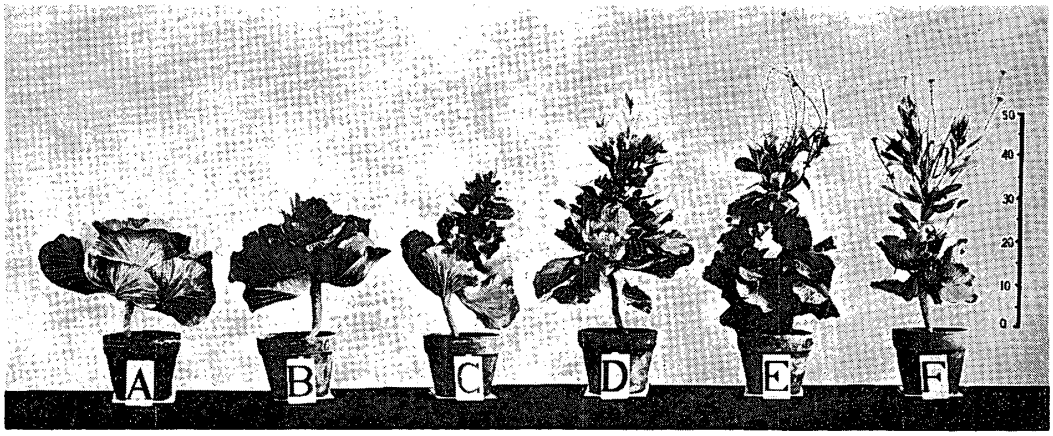

Fig. 2. Effects of the duration of 4°C on the flower formation (Watanabe-Seiko).
A : Non-treatment B : 20 days treatment C : 30 days treatment
D : 40 days treatment E : 50 days treatment F : 60 days treatment

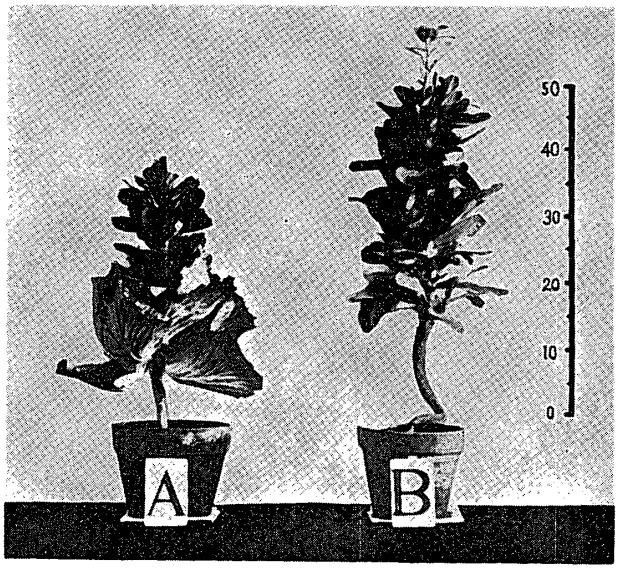

Fig. 3. Effects of the range of low temperature (4° and 9°C) treatment on the flower formation (Watanabe-Seiko).
A : 30 days treatment at 4°C B : 30 days treatment at 9°C

failed to bloom, on the apical parts of ten secondary laterals succeeding beneath.

Plants, in which microscopic observation immediately after the lower temperature treatment failed to find the sign of the flower buds differentiation, formed bracts or flowers after they are placed in the warmer greenhouse.

Effects of range and duration of lower temperatures are manifested in the tendency of the plants changing from the vegetative to the reproductive organ formation; a) stem elongates, and bract is formed, but apical growth point goes on producing leaves and forms leafy head, b) short stem with bract elongates and flower buds which drop before anthesis are formed on the apical part of the main stem and the upper laterals, followed with the leafy head

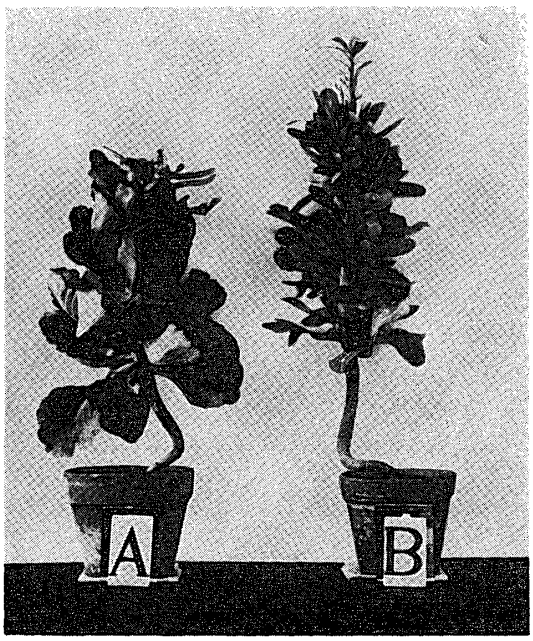

Fig. 4. Effects of the range of low temperature (0° and 9°C) treatment on the flower formation (Watanabe-Seiko).
A : 50 days treatment at 0°C B : 30 days treatment at 9°C

formation on the lower laterals, c) unfruitful flower stalk with bract elongates. Flower buds which mostly drop before anthesis are formed on the apicals of the main stem and the upper laterals, and leafy heads are formed on the apicals of the lower laterals and the secondary laterals, d) fruitful flower stalk elongates, early flowers, however, mostly failing to develop and leafy heads are formed on the lower laterals.

(2) *Range of temperature: 9° and 17°C*

The varieties Yosin, Watanabe-Sakigake and Himezakura were used for the experiments and the effects of the low temperatures 9° and 17°C were investigated. Plants of the size 8 mm in the stem diameter were used.

Table 3. Effects of the range and duration of low temperatures on flower formation.

Varieties	Temperature (°C)	Number of days exposed to low temperature							
		7	15	20	30	40	50	60	80
Yosin	9	×	○	○	○	○	○		
	17	×	×	○	○	○	○		
Watanabe-Sakigake	9			×	○	○	○	○	○
	17			×	×	×	×	×	×
Himezakura	9			×	×	×	×	○	○
	17			×	×	×	×	×	×

× : Undifferentiated
○ : Flower bud differentiated

The plants are transferred into the warmer greenhouse at intervals of ten days after the low temperature treatment of a definite length in the 9° and 17°C greenhouse (Table 3).

Yosin plants placed in 9°C greenhouse formed flower buds in 15 days and those placed in 17°C greenhouse formed flower buds in 20 days. All those plants shooted to bloom.

Watanabe-Sakigake placed in 9°C greenhouse formed flower buds in 30 days and shooted to bloom but those placed in 17°C greenhouse failed to form flower buds even in 80 days.

Himezakura placed in 9°C greenhouse formed flowers in 60 days and shooted to bloom, but those placed in 17°C greenhouse failed to form flower buds even in 80 days.

Table 4. The critical length of the temperature (0°, 4°, 9°, and 17°C) treatment needed for the cabbage plants of the various varieties (Size of plant : 8 mm in the diameter). Days placed in the greenhouse of the respective temperatures.

Temperatures / Varieties	0°C	4°C	9°C	17°C
Watanabe-Seiko	40–50	40	30	—
Yosin	—	—	15	20
Watanabe-Sakigake	—	—	30	—
Himezakura	—	—	60	—

It is shown that at the lower temperatures (0° and 4°C), the growth of the plants are depressed and a longer time is needed for the elevation of the growing points and flower buds differentiation than at the higher temperature (9°C).

At 9°C, plants form flower buds in 15 to 60 days. At 17°C, however, Watanabe-Sakigake and Himezakura varieties failed to form flower buds even with 80 days treatment. Yosin, on the other hand, formed flower buds in 20 days at 17°C.

Except Yosin, it may be concluded that at 17°C, plants developed even to the size 8 mm in the stem diameter, fail to form flower buds.

2. Effect of the low temperature treatment interrupted by the interposed higher temperatures

(1) Repetition of cyclic pairs of low temperature and higher temperature (Alternation of 9°C and 25°-30°C paired at definite intervals).

As above indicated, cabbage plants are influenced by the low temperature treatment quantitatively associating with temperature range and duration.

The next experiments were conducted to determine the influence of the low temperature as interrupted by the higher temperatures.

Plants of the variety Watanabe-Sakigake of 10 mm in stem diameter were used for the experiments.

Table 5. Effects of high temperature interruption during the low temperature treatment on the flower formation (Watanabe-Sakigake).

Number of days exposed to low temperature	Number of days after biginning of low temperature treatment	Plot	No. of plants	Mode of the growing point						
				Undifferentiated	Dome shaped	Differentiated		Sepals formed	Petals formed	Stamens formed
						Early stage	Middle stage			
25	25	Control	3	—	3	—	—	—	—	—
	35	10- 5	3	3	—	—	—	—	—	—
	45	5- 5	3	3	—	—	—	—	—	—
	45	10-10	3	3	—	—	—	—	—	—
	65	5-10	3	3	—	—	—	—	—	—
30	30	Control	3	—	—	2	1	—	—	—
	40	10- 5	3	3	—	—	—	—	—	—
	55	5- 5	3	3	—	—	—	—	—	—
	50	10-10	3	3	—	—	—	—	—	—
	80	5-10	3	3	—	—	—	—	—	—
35	35	Control	3	—	—	—	1	2	—	—
	50	10- 5	3	3	—	—	—	—	—	—
	65	5- 5	3	3	—	—	—	—	—	—
	65	10-10	3	3	—	—	—	—	—	—
	95	5-10	3	3	—	—	—	—	—	—
40	40	Control	3	—	—	—	—	—	2	1
	55	10- 5	3	1	2	—	—	—	—	—
	75	5- 5	3	3	—	—	—	—	—	—
	70	10-10	3	3	—	—	—	—	—	—
	110	5-10	3	3	—	—	—	—	—	—
45	45	Control	—	—	—	—	—	—	—	—
	65	10- 5	3	—	3	—	—	—	—	—
	85	5- 5	3	3	—	—	—	—	—	—
	85	10-10	3	3	—	—	—	—	—	—
	125	5-10	3	3	—	—	—	—	—	—
50	50	Control	—	—	—	—	—	—	—	—
	70	10- 5	3	—	1	2	—	—	—	—
	95	5- 5	3	—	3	—	—	—	—	—
	90	10-10	3	3	—	—	—	—	—	—
	140	5-10	3	3	—	—	—	—	—	—
55	55	Control	—	—	—	—	—	—	—	—
	80	10- 5	3	—	—	2	1	—	—	—
	105	5- 5	3	—	2	1	—	—	—	—
	105	10-10	3	3	—	—	—	—	—	—
	155	5-10	3	3	—	—	—	—	—	—
60	60	Contral	—	—	—	—	—	—	—	—
	85	10- 5	3	—	—	—	2	1	—	—
	115	5- 5	3	—	—	3	—	—	—	—
	110	10-10	3	3	—	—	—	—	—	—
	170	5-10	3	3	—	—	—	—	—	—

Scheme of experiment; Nine degrees centigrade and 25-30°C alternations are paired as follow:

a) 9°C, continuous,
b) 9°C for 10 days paired with 25-30°C for five days,
c) 9°C for five days paired with 25-30°C for five days,
d) 9°C 10 days paired with 25-30°C 10 days,
e) 9°C for five days paired with 25-30°C 10 days.

Plants were microscopically observed after each 9°C treatment (Table 5). It is shown in Table 5 that in the case of continuous low temperature

Table 6. Effects of high temperature interruption during the low temperature treatment on the flower formation (Watanabe-Sakigake).

Number of days exposed to low temperature	Hours exposed to low temperature per day	No. of plants	Mode of the growing point						
			Undifferentiated	Dome shaped	Differentiated		Sepals formed	Petals formed	Stamens formed
					Early stage	Middle stage			
25	24	3	—	3	—	—	—	—	—
	16	3	3	—	—	—	—	—	—
	8	3	3	—	—	—	—	—	—
30	24	3	—	—	2	1	—	—	—
	16	3	3	—	—	—	—	—	—
	8	3	3	—	—	—	—	—	—
35	24	3	—	—	—	1	2	—	—
	16	3	3	—	—	—	—	—	—
	8	3	3	—	—	—	—	—	—
40	24	3	—	—	—	—	—	2	1
	16	3	2	1	—	—	—	—	—
	8	3	3	—	—	—	—	—	—
50	24	—	—	—	—	—	—	—	—
	16	3	—	3	—	—	—	—	—
	8	3	3	—	—	—	—	—	—
60	24	—	—	—	—	—	—	—	—
	16	3	—	—	3	—	—	—	—
	8	3	3	—	—	—	—	—	—
70	24	—	—	—	—	—	—	—	—
	16	3	—	—	1	2	—	—	—
	8	3	3	—	—	—	—	—	—
80	24	—	—	—	—	—	—	—	—
	16	3	—	—	—	—	3	—	—
	8	3	3	—	—	—	—	—	—
90	24	—	—	—	—	—	—	—	—
	16	3	—	—	—	—	—	2	1
	8	3	3	—	—	—	—	—	—
100	24	—	—	—	—	—	—	—	—
	16	3	—	—	—	—	—	—	3
	8	3	3	—	—	—	—	—	—

treatment, the growing point flattened after 25 days treatment, and in the cases of the higher temperature interruptions, much longer duration of low temperature treatment is needed to induce the differentiation of the meristematic tissues. Longer interruption of the higher temperature apparently necessitates the longer total length of the effective lower temperature treatment. Ten days cycles paired with higher temperature interruption nullified the effect of lower temperature up even to 60 days.

(2) Daily interruption of the higher temperature

The variety Watanabe-Sakigake was used. Plants of the size of 10 mm in the stem diameter are induced to form flower buds in 30 days at 9°C (9°C being continued up to 720 hrs). In the case of daily interruption of the higher temperature, i.e. 9°C-16 hrs and 25°C-30°C-8 hrs daily cycles, plants are induced to flower differentiation after 60 days (9°C being continued up to 960 hrs), and in the case of 9°C-8 hrs and 25°-30°C-16 hrs daily cycles, 9°C treatment failed to induce the flower differentiation even after 120 days (9°C being contiuned up to 960 hrs) duration.

3. Plant size and sensitivity to low temperature

The variety Watanabe-Seiko was used.

Plants were transferred into the 4° or 9°C greenhouse when they attained 4.0, 5.0, 6.2, 7.0 or 8.2 mm in the stem diameter (Table 7).

(1) Plants placed in the 9°C greenhouse

Plant growth proceeded steadily in the 9°C greenhouse (Fig. 5).

Microscopic observation ascertained the flower bud differentiation as shown in Table 8.

Plants that attained 4 mm in the stem diameter showed the sign of flower bud differentiation after 80 days. Plants that attained 8.2 mm in the stem diameter differentiated flower buds in 40 days.

Larger plant size showed earlier differentiation of the flower bud and more advancement of the development thereafter.

Some of the plants are transferred into the warmer greenhouse after the low temperature treatment of a definite length in the 9°C greenhouse (Fig. 6).

Plants, 8.2 mm and/or 10 mm in the stem diameter formed leafy heads after being placed for 20 days in the 9°C greenhouse, and differentiated flower buds and bolted after being placed for 30 days in the 9°C greenhouse. Plants 7 mm and/or 6.2 mm in the stem diameter differentiated flower buds and bolted after being placed for 40 days in the 9°C greenhouse. Plants, 5 mm in the stem diameter, differentiated and bolted after being placed for 50 days, and plants, 4 mm in the stem diameter, differentiated and bolted after being placed for 80 days in the 9°C greenhouse.

It is ascertained that the plants developed to the flattening of the growing

Table 7. The growth status of plants at the beginning of the low temperature treatment (Watanabe-Seiko).

Plant size (Represented by the stem diameter in mm)	Top weight (g)	Number of expanded leaves	Number of differentiated leaves	Stem diameter (mm)	Stem weight (g)	Stem length (cm)
4.0	30.8	14.2	28.6	4.0	3.2	6.6
5.0	45.7	18.0	36.5	5.0	5.1	7.8
6.2	68.2	28.0	48.2	6.2	8.4	9.1
7.0	102.0	33.2	58.2	7.0	14.4	13.0
8.2	197.4	39.6	69.5	8.2	26.1	17.9
10.0	421.3	51.4	85.4	10.0	48.2	19.2

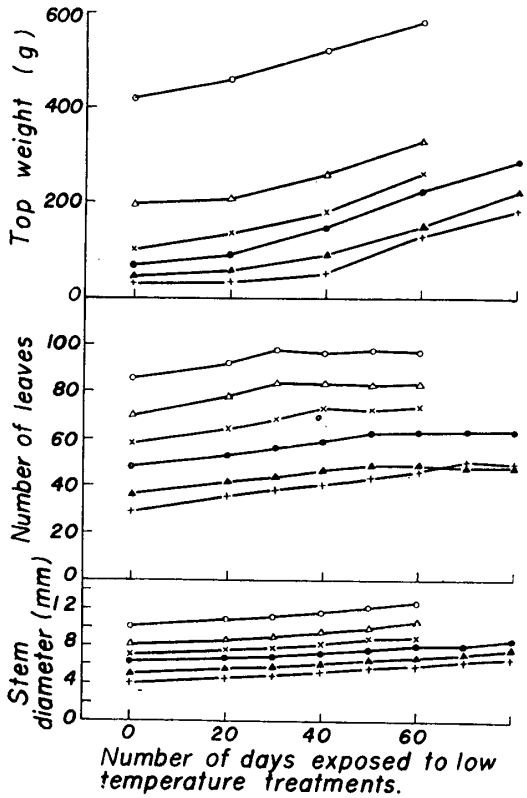

Fig. 5. Growth of various sized plants exposed to low temperature (Watanabe-Seiko).
+—+ 4.0 mm plant ▲—▲ 5.0 mm plant
●—● 6.2 mm plant ×—× 7.0 mm plant
△—△ 8.2 mm plant ○—○ 10.0 mm plant

points in the 9°C greenhouse, about ten days before the flower buds differentiation, bolted and flowered after being transferred into the warmer greenhouse.

(2) Plants placed in the 4°C greenhouse

Plants ceased growth in the 4°C greenhouse. Microscopic observation showed flower bud differentiation at intervals of ten days as shown in Table 9.

Some of the plants are transferred into the warmer greenhouse after the low temperature treatment of a definite length in the 4°C greenhouse (Fig. 6).

Table 8. The flower induction of various sized plants exposed to low temperature (9°C) (Watanabe-Soiko).

Number of days of low temperature treatment	Plant size (Represented by the stem diameter in mm)	No. of plants	Mode of the growing point						
			Undifferentiated	Dome shaped	Differentiated		Sepals formed	Petals formed	Stamens formed
					Early stage	Middle stage			
20	4.0	3	3	—	—	—	—	—	—
	5.0	3	3	—	—	—	—	—	—
	6.2	3	3	—	—	—	—	—	—
	7.0	3	3	—	—	—	—	—	—
	8.2	3	3	—	—	—	—	—	—
	10.0	3	3	—	—	—	—	—	—
30	4.0	3	3	—	—	—	—	—	—
	5.0	3	3	—	—	—	—	—	—
	6.2	3	3	—	—	—	—	—	—
	7.0	3	3	—	—	—	—	—	—
	8.2	3	1	2	—	—	—	—	—
	10.0	3	—	3	—	—	—	—	—
40	4.0	3	3	—	—	—	—	—	—
	5.0	3	3	—	—	—	—	—	—
	6.2	3	1	2	—	—	—	—	—
	7.0	3	—	3	—	—	—	—	—
	8.2	3	—	2	1	—	—	—	—
	10.0	3	—	—	3	—	—	—	—
50	4.0	3	3	—	—	—	—	—	—
	5.0	3	—	3	—	—	—	—	—
	6.2	3	—	—	1	2	—	—	—
	7.0	3	—	—	—	2	1	—	—
	8.2	3	—	—	—	1	2	—	—
	10.0	3	—	—	—	—	3	—	—
60	4.0	3	3	—	—	—	—	—	—
	5.0	3	—	1	2	—	—	—	—
	6.2	3	—	—	—	—	1	2	—
	7.0	3	—	—	—	—	—	3	—
	8.2	3	—	—	—	—	—	3	—
	10.0	3	—	—	—	—	—	1	2
70	4.0	3	2	1	—	—	—	—	—
	5.0	3	—	—	1	2	—	—	—
	6.2	3	—	—	—	—	—	2	1
80	4.0	3	—	3	—	—	—	—	—
	5.0	3	—	—	—	—	2	1	—
	6.2	3	—	—	—	—	—	—	3

After being placed for 50 days, all of the plants differentiated the flower buds. In the case of 4°C treatment, there are few differences among the plant performance of the different sizes.

4. Relations of the plant size and age with the sensitivity to the lower temperatures

As above related, it is shown that the response to the effect of the lower temperatures varies with the plant size, in other words, it varies with the

earliness of the sowing.

Next, two sowings were made. Plants from each sowing were grouped with regard to their size. The response of the plants with the different size from the same sowing was compared. On the other hand, the response of the younger plants was compared with that of the older plants with the identical size, growth of the latter having been much suppressed by the reduction in water and fertilizer application.

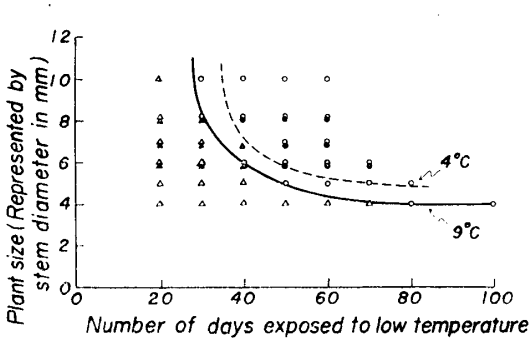

Fig. 6. Relation between the plant size at the beginning of low temperature treatments and the chilling requirement for the flower induction (Watanabe-Seiko).
Undifferentiated {△ : 9°C, ▲ : 4°C
Flower bud differentiated {○ : 9°C, ● : 4°C

The varieties Yosin, Himezakura, Watanabe-Sakigake, Watanabe-Seiko, Fuziwase and Nanbu were used for the experiments.

For the comparison of the plants of different ages, the younger and older plants of the various varieties from the two sowings were trasferred at the same time into the 9°C greenhouse. Plants of the size from about 3 mm to about 7 mm in the stem diameter were used.

For the comparison of the plants of the different size, the plants from the same sowing were transferred into the warmer greenhouse successively at

Table 9. The flower induction of various sized plants exposed to low temperature (4°C) (Watanabe-Seiko).

Number of days of low temperature treatment	Plant size (Represented by the stem diameter in mm)	No. of plants	Mode of the growing point					
			Undifferentiated	Dome shaped	Differentiated: Early stage	Differentiated: Middle stage	Sepals formed	Pepals formed
20	6.2	3	3	—	—	—	—	—
	7.0	3	3	—	—	—	—	—
	8.2	3	3	—	—	—	—	—
30	6.2	3	3	—	—	—	—	—
	7.0	3	3	—	—	—	—	—
	8.2	3	3	—	—	—	—	—
40	6.2	3	3	—	—	—	—	—
	7.0	3	1	2	—	—	—	—
	8.2	3	—	3	—	—	—	—
50	6.2	3	—	1	2	—	—	—
	7.0	3	—	—	3	—	—	—
	8.2	3	—	—	1	2	—	—
60	6.2	3	—	—	—	2	1	—
	7.0	3	—	—	—	1	2	—
	8.2	3	—	—	—	—	3	—

intervals of ten days after the low temperature treatment of a definite length in the 9°C greenhouse.

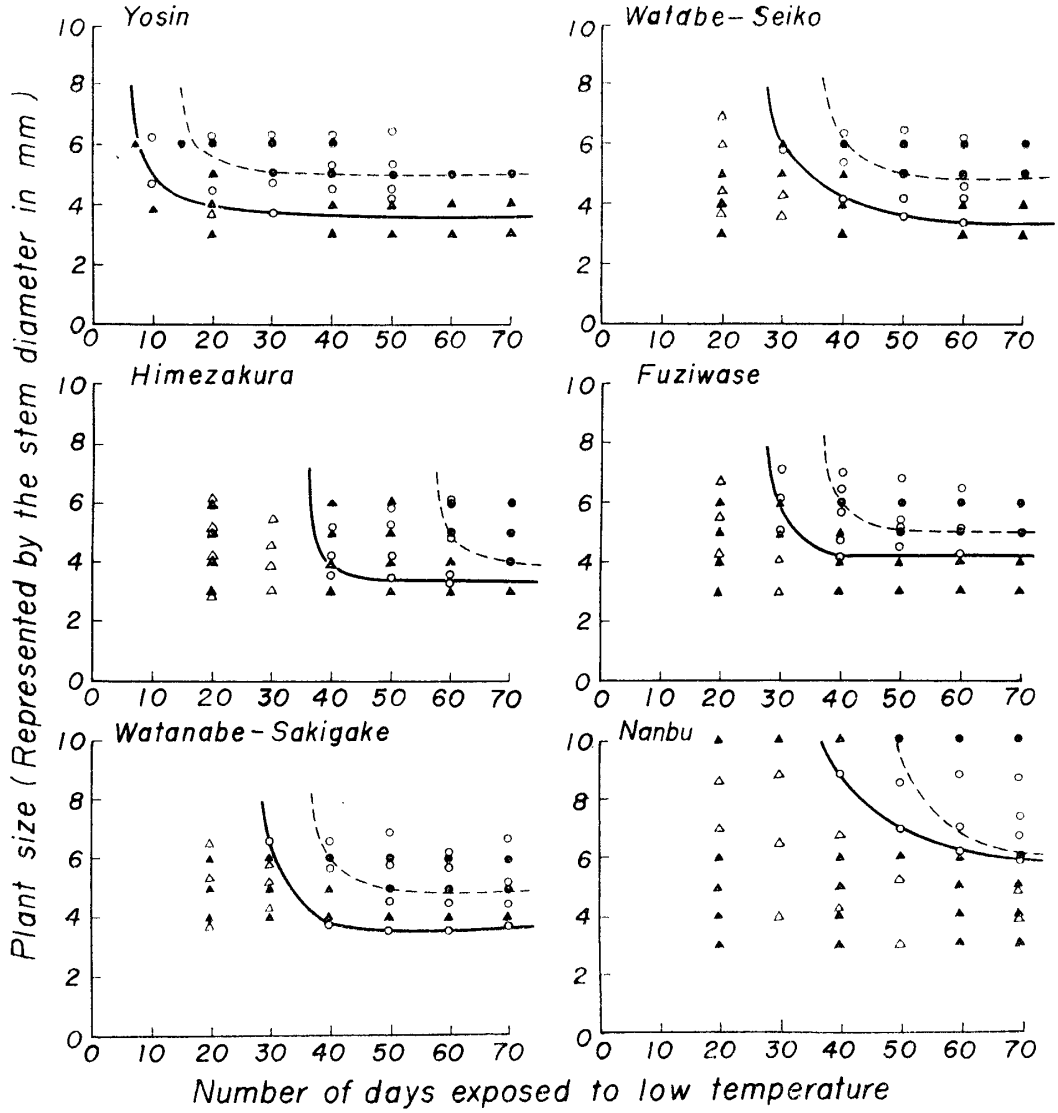

Fig. 7. Relations between the plant size and age in various varieties with the sensitivity to the effect of the low temperature.

Undifferentiated {▲ : Younger plant, △ : Older plant} Differentiated {● : Younger plant, ○ : Older plant}

--------- Younger plant ——— Older plant

It is shown in Fig. 7. that with plants of different size from the same sowing, the larger plants have been found to produce the more seeders under the influence of the shorter duration of the low temperature in contrast with the smaller plants.

It is shown, on the other hand, that the older plants are induced to differentiate the flower buds much earlier than the younger plants of the same size. Growth suppressed in any way, the early sown older plants have been

found to produce the more seeders than the later sown younger plants of the same size.

The performance of the cabbage plants seems to depend upon two factors, the size and the age of the plants.

5. The sensitivity of cabbage varieties

Interrelation between the range of plant size and the duration of low temperature

The varieties used were Yosin, Himezakura, Watanabe-Sakigake, Watanabe-Seiko, Fuziwase and Nanbu, selected relating to their modes of responses to low temperature.

Plants were transferred to the 9°C greenhouse when they reached 2, 3, 4, 5, 6, 10 and 15 mm in the stem diameter. The plants were transfered to the warmer greenhouse after the low temperature treatment of definite length and then examined for floral differentiation.

The critical length of cold treatment (9°C) needed for the cabbage plants of the various varieties of different sizes to differentiate flower buds are shown in Fig. 8.

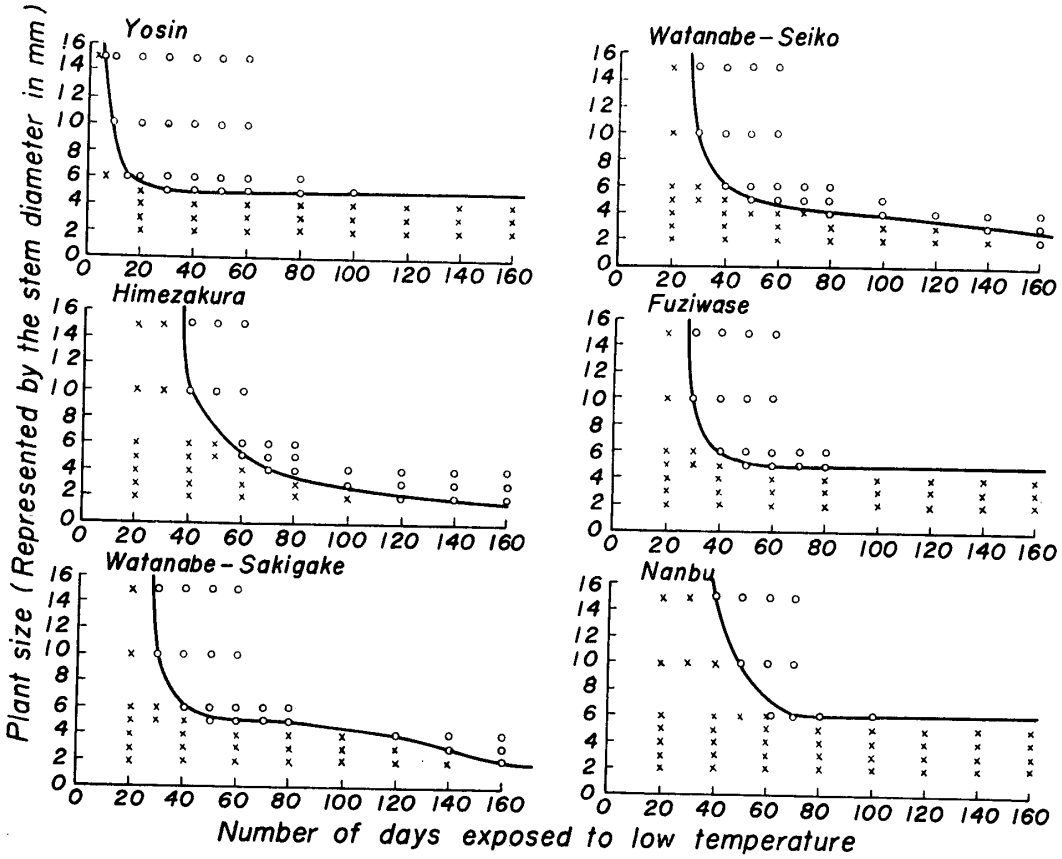

Fig. 8. Relations between the plant size at the beginning of treatment and the duration of temperature required for the flower induction.
× : Undifferentiated
○ : Flower bud differentiated

It is shown in Fig. 8. that the larger the plant size, the length of the cold treatment needed for inducing floral differentiation becomes shorter. The critical length of the cold treatment tends to shorten closely corresponding to the relative increase in size of the stem diameter.

Yosin and Fuziwase varieties with stems less than 4 mm and Nanbu with stems less than 5 mm in diameter formed no flower buds even after 160 days low temperature treatment. Other varieties formed flower buds even with stems less than 4 mm in diameter in 160 days or much less low temperature treatment.

Yosin with stems exceeding 5 mm in diameter, on the other hand, formed flower buds much sensitively responding to less low temperature treatment in contrast to the plants of the other varieties of the same size.

It is indicated in Table 10 that the plant size of 5-6 mm in diameter is the critical size of the cabbage plants of most varieties to attain before the coldness of the winter sets in.

Table 10. The critical length of cold treatment (9°C) needed for the cabbage plants of the various varieties with different size to differentiate flower buds. (Days)

Varieties \ Plant size	2 mm	3 mm	4 mm	5 mm	6 mm	10 mm	15 mm
Yosin	—	—	—	30	15	10	6
Himezakura	120	100	70	60	60	50	50
Watanabe-Sakigake	160	140	120	50	30-40	25	25
Watanabe-Seiko	160	120	80	50	40	30	30
Fuziwase	—	—	—	50	40	30	30
Nanbu	—	—	—	—	60-70	50	40

The performance of the plant of the Watanabe-Sakigake, Watanabe-Seiko and Nanbu varieties, placed at low temperature for the respective lengths at the size of 7-8 mm in the stem diameter is shown in Fig. 9.

Nanbu needed the longest duration of the low temperature sixty days low temperature makes the Nanbu plant to differentiate flower buds, but these flower buds failed to grow up to the anthesis.

In the cases of the shorter duration of low temperature, vegetative stems grow up in the place of the flower stalks. The shorter the low temperature duration, more likely the transitory stems grow up.

Lateral branches grow up more and more with longer duration of low temperature. The tendency of the appearance of lateral branches is most marked in Watanake-Sakigake and successively in Watanabe-Seiko.

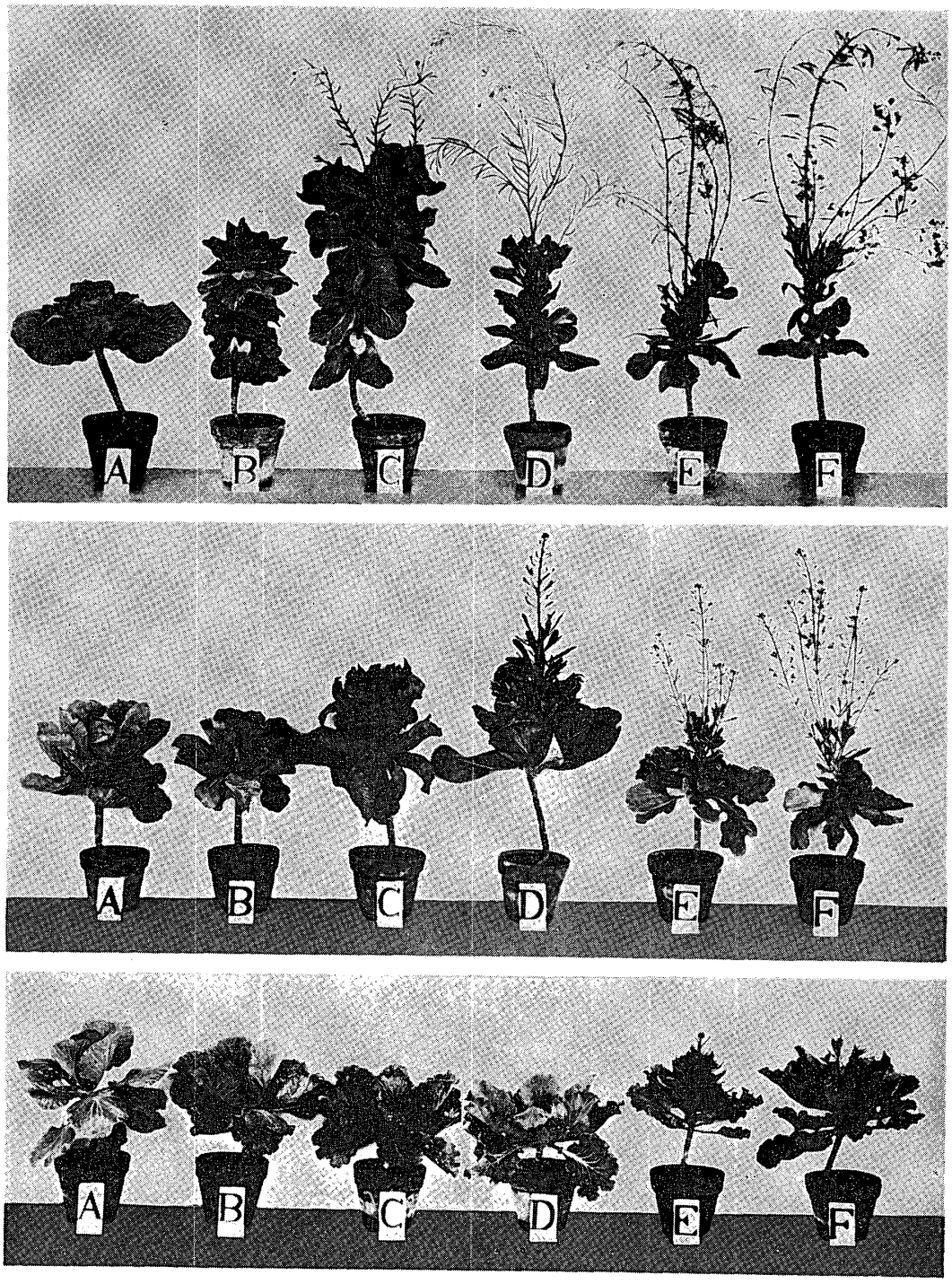

Fig. 9. Varietal differences in the plant performance exposed to low temperature (9°C) treatment of various length.

1 : Watanabe-Sakigake	2 : Watanabe-Seiko	3 : Nanbu
A : Non-treatment	B : 20 days treatment	C : 30 days treatment
D : 40 days treatment	E : 50 days treatment	F : 60 days treatment

Discussion

Cabbage plants form flower buds and shoot to bloom after they have been placed for a certain period under low temperature.

The most effective temperature that induces flower differentiation in cabbage plants is ascertained to be about 9°C. Lower or higher temperature is less effective. The effective highest temperature is 17°C.

At temperatures other than 9°C, a longer duration of the respective temperatures is needed to induce the flower bud differentiation.

The amount of the response of the plant to the low temperatures seems to be a function of the range and duration of the prevailing temperatures.

The range and the duration of the lower temperature quantitatively influence the plant performance. Unadequate temperature treatment makes the cabbage plant to form less, misdeveloped flower primordia, those absciss before anthesis.

When the higher temperature treatments are interposed between the temperature treatments, a longer duration of the identical low temperature treatment is needed. Higher temperatures interposed periodically among the low temperatures proved to counterbalance the effects of the latter.

The sensitivity of the plants to the low temperature depends upon the size and age of the cabbage plants.

The larger the plants, the more sensitively the plants response to the temperature treatment. Older plants of the same size, on the other hand, response more sensitively than the younger plants. Even the less temperature treatment, in range and/or duration, induced much striking response in larger or older plants than in the smaller or younger plants.

Response to the low temperature is different among the cabbage varieties. Sensitivity of the respective varieties depends either more upon the plant size or upon the duration of the low temperature.

Plant size results from the growth proceeded during the plant bed. The sensitivity of the older plants of the same size, on the other hand, surpasses that of the younger plants. So, the sensitivity closely related with the size and age of the plant may be explained on the basis of the phasic development of the cabbage plant (Sinohara (2)). The phases may be classified into the vegetative growth phase before the onset of the low temperature and the succeeding differentiation phase responsive to the low temperature. It seems that as to the length of the growth phase and/or the differentiation phase requisite to the flower differentiation, there is rather wide diversity among the cabbage varieties.

The plant response, however, varies as above related, quantitatively. Unadequate duration of the low temperature or low temperature treatment interrupted by the higher temperature, bringing about the restriction of the

meristematic tissues changing into the reproductive development, show that the effect of the low temperature or the response of the plant under the treatment is cumulative. Sensitivity relating with the plant size may be explained also to be of the quantitative nature. Boswell (1) explained on the basis of the absolute amount of reserve materials in the stem of the cabbage plant, reflecting the plant size in this turn. Reducing the stored food by the removal of leaves, he showed the lowering of the percentage of seeders produced. He also ascertained that the older plants, even though of the same size, have heavier stems and bear distinctly more carbohydrate reserves in the stems.

Studies are further in progress.

Summary

1. Except for the Yosin plant of the size 8 mm in the stem diameter, which formed flower bud after having been placed at 17°C for 20 days, plants of most cabbage varieties of the size of 6 mm in the stem diameter initiate flower buds after being placed at 9°C for a certain period. It may be concluded that a temperature lower than 17°C is requisite for the cabbage plants to form flower buds.

2. At lower temperature flower buds differentiated with shorter duration of the low temperature. The effectiveness of the low temperature upon the flower bud differentiation seems to be the function of the range and the duration of the prevailed low temperature.

3. When the higher temperature treatment is interposed between the low temperature treatment, the effect of the latter seems to be counterbalanced by the effect of the former. Longer cumulative repetition of the low temperature treatment is requisite for the flower initiation as compared with the continued treatment of the identical low temperature.

4. The larger the plant size, the more sensitive becomes the plant to the low temperature. In larger plants flower buds initiate with the shorter length of the identical low temperature.

5. Older plants of the identical size responsed more sensitively to the low temperature as compared with the younger plants.

6. Among varieties, there is rather wide diversity in the sensitivity. Yosin initiates flower bud differentiation even at 17°C. For other varieties, a lower temperature of about 10°C is requisite for the flower bud differentiation. Nanbu forms flower bud at the largest development with the longest low temperature treatment. The critical size of the plant and the duration of the low temperature requisite for the flower bud differentiation is different among the varieties.

Acknowledgement

The authors gratefully acknowledge the courtesy of Dr. Sinohara and Kanno for supplying the cabbage seeds of the pure strains.

Refercnces

1) Boswell, V.R. (1929). Bull. 313 Univ. Maryland.
2) Sinohara, S. (1959). Tech. Bull. **6**, Sizuoka Agr. Exp.Sta.