Germination Behaviour of Seeds as Affected by Different Temperatures in Some Species of *Brassica*¹

Satoru TOKUMASU, Izumi KANADA and Masahiro KATO

College of Agriculture, Ehime University, Matsuyama 790

Summary

Germination tests of seeds were carried out at 5 different temperatures, i.e., 5, 15, 25, 35, and 45°C, using 11 different crops of *Brassica*. Germination was examined every two hours and, afterwards, every 12 or 24 hours. In every crop, seeds began to germinate earliest at 35°C and latest at 5°C. The start of germination became later in the decreasing order of temperature from 35 to 5°C. Seeds at 45°C began to germinate as early as those at 35°C in many crops, but in some crops the start of germination was much delayed. Mean germination period was shortest at 35°C, and shorter at 25°C in every crop. These temperatures were followed by either 15 or 45°C with respect to mean length of period. The longest period was needed for germination at 5°C. As for germination percentage, seeds at 35, 25 and 15°C showed more than 85% in all of the crops examined. At 45 or 5°C, low percentages of germination were frequently observed. Differences among crops were observed at these temperatures: some crops showed bad germination at 45°C, and some at 5°C, and others at both 45 and 5°C. The response of non-dormant seeds was different from that of dormant seeds in terms of germination temperature. Optimum temperatures for germination of non-dormant seeds were higher than those of partially dormant seeds.

Introduction

It is well known that there are so-called 'cardinal temperatures'—minimum, optimum and maximum—when seeds germinate. In *Brassica* species, germination temperature has not been studied systematically, though some reports are found (2, 3, 11, 12). In particular, there are no reports dealing with the process of germination behaviour of seeds with the lapse of time. The present study was conducted to examine the germination of seeds at different temperatures in various crops of *Brassica*.

Materials and Methods

Materials in the present study were seeds of eleven crops in *Brassica* (Table 1). Potherb mustard, rape and leaf mustard had been maintained at Ehime University and sometimes used in the studies of seed dormancy (4, 5, 6, 7, 8, 9, 10). Red cabbage was kindly

supplied by Dr. C. Gomez-Campo, Madrid, Spain. The other crops were obtained from some commercial seed firms.

Germination tests were begun at 0 a. m. on November 23, 1980, in Chinese cabbage, red cabbage, rape and leaf mustard, and on January 27, 1981, in other crops. Petri-dishes, in which seeds were laid on two sheets of blotting paper moistened with water, were placed in the thermostat. The tests were conducted at five different temperatures, i.e., 5, 15, 25, 35 and 45°C. In every crop, 200 seeds were employed at each temperature. Radicle protrusion through the seed coat was regarded as germination. The number of germinated seeds was recorded every two hours until 60 hours after sowing. After that, counting of germinated seeds was done at 12 or 24 hour intervals until about 300 hours, and water was sometimes added to the petri-dishes during this period.

¹ Received for publication March 11, 1985.

Table 1. Materials used in the germination test of seeds.

Species (<i>Brassica</i>)	Crops	Cultivars
<i>B. campestris</i> L. (pekinensis group) [<i>B. pekinensis</i> Rupr.]	Chinese cabbage	Matsushima No.2
<i>B. campestris</i> L. (chinesis group) [<i>B. chinensis</i> L.]	Chinese mustard	Seppaku taisai
<i>B. campestris</i> L. (rapifera group) [<i>B. rapa</i> L.]	turnip	Hakutaka kokabu
<i>B. campestris</i> L. ssp. <i>purpuraria</i> Bailey	purple mustard	Hong cai tai
<i>B. campestris</i> L. (japonica group) [<i>B. japonica</i> Sieb.]	potherb mustard	Mizuna
<i>B. oleracea</i> L. (capitata group) [var. <i>capitata</i> L. f. <i>rubra</i>]	red cabbage	Spanish cultivar (name unknown)
<i>B. oleracea</i> L. (gemmifera group) [var. <i>gemmifera</i> Zenk.]	Brussels sprouts	Hisui
<i>B. oleracea</i> L. (gongylodes group) [var. <i>gongylodes</i> L.]	kohlrabi	Grand Duke
<i>B. napus</i> L. ssp. <i>oleifera</i> (Metzg.) Sinsk.	rape	Chusei natane
<i>B. × napus</i> hort. [a synthesized (head-forming) leaf vegetable]	'Hakuran'	New Hakuran
<i>B. juncea</i> Czern. et Coss. (cernua group) [var. <i>cernua</i> Jorb et Hem.]	leaf mustard	Hakarashina

Results

1. Process of seed germination

Cumulative percentage germinations at dif-

ferent temperatures were plotted in every crop. In Fig. 1, however, only three crops, i. e., leaf mustard, potherb mustard and rape, are presented as examples.

Fig. 1 Progress of cumulative percentage germination of seeds in leaf mustard, potherb mustard and rape.

1) *Leaf mustard*

In leaf mustard, seeds at 35°C began to germinate at 14 hours after sowing, and, after that, the germination percentage increased rapidly and reached 99% at about 50 hours. Seeds at 25°C began to germinate at 18 hours. The germination curve of this seed lot was not so steep as that at 35°C. The germination percentage reached 100% at about 100 hours. The time when seeds at 45°C began to germinate was 30 hours after sowing. They showed a maximum germination (79%) at 110 hours. Thereafter, they did not germinate any more. The start of seed germination at 15°C was delayed, being at 54 hours after sowing. It took 270 hours for seeds to attain 98% germination. The germination of seeds at 5°C was much later and slower. They began to germinate at 92 hours and the final germination percentage was 83% at the end of the experiment.

2) *Potherb mustard*

In potherb mustard, the germination of seeds at 35°C began much earlier than that of leaf mustard at the same temperature. That is, they began to germinate at 8 hours after sowing. The germination curve rose very rapidly in a short time, and almost all seeds finished their germination at 24 hours after sowing. In seeds at 25°C, which began to germinate at 12 hours, the germination curve had a steep slope similar to that at 35°C. The germination percentage reached 98% at about 30 hours. Though seeds at 45°C began to germinate as early as those at 35°C, their germination was generally slow. Even after 300 hours the germination percentage remained 49%. The germination curve of seeds at 15°C rose to a certain high level in a comparatively short time, after the germination began at 46 hours. The germination percentage reached 90% at 90 hours, though 260 hours were required for 98% germination. The germination of seeds at 5°C was late and slow. The beginning time of germination was 96 hours after sowing, and the final germination percentage was 78%.

3) *Rape*

In rape, seeds at 35°C began to germinate at 10 hours after sowing. The germination

curve of this seed lot closely resembled that of potherb mustard at the same temperature, showing a very steep slope. In the case of seeds at 25°C, germination began at 14 hours after sowing. They presented a germination curve similar to that of potherb mustard at 25°C. At 45°C, the time when seeds began to germinate was as early as 12 hours after sowing. However, owing to their slow germination, the germination percentage remained 59% at the end of the experiment. Seeds at 15°C began to germinate at 32 hours after sowing and reached 100% germination at 80 hours. The germination of seeds at 5°C was late and slow. They began to germinate at 60 hours after sowing, and the final germination percentage was only 46%.

4) *Other crops*

In the crops other than the above-mentioned three, there were more or less variations in the pattern of germination curves. If they are roughly grouped according to the similarity of their patterns, the following can be made. (1) leaf mustard type : Chinese cabbage and turnip ; (2) potherb mustard type : Chinese mustard, purple mustard, red cabbage, Brussels sprouts and kohlrabi ; (3) rape type : 'Hakuran'.

2. *Earliness or lateness of the start of germination*

Table 2 shows the time from sowing to the start of germination at different temperatures

Table 2. Time from sowing to the start of germination in *Brassica* seeds at different temperatures.

Crops	Germination temperature				
	45°C	35°C	25°C	15°C	5°C
	hrs.	hrs.	hrs.	hrs.	hrs.
Chinese cabbage	8	8	16	48	82
Chinese mustard	8	8	12	30	92
Turnip	10	8	10	48	70
Purple mustard	10	8	8	22	54
Potherb mustard	8	8	12	46	96
Red cabbage	26	12	14	52	84
Brussels sprouts	10	14	18	38	98
Kohlrabi	8	8	20	54	134
Rape	12	10	14	32	60
'Hakuran'	8	8	22	38	134
Leaf mustard	30	14	18	54	92
Mean	13	10	15	42	91

with respect to 11 different crops. In every crop, except Brussels sprouts, the earliest germination was found at 35°C. Seeds at 35°C began to germinate at 8 to 14 hours after sowing. On the other hand, the latest germination was observed at 5°C in all crops, among which there was a wide variation in the starting time of germination ranging from 54 to 134 hours. As far as the temperature range between 35 and 5°C is concerned, germination became later and its variation became wider in the decreasing order of temperature: 35, 25, 15 and 5°C. As a whole, seeds at 45°C began to germinate as early as those at 35°C. In Brussels sprouts seeds at 45°C began to germinate earlier than at 35°C. In red cabbage and leaf mustard, however, germination at 45°C was much later than at 25°C.

3. Mean germination period

Table 3 presents average time required for germination (mean germination period). In every crop, mean germination period was shortest at 35°C, and shorter at 25°C. Seeds at these temperatures were followed by those at 15°C in some crops or at 45°C in others. The longest period was needed for germination at 5°C. In Brussels sprouts and kohlrabi, however, seeds at 45°C had the same length of period as at 35°C, and in rape germination period was longest at 45°C. In conclusion, germination was rapid at the temperature of 35 and 25°C in every crop. This

Table 3. Average time required for germination.

Crops	Germination temperature				
	45°C	35°C	25°C	15°C	5°C
	hrs.	hrs.	hrs.	hrs.	hrs.
Chinese cabbage	44	17	26	109	196
Chinese mustard	67	17	25	49	124
Turnip	41	13	22	96	175
Purple mustard	92	15	20	47	92
Potherb mustard	127	13	20	83	211
Red cabbage	84	20	27	87	180
Brussels sprouts	47	48	50	88	148
Kohlrabi	45	46	46	104	223
Rape	175	14	21	47	124
'Hakuran'	84	38	48	105	241
Leaf mustard	56	25	52	114	176
Mean	78	24	33	85	172

rapidness of germination extended to either higher temperature range (45°C) or to lower temperature one (15°C) according to crops. About half of the crops showed the extension to the higher temperature, and the rest half to the lower one.

4. Germination Percentage

Germination percentage at the end of the experiment differed according to crops (Table 4). In all of the crops, seeds at 35, 25 and 15°C showed good germination (more than 85%), whereas low percentages of germination were frequently found at 45 or 5°C. Each crop could be classified into one of the following three groups in terms of the temperatures at which low percentages, say, less than 85%, were observed. (1) Crops showing bad germination at 45°C only were Chinese mustard, purple mustard, red cabbage and Brussels sprouts, (2) those at 5°C only were Chinese cabbage and turnip, and (3) those at both 45 and 5°C were potherb mustard, kohlrabi, rape, 'Hakuran' and leaf mustard. Average percentages of germination in the whole crops were 98% at 35 and 25°C, 96% at 15°C, 77% at 5°C, and 50% at 45°C.

Table 4. Percentage germination of *Brassica* seeds at different temperatures.

Crops	Germination temperature				
	45°C	35°C	25°C	15°C	5°C
	%	%	%	%	%
Chinese cabbage	95	100	97	87	83
Chinese mustard	19	97	96	99	91
Turnip	95	97	99	85	50
Purple mustard	7	99	98	100	98
Potherb mustard	49	99	98	98	78
Red cabbage	82	100	99	100	100
Brussels sprouts	3	98	97	97	92
Kohlrabi	12	97	98	96	76
Rape	59	100	99	100	46
'Hakuran'	47	89	96	93	54
Leaf mustard	79	99	100	98	83
Mean	50	98	98	96	77

Discussion

Kotowski (3) carried out the germination tests of various vegetable seeds at different temperatures and found that the highest number of seedlings was obtained at 8°C for

cabbage, but the number of seedlings was equal within the interval between 8 and 18°C for cauliflower. According to Toole and Toole (11), the temperatures at which non-terminant seeds showed germination of more than 50% were 15 to 25°C in Argentine bird rape (*Brassica campestris*), and 10 to 30°C in Indian bird rape (*B. campestris*) and leaf mustard (*B. juncea*). In *B. nigra*, a comparatively high percentage of germination, i.e., about 80%, was found at temperatures between 10 and 25°C. Inagawa and Miyase (2) found that optimal temperatures for seed germination were 15 to 25°C in turnip, 15 to 35°C in Chinese cabbage, and 15 to 30°C in cabbage. Toole *et al.* (12) reported optimal temperatures for germination to be in the region of 15 to 25°C in *B. juncea* seeds. Since 'optimal' temperatures are usually indicated by the temperatures at which seeds can germinate in large numbers, it may be necessary to examine the range of temperatures at which more than 90% of seeds could germinate in each crop of the present experiment. Such ranges of temperatures were 5 to 35°C in Chinese mustard, purple mustard, red cabbage, and Brussels sprouts, 15 to 35°C in potherb mustard, kohlrabi, rape, 'Hakuran', and leaf mustard, and 25 to 45°C in Chinese cabbage and turnip (Table 4). From the above data obtained by the different authors as well as by the present experiment, it is inferred that optimal temperature ranges differ more or less with cultivars or strains even in the same species. Further, no direct relation could be noticed between genomic constitutions of species and optimal temperature ranges. For instance, Chinese cabbage, Chinese mustard, turnip, purple mustard, and potherb mustard are classified into the same A-genomic species ($n=10$), but their optimal temperature ranges are not always the same. Such differences may be caused not only by genetic traits of seeds but also by environmental backgrounds in which seeds were harvested. As a whole, however, it may be concluded that in *Brassica* species, on an average, germination percentages are high at temperatures between 15 and 35°C, low at 5°C, and very low at 45°C

(Table 4).

As for the start and duration of seed germination, a marked feature is noticed within the temperature range between 35°C and 5°C (Tables 2 and 3). In every crop the temperature at which seeds germinated earliest and fastest was 35°C. Then, the start of germination became later and the time required for germination became longer as temperatures declined from 35 to 5°C. Finally, seeds at 5°C showed the latest and slowest germination. In conclusion, the start and duration of seed germination are inversely proportional to temperatures, as far as the temperature range between 35 and 5°C is concerned. This tendency was the same in all the crops examined here and also in cabbage and cauliflower treated by Kotowski (3). However, seeds subjected to 45°C were differently affected. In many crops seeds at 45°C began to germinate as early as those at 35°C, but in some crops the start of germination was much delayed (Table 2). Further, at 45°C the mean germination period of seeds was more variable than the starting time of germination. In many crops the length of mean germination period at 45°C fell within that of the period found between 25 and 5°C (Table 3), but in some crops much shorter or much longer period was needed for germination. Roughly speaking, the effect of very high temperature such as 45°C is promotive for the start of germination, and inhibitive for the duration and percentage of germination. Therefore, it seems that each of germination factors, i.e., the start, duration and percentage of germination, may be separately affected by the temperature.

Curves of cumulative germination in seeds whose germination was rapid were typically sigmoid as shown at 35 and 25°C (Fig. 1). However, as the germination period became longer, curves became stretched and sometimes quasi-linear as found at 15, 45 or 5°C. Edwards (1) stated that soybean seeds at different germination temperatures showed all sigmoid curves of similar type and the only difference among temperatures was starting points at which germination began. The temperature range in his experiment, how-

ever, was between 24.5 and 40°C. If temperatures were extended beyond this range, sigmoid curves would be deformed and stretched as seen in the present experiment. In *Brassica*, the steepness of slope of curves is related to the duration of germination and neither necessarily to the starting points nor to the percentage of germination.

The germination response of seeds to different temperatures as described above was that of seeds whose dormancy was completely removed, as evidenced by 96-100% germination at favorable temperatures (Table 4). This response is different from that of dormant seeds. Tokumasu *et al.* (9) demonstrated the germination response of seeds taken from 0 to 12 weeks after harvest in three crops: leaf mustard, potherb mustard and rape. These seeds were in the course of removal of dormancy, that is, so-called after-ripening. In leaf mustard, germination began at 15°C, which was followed by 25, 35, 5 and 45°C in sequence. In potherb mustard, seeds germinated simultaneously at 15, 25 and 35°C, and later at 5 and 45°C. In rape, the earliest germination was found at 5°C, but seeds in this lot were surpassed by those at 15 and 25°C after a week. Later germination was shown at 35°C and latest at 45°C. These results support the opinion of Vegis (13) that freshly harvested seeds begin to germinate only at a certain comparatively low temperature and, with the advance of after-ripening, they widen temperature ranges at which they can germinate. This phenomenon was also shown in *B. campestris* and *B. juncea* (11). In short, 15 to 25°C were favorable for the germination of partially dormant seeds in *Brassica*, and the most favorable was probably 15°C or a little above. These temperatures are low as compared with favorable temperatures (25~35°C) proved in the present experiment for germination of non-dormant seeds.

Literature cited

1. EDWARDS, S. T. I. 1934. Relations of germinating soybeans to temperature and length of incubation time. *Pl. Physiol.* Lancaster 9: 1-30.
2. INAGAWA, T. and I. MIYASE. 1943. Minimum, optimum and maximum germination temperatures in vegetable seeds (In Japanese). *Agric. & Hort.*, Tokyo 18: 763.
3. KOTOWSKI, F. 1927. Temperature relations to germination of vegetable seeds. *Proc. Amer. Soc. Hort. Sci.* 23: 176-184.
4. TOKUMASU, S. 1970. Prolongation of seed dormancy by dry storage in *Brassica japonica* Sieb. *J. Japan. Soc. Hort. Sci.* 39: 169-177.
5. TOKUMASU, S. 1971. Effect of dry and wet storage upon seed dormancy in cruciferous vegetables. *J. Japan. Soc. Hort. Sci.* 40: 23-28.
6. TOKUMASU, S. 1975. Prolonged dormancy in the seeds preserved in harvested fruits of *Brassica* vegetables. *Scientia Hort.* 3: 267-273.
7. TOKUMASU, S. 1977. Seasonal periodicity of the loss of dormancy of imbibed seeds in *Brassica* vegetables. *Scientia Hort.* 6: 101-106.
8. TOKUMASU, S., M. KATO and F. YANO. 1975. The dormancy of seed as affected by different humidities during storage in *Brassica* (In Japanese with English summary). *Japan. J. Breed.* 25: 197-202.
9. TOKUMASU, S., S. KAMEI and M. KATO. 1981. Effects of storage humidity and germination temperature on germination percentage of *Brassica* seeds (In Japanese with English summary). *Japan. J. Breed.* 31: 109-120.
10. TOKUMASU, S., F. KAKIHARA and M. KATO. 1981. The change of dormancy of seeds stored in desiccators and/or harvested fruits in cruciferous crops (In Japanese with English summary). *J. Japan. Soc. Hort. Sci.* 50: 208-214.
11. TOOLE, E. H. and V. K. TOOLE. 1939. Germination of some *Brassica* types at different temperatures. *Proc. int. Seed Test Ass.* 11: 51-56.
12. TOOLE, E. H., V. K. TOOLE, H. A. BORTHWICK and S. B. HENDRICKS. 1955. Interaction of temperature and light in germination of seeds. *Plant Physiol.* 30: 473-478.
13. VEGIS, A. 1964. Dormancy in higher plants. *Ann. Rev. Plant Physiol.* 15: 185-224.

1. EDWARDS, S. T. I. 1934. Relations of germinating soybeans to temperature and length

アブラナ属作物種子の発芽に対する温度の影響

徳増 智・金田 泉・加藤正弘

愛媛大学農学部 790 松山市樽味

摘 要

アブラナ属作物 11 種類の種子を用いて、5, 15, 25, 35 及び 45°C の 5 段階の温度で発芽試験を行い、置床後 2 時間ごとに発芽種子数を調べ、種類による発芽のパターンを比較した。累積発芽率の経時的推移を見ると、種類によってのパターンは異なるが、共通した傾向も認められる。

各作物種子ともに、最も早く発芽を開始したのは 35°C で、次いで 25, 15, 5°C と温度が低下するにつれて発芽は遅くなり、また、種類による発芽開始時期の変異幅が大となった。45°C では 35°C と同時期に発芽を開始するか、またそれより遅く、種類によって異なった。

平均発芽期間は 35°C が最も短く、25°C がこれに次い

だ。さらに、作物の種類により 15°C または 45°C が続き、5°C はいずれの作物でも発芽に最長の時間を要した。

実験終了時における最終発芽率を見ると、35, 25 及び 15°C ではいずれの場合も 85% 以上の良好な発芽率を示した。その他の温度区では作物の種類により発芽率が 45°C のみで低いもの、5°C のみで低いもの、また 45°C 及び 5°C の両方で低いものに分けられた。

以上の結果から、休眠の覚醒した種子の最適発芽温度は 25°C から 35°C で、これは休眠覚醒途上種子の最適発芽温度が 15°C 以下であるのに比べて明らかに高い。