

THE EFFECT OF TEMPERATURE ON GERMINATION OF
RAPESEED (BRASSICA NAPUS L. AND BRASSICA CAMPESTRIS L.)
AND
MUSTARD (BRASSICA JUNCEA (L.) CZERN AND (SINAPIS ALBA L.)

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Teresio Caesar Riungu

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The Effect of Temperature on Germination of Rapeseed (Brassica napus L. and Brassica campestris L.) and Mustard (Brassica juncea L.) Czern and (Sinapis alba L.).

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ABSTRACT

Riungu, Teresio Caesar. M.Sc., The University of Manitoba, February, 1984. The Effect of Temperature on Germination of Rapeseed (*Brassica napus* L. and *Brassica campestris* L.) and Mustard (*Brassica juncea* (L.) Czern and *Sinapis alba* L.). Major Professor; B.R. Stefansson.

The effect of temperature on germination of rapeseed and mustard was investigated. The objectives were, to determine minimum, optimum and maximum temperatures, effect of temperature on germination percentage and germination rate, response of varieties on exposure to low and high temperatures and seed source effect on germination percentage and germination rate.

The study was conducted on seed of Canadian varieties and an Indian variety, in petri-dishes at constant temperatures in the laboratories.

There was significant temperature effect on varieties of Brassica species studied. Low and high temperatures had induced greater variability on germination percentage and germination rate than intermediate temperatures. Germination percentage and germination rate increased as temperature increased up to an optimum and declined when temperature increased above the optimum. The minimum, optimum and maximum temperature varied with varieties but for the mean of all varieties tested, they were, less than 5°C, from

20°C to 30°C and less than 40°C respectively. Temperatures for maximum germination percentage and germination rate were 25°C and 30°C respectively. At low and high temperatures, germination percentage and germination rate decreased as exposure period increased. Seed source had significant effect on germination percentage and germination rate.

INTRODUCTION

Rapeseed and the mustards belong to the genus Brassica of the family cruciferae. They are believed to have originated in the Mediterranean region and in Asia. The early records suggest that rapeseed was cultivated in India as early as 2000 BC and introduced into China and Japan around the time of Christ (Hougen and Stefansson 1982). The cultivation is believed to have begun in Europe in the 13th century. Hougen and Stefansson (1982) stated that due to stimulation of government guaranteed prices, rapeseed production began in Canada in 1943, while production of the mustard began in 1936.

Rapeseed and the mustards are grown for oil and meal production; the oil is used for food or industrial purposes and the meal is used as animal feed. Rapeseed is one of the world's major edible vegetable oil seeds. This crop supplies about 8% of the world's edible oil. Improvement in production and quality has led to large scale exports of rapeseed from Canada.

Seeds pass genetic information from generation to generation. The initial process of development is germination.

Germination which has been defined as radicle emergence (Kotowski 1926) is the outward biological expression of physiological, biochemical and morphological changes which

begin with water uptake and finally transform a seed into a seedling (Hegarty 1972 and Rebecca et al. 1977).

Seed germination and subsequent seedling establishment are influenced by both internal and external factors. The external factors include water, temperature, gases, light and pathogens.

The experiments in this study were limited to temperature in an attempt to obtain a better basic understanding of the effect of temperature on germination and also because of time available.

Efforts are being made to develop winter rapeseed (Canola) cultivars suitable for certain parts of Canada. Low temperature may reduce germination capacity and rate. By reducing the rate of germination, the seeds may become more vulnerable to soil borne pathogenic invasion. High temperature at germination may also affect germinability. A study on effect of temperature on germination was undertaken to provide information that can be used to facilitate selection in the laboratory or in the field.

The seeds used were mainly from Canadian cultivars of rapeseed and the mustards, and on the basis of information obtained from Canadian cultivars, Brassica campestris lines from India were used.

The information on the effect of temperature on germination of rapeseed and the mustards appear to be incomplete because of insufficient temperature ranges used in most of

the earlier studies. The experiments described in this thesis were undertaken to provide more complete information for a wide range of temperatures using cultivars grown in Canada.

The objectives of this study were to determine:

- (a) Minimum, optimum, and maximum germination temperatures.
- (b) Effect of temperature on germination percentage and germination rate.
- (c) Effect of temperature on germination response of different varieties.
- (d) Effect of low temperature on germination percentage and germination rate.
- (e) Effect of high temperature on germination percentage and germination rate.
- (f) Effect of temperature on germination percentage and germination rate of varieties grown at different locations.

LITERATURE REVIEW

Germination is the outward biological expression of physiological, biochemical and morphological changes which begin with water uptake and finally transform a seed into seedling (Hegarty 1972 and Rebecca et al. 1977).

except B. nigra that contained considerable immature, undeveloped seed germinated well over a wide range of temperatures. They also found that seeds of B. campestris germinated very well at constant temperatures, and better (but not completely) at various alternations of temperatures. The same experiment showed that, seeds of B. juncea when tested, immediately after harvest, germinated well only at very low temperatures.

Kumar and Alka (1977) investigated the influence of increasing temperature on the germination of seed of B. campestris. The results showed that germination of seeds was favourably affected with increasing temperature up to 30°C but above 30°C, germination declined indicating that 30°C was the optimum temperature for germination of B. campestris seeds.

The effect of low and high temperature on the germination of rapeseed and niger seed was studied by Pasha and Salehuzzaman (1978). In both species, germination was stimu-

temperature at which it germinates. The minimum temperature for white mustard was found to be 0°C. He also stated that if temperature is too low, germination is prevented.

Eben et al. (1938) studied germination of some Brassica species (B. campestris, B. nigra and B. juncea) at different temperatures. They found that seeds of all species tested except B. nigra that contained considerable immature, undeveloped seed germinated well over a wide range of temperatures. They also found that seeds of B. campestris germinated very well at constant temperatures, and better (but not completely) at various alternations of temperatures. The same experiment showed that, seeds of B. juncea when tested, immediately after harvest, germinated well only at very low temperatures.

Kumar and Alka (1977) investigated the influence of increasing temperature on the germination of seed of B. campestris. The results showed that germination of seeds was favourably affected with increasing temperature up to 30°C but above 30°C, germination declined indicating that 30°C was the optimum temperature for germination of B. campestris seeds.

The effect of low and high temperature on the germination of rapeseed and niger seed was studied by Pasha and Salehuzzaman (1978). In both species, germination was stimulated at high temperature. However, the low temperature treatment did not affect the ultimate germination capacity.

In B. campestris, rate of germination and percentage of germination could be increased with the exposure of 8 hours at 35°C while in Guizotia abyssinica, only percentage of germination increased.

Meta Bihlmeir reviewed by Edward (1932) studied the relationship of temperature and light for germinating seeds of ten species of Labiatae and Cruciferae. He found that the optimal temperature for germination was the same from tests with and without light.

A study of selection and heritability on canola/rapeseed for low temperature was conducted by Achaya et al. (1983). They used B. napus and B. campestris varieties at temperatures 5°C, 7.5°C, 10°C, 15°C, 20°C and 25°C. Their results showed that genotypes tested differed in their ability to germinate and grow over the range of temperatures applied. Germination rate was found to decrease with decreasing temperature irrespective of genotype. Selection within canola cultivars was successful but canola genotypes available displayed a limited variability.

Went (1957) reported that some plant seeds, including those of Brassica arvensis have a marked optimum in germination at relatively low temperatures.

Thompson (1970) reported results that confirmed observations by other workers relating germination behaviour at low temperatures to geographical distribution.

Earlier, Edward (1932) in his review stated that the lowest temperature at which germination had been observed showed very slow responses, requiring long incubation periods. Failure to germinate at low temperature within a given period does not necessarily imply germination might not be possible with prolonged incubation.

Bryan et al. (1973) put forward the assumption that retardation of germination at low temperature is due to formation of inhibitors whose rate of formation increases with decrease in temperature. Experiments with Brassica arvenses at low temperature without use of charcoal for inhibitor absorption showed germination retardation.

Tokumasu and Kato (1980) working with Brassica seeds (B. japonica, B. cernua and B. napus) at temperatures 5, 15, 25, 35 and 40°C found that the optimum temperature for germination of B. napus was from 15°C to 35°C. Minimum temperature in every species was shown to be below 5°C. The maximum temperature for B. napus seeds was indicated to be above 45°C. When seeds were dormant, seeds began to germinate at 15°C, which was followed by 25°C, 35°C, 5°C and finally 45°C in every species but when dormancy was removed, seeds could germinate at all the temperatures, 5°C to 45°C.

The optimum temperature for germination is markedly affected by previous treatment of seed, or its age. Went (1953) working with Brassica species found that optimal temperature increased from 5°C or 10°C to 20°C-25°C in the course of 7 months of storage.

Harrington (1921) performed experiments on seed germination from which he stated that warm temperature usually increases the rapidity of germination, but comparatively low temperature decreases germination capacity and increases time required.

Coffman (1923) studied the minimum temperature at which seeds of different common plants would germinate. His results indicated that seeds of different species germinate differently at different temperatures. He also found that within a given species, oily seeds resist low temperature more than starchy ones.

Temperature relations to germination of vegetable seeds was investigated by Kotowski (1926). He found that for all species, the rate of germination increased as the temperature increased.

Gordon (1971) studied the relationship between rate of germination and total germination percentage in cereals and conifers. He found that germination resistance is invariably linked with percent germination. The percentage is initially low and the resistance is high. The resistance then gradually declines as the percentage increases, although the resistance is still not at its lowest when the percentage has first reached its maximum. He also showed that differences in resistance existed within species or cultivars. This is an indication of genetic control. Further analysis of data on barley grown at different locations was conducted. The

analysis showed that there were significant differences among cultivars and between location and cultivar X location interaction in germination resistance.

Naylor and Abdalla (1982) using seeds of Poa annua and Alopecurus myosuroides, also showed that there was variation in the mean germination time (rate) between populations of similar germinability.

Experiments on genotype by environment interaction have been performed by several researchers. Witcombe and Whittington (1971) using seeds of Brassica napus demonstrated that there was genotype by environment interaction for germination in a range of temperatures and different water potential environments.

Achaya et al. (1983) investigated heritability characters of germinability of canola/rapeseed at low temperatures. The results indicated complex inheritance and a very strong influence of environment.

Germination behaviours, which are heritable characteristics can be classified into different types by germination responses to environmental factors. Norido et al. (1980) using different kinds of Brassica species seeds from different habitats found that germination behaviours were affected by the environments in their native habitats.

MATERIALS AND METHODS

General Procedures

The experiments were conducted in laboratories at the University of Manitoba in 1981 and 1982. Seeds of four species of rapeseed and mustard were used. The four species were Brassica napus L., Brassica campestris L., Brassica juncea (L.) Czern and Sinapis alba L. The species B. napus and B. campestris included in rapeseed are commonly known as summer rape and summer turnip rape respectively. B. juncea and Sinapis alba are known as leaf mustard and white mustard respectively.

The varieties used in all experiments except experiment four were; two from B. napus (Regent and Reston from University of Manitoba), three from B. campestris (Span, Torch and Candle from the Canada Agriculture Department in Regina), one from B. juncea (Lethbridge 22A from the Lethbridge Research Station) and one from Sinapis alba (Ochre from Saskatoon). B. campestris variety Toria originally from India was used later at four temperatures (5°C, 25°C, 40°C and 45°C) for comparison purposes, after other varieties failed to germinate at 40°C.

The seeds for all varieties were stored under low temperature (4°C).

The seed sizes for each variety were standardized by successive sieving with appropriate sieves.

Fifty seeds per petri-dish were counted using a vacuum seed counter. The seeds were then dusted with fungicide Benlate T (30% Benomyl + 30% Thiram + 40% other ingredients) to prevent fungal growth.

Germination was conducted in covered 9 cm petri-dishes on top of 2 Fisher brand filter papers No. 9-801B. The filter papers in each petri-dish were moistened with five millilitres of de-ionized water (International Seed Testing Association 1976). Before use, the water was brought to the temperature of the germinator by heating or cooling it and then keeping it in the germinator until it attained the temperature of the germinator at which the test was to be carried out.

Tests were carried out in germination cabinets for low temperatures (from 3°C to 30°C) and in an oven for higher temperatures (from 35°C to 45°C). The high relative humidity in the germinator or oven was maintained by using a humidifier or by keeping water in the germinator.

The tests were conducted at constant temperatures. The temperature constancy was re-checked by using a minimum and maximum thermometers in the germinators.

The experiments were laid down as randomized complete block design (RCBD) with four replications.

Germination counts were taken 24 hours after the beginning of exposure to temperature under test, until no

further germination was observed or the number of days aimed for the test had elapsed.

The seed was considered germinated when the radicle was distinctly visible (Figure 1). The data collected was used to calculate germination percentage and germination index.

Germination index values were derived by following the formula:

$$\frac{(n \times z)}{N} \quad (\text{Heydecker 1966})$$

Where n = the number of seeds germinated daily.

z = the number of days since seed was set for germination.

N = total number of seeds germinated at the end of test period.

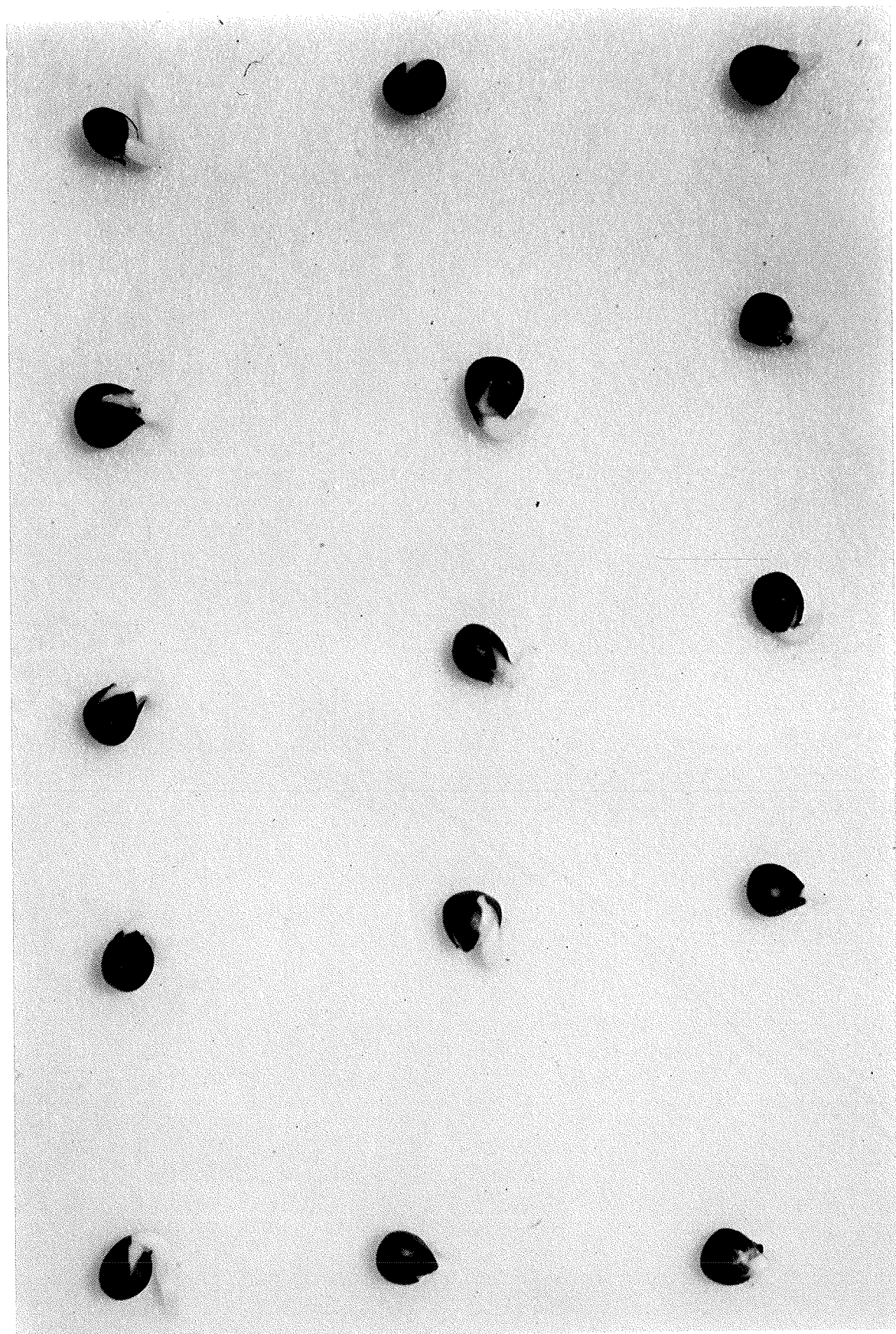
The germination index provides an indication of the rate of germination. The index is high when germination rate is low, and low when germination rate is rapid. Thus there is an inverse relationship between germination rate and germination index (Dubetz et al. 1961 and Gordon 1971).

Experiment 1. Effect of temperature on the germination of seven varieties of Brassica species at ten temperatures.

The objectives were to determine:

- (a) Minimum, optimum and maximum temperatures.
- (b) Effect of temperature on germination percentage and germination rate.
- (c) Effect of temperature on the response of varieties.

FIGURE 1. Stage at which seeds of Brassica species were considered to be germinated.



Seeds of the seven varieties belonging to four species were studied. Tests were carried out in darkness at temperatures, 3°C, 5°C, 10°C, 15°C, 20°C, 25°C and 30°C in a germination cabinet and 35°C, 37°C and 40°C in an oven. In the oven, the filter papers in the petri-dishes were kept moist by adding 3 millilitres of de-ionized water after every two days. The germination percentage and germination index data was evaluated by standard analysis of variance for each temperature treatment and for each variety. A combined analysis over all temperatures for all the varieties was made using an analysis for split plot design. The comparisons of treatment means for germination percentage and germination index were made using Duncan's Multiple Range test. The analysis and test for significance between treatment means were carried out by using statistical analysis system (SAS) at the University of Manitoba computer centre. LSD (least significant difference) was calculated and the values are presented in figures illustrating the interactions.

Experiment 2. Effect of exposure to low temperature (3°C) on the germination percentage and germination rate at 25°C.

Effect of exposure to low temperature was studied on the seven varieties of the Brassica species. The temperature treatment used was 3°C. This temperature was the lowest temperature used in Experiment 1. Fifty-two petri-dishes

containing seeds were exposed to 3°C. Two petri-dish samples for each variety were transferred to 25°C (temperature found in Experiment 1 to give the highest mean germination) after exposure periods of 10, 20 and 30 days.

The number of seeds germinated at the time of transfer was counted and the germinated seeds were removed. Germination counts were taken after every 24 hours after the transfer, for a period of 10 days. The data collected was used to compute germination percentage and germination index.

Experiment 3. Effect of exposure to high temperature (40°C) on germination percentage and germination rate at 25°C.

The seven varieties of Brassica species were used in this experiment. The temperature treatment used was 40°C. This temperature was chosen because germination failed on all varieties in Experiment 1.

One hundred and fifty-four petri-dishes, each with fifty seeds were set in the oven. Samples of 2 petri-dishes were removed and transferred to germination cabinet at 25°C after one day to day six and after two days from day six to day sixteen. 25°C was used because Experiment 1 showed that germination percentage was highest at this temperature. Germination did not occur when seeds were exposed to 40°C, therefore no germination counts were obtained at the time of transfer.

After transfer to 25°C, germinated seeds were counted and removed daily for 10 days. No germination was observed

after 10 days. The germination counts obtained were used to calculate germination percentage and germination index.

Germination of varieties Toria, Regent and Ochre.

Germination of three lines of Brassica campestris variety Toria from India, and varieties Regent and Ochre was tested at 40°C and 45°C, and also later at 5°C and 25°C. The experiment was carried out because the seven Canadian varieties did not germinate at 40°C, but reports by Tukumaso and Kato (1980) and Kumar and Alka (1977) had indicated that germination of B. campestris varieties occurred above 40°C.

Fifty seeds per petri-dish, replicated four times, were set for germination at the four temperatures. Germination counts were taken after 30 days for seeds exposed to 5°C and after 10 days for seeds exposed to 25°C, 40°C and 45°C. After 10 days at 45°C, the samples were transferred to 25°C and germination counts were taken for 10 days after transfer. The data obtained was used to calculate germination percentage.

Experiment 4. Effect of temperature on germination percentage and germination rate of varieties grown at different locations.

The influence of temperature on germination was studied at 5°C and 25°C. The low temperature (5°C) was chosen to explore differences among varieties and the more moderate temperature (25°C) to provide an estimate of the germination of the seed. Other temperatures were not used because the seed samples were too small to permit testing at other temperatures.

The study was conducted using seed from five varieties of Brassica species. The five varieties included one from B. napus (Regent), two from B. campestris (Candle and Torch), one from B. juncea (Lethbridge 22A) and one from S. alba (Ochre). The seeds were obtained from cooperative rapeseed trials grown at six locations. The six locations were Melfort, Irricana, Morden, Indian Head, Scott and Winnipeg.

Fifty seeds of each variety from each location were placed in petri-dishes on moistened filter paper for germination. The design used was a split plot design with three replications per variety for each location at each temperature treatment.

Germination counts were taken after every 24 hours from the start of incubation. At 25°C germination was continued for a period of 10 days but at 5°C the exposure period was extended to 30 days.

Data collected from the daily counts was used to calculate germination percentage and germination index. Analysis of variance was used to evaluate germination percentage and germination index data. Duncan's Multiple Range Test was used to test significance between treatment means of varieties at relatively low temperatures.

Thompson, P.A. (1970) reported results that confirmed observations by other workers relating germination behaviour at low temperatures to geographical distribution.

RESULTS AND DISCUSSION

Results

Experiment 1. The effect of temperature on the germination percentage and germination rate for the seven varieties of Brassica species at ten temperatures.

Brassica napus Variety Regent

Germination Percentage

Germination percentage at different temperatures is shown in Figures 2 and 3. The percentage increased as the incubation temperature increased up to an optimum range, then decreased. Total germination percentage was high and not significantly different from 10°C to 30°C and ranged from 97% to 98%. The percentage decreased above and below 30°C. At 5°C the germination percentage was 90% and at 3°C it was 44%. Germination percentages at 35°C and 37°C were 72% and 3% respectively. No germination was obtained at 40°C. Analysis of variance for germination percentage (Appendix Table 10) showed significant temperature effect. Duncan's Multiple Range Test (Appendix Table 19) showed that there were significant differences between treatment means.

The days required for germination to begin and to be completed varied with the temperature. The most rapid germination was at 30°C where 46% of the seeds had germinated in one day. At 10°C, 20°C, 25°C and 35°C germination was also

observed after one day but the percentages were lower. At 15°C germination was observed on the 2nd day. At 10°C to 37°C germination was completed in approximately 4 to 8 days. At 5°C, no germination was observed until the 7th day and was completed in 26 days with germination percentage of 90%. At 3°C, no germination was observed until day 14; and only 44% was obtained after 30 days. At 37°C, no germination was obtained until the 7th day and then, only 3% was attained and no further germination occurred.

Germination Rate

Germination index values varied with temperature (Figure 3). The lowest germination index (1.63) at 30% as expected corresponds to most rapid germination at 30°C. The increase in germination index above and below 30°C within 15°C to 35°C, reflect the somewhat slower germination rate slightly above and somewhat below 30°C. The index values were higher at 10°C (4.79) and much higher at 5°C (15.65) and 3°C (22.25) indicating reduced rate of germination as temperature decreased. Germination index increased at 37°C (5.75). The index was infinite at 40°C because no seed germinated.

Analysis of variance for germination index (Appendix Table 10) showed that temperature effect was highly significant. Duncan's Multiple Range Test (Appendix Table 19) showed that treatment means differed significantly.

The minimum and maximum temperatures for germination of the variety Regent are, less than 5°C and less than 40°C (Appendix Table 3) respectively. Germination percent was high from 10°C to 30°C and germination index which indicated rapid germination was low from 20°C to 30°C (Appendix Table 19). On the basis of the highest germination percentages and rapid germination rates, the optimum temperature for germination of variety Regent is from 20°C to 30°C (Figure 3 and Appendix Table 19).

Brassica napus variety Reston

Germination Percentage

Germination percentages are presented in Figures 4 and 5. The percentage varied with incubation temperature. The total germination percentages were high and not significantly different from 5°C to 30°C and ranged from 91% to 98%. The percentages declined below 5°C and above 30°C. At 3°C the germination percentage attained was 81%, while at 35°C and 37°C the percentages were 68% and 4%, respectively. No germination was observed at 40°C.

Analysis of variance for germination percentage (Appendix Table 11) and Duncan's Multiple Range Test (Appendix Table 20) indicated that temperature effect was highly significant, and the treatment means differed significantly.

FIGURE 2. Germination of Brassica napus variety Regent at ten temperatures.

Legend:

◇ — ◇ 3 °C

▲ — ▲ 5 °C

■ — ■ 10 °C

● — ● 15 °C

× — × 20 °C

+ — + 25 °C

□ — □ 30 °C

△ — △ 35 °C

○ — ○ 37 °C

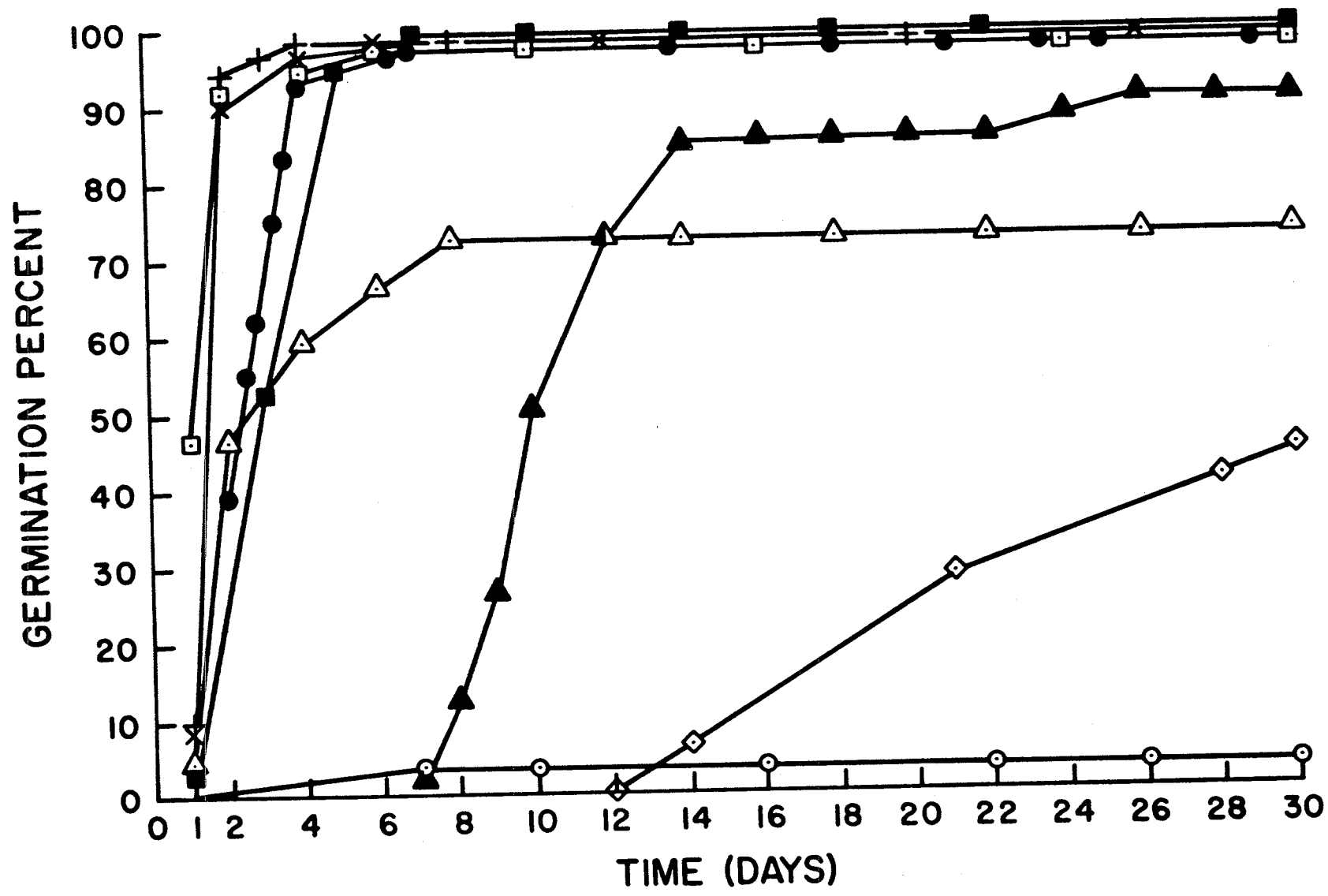
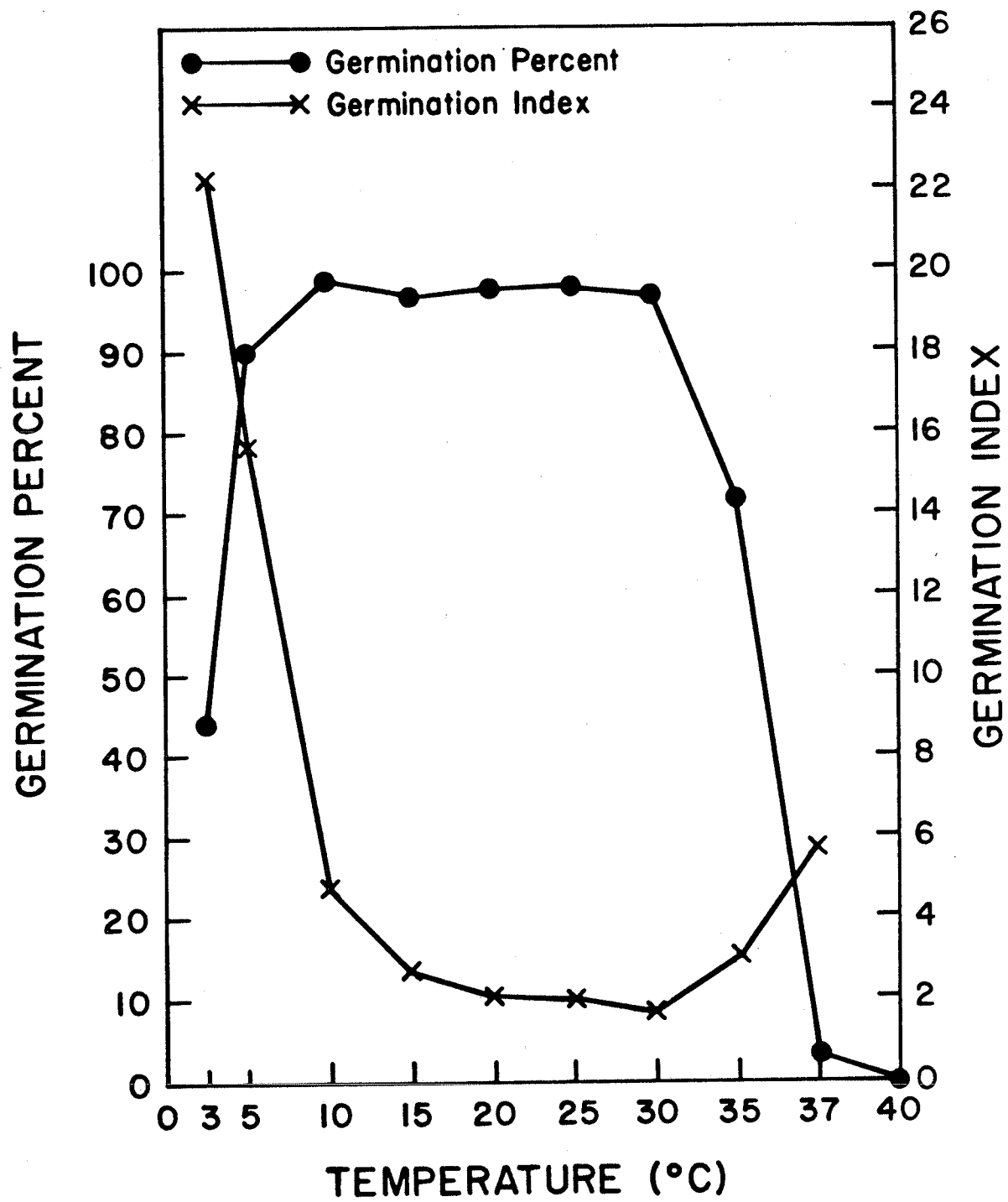


FIGURE 3. Effect of temperature on germination percentage and germination index of Brassica napus variety Regent.



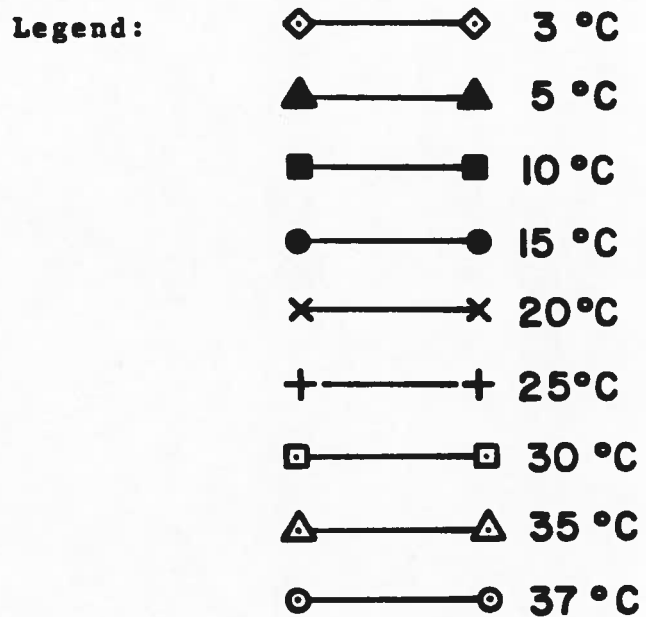
The days required for germination to begin and to be completed varied with temperature (Figure 4). The most rapid germination occurred at 30°C; 42% was obtained in 1 day. Germination was also observed after 1 day from 10°C to 35°C except at 15°C, but the percentages were lower. At 15°C germination was observed on the 2nd day. From 10°C to 35°C germination was completed in approximately 4 to 10 days. At 5°C germination was observed on the 7th day and at termination of experiment after 30 days, 97% of the seeds had germinated. At 3°C germination was observed on the 14th day and was completed on the 28th day with a percentage of 81%. At 37°C, germination was observed on the 3rd day and was completed on day 6 and only 4% germinated.

Germination Rate

Germination index values are presented in Figure 5. The temperature effect was highly significant (Appendix Table 11), and the treatment means differed significantly as determined by Duncan's Multiple Range Test (Appendix Table 20).

The lowest germination index (1.68) corresponding to most rapid germination was at 30°C. The index values increased above and below 30°C. From 25°C to 10°C the index ranged from 2.33 to 4.39. The index was high at 5°C (15.43) and higher at 3°C (20.45) indicating reduced rate of germination as temperature decreased. At 35°C and 37°C, the index values were 2.81 and 4.95 respectively

FIGURE 4. Germination of Brassica napus variety Reston at ten temperatures.



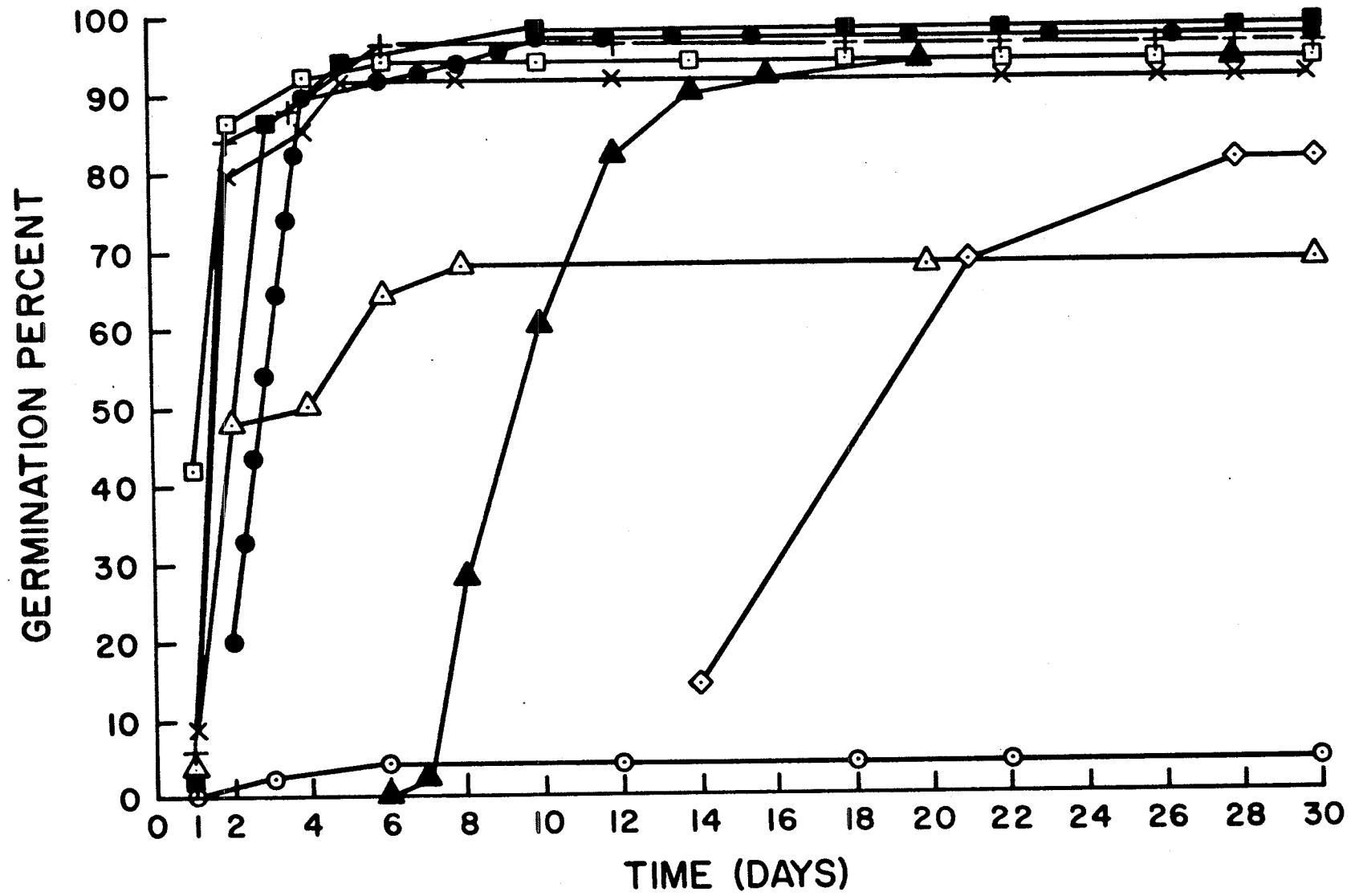
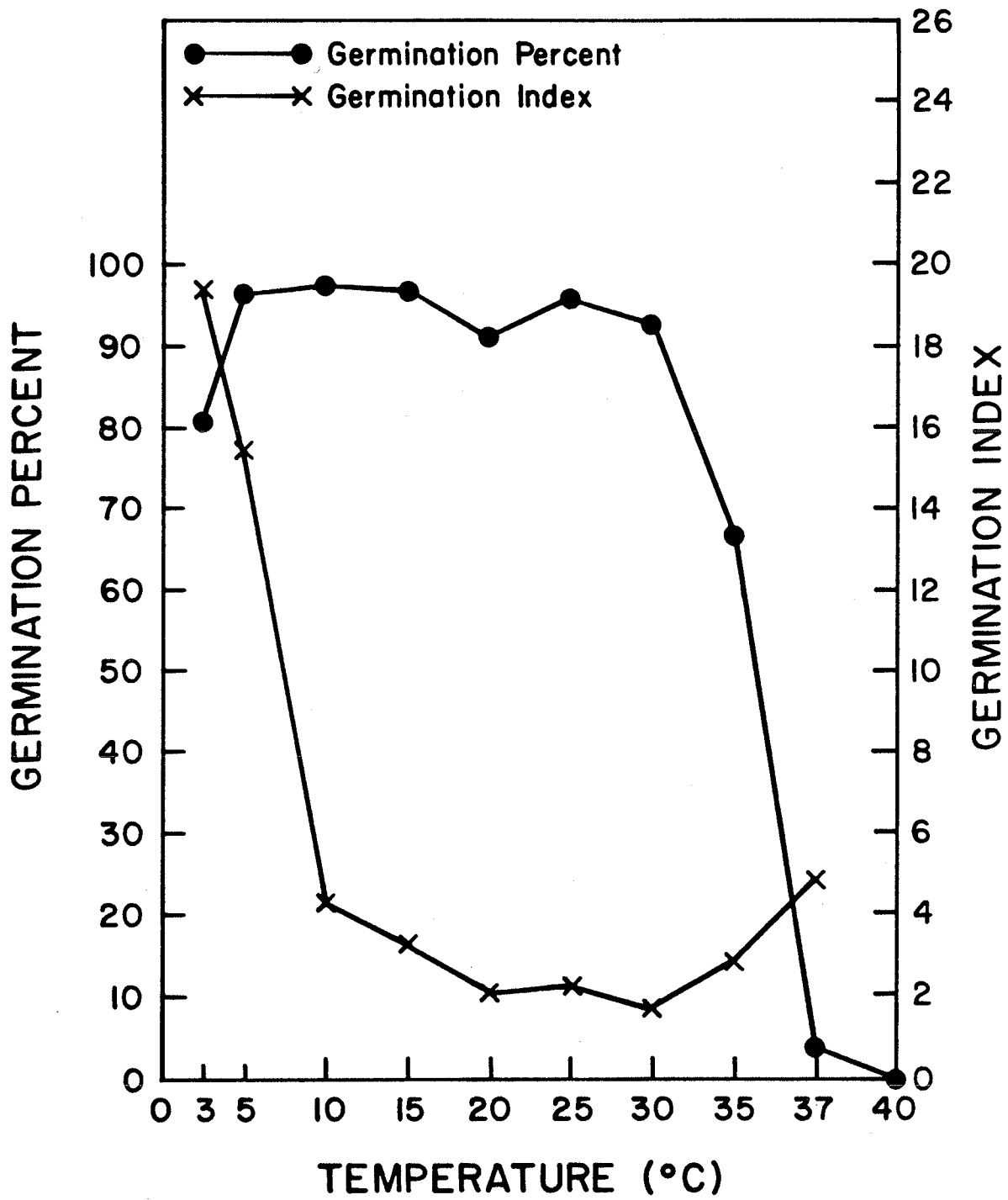


FIGURE 5. Effect of temperature on germination percentage and germination index of Brassica napus variety Reston.



reflecting reduced germination from too high a temperature. The index was infinite at 40°C because no seed germinated.

The minimum and maximum germination temperatures for variety Reston are, less than 5°C and less than 40°C respectively. Germination percentages were high from 5°C to 30°C (Figure 5 and Appendix Table 4). Germination index representing rapid germination rate was low from 20°C to 30°C. On the basis of the highest germination percentages and rapid germination rates, the optimum temperature for germination of variety Reston is from 20°C to 30°C (Figure 5 and Appendix Table 4).

Brassica campestris variety Span

Germination Percentage

Germination percentage varied with temperature (Figures 6 and 7). The temperature effect was highly significant (Appendix Table 12). Duncan's Multiple Range Test (Appendix Table 21) showed that treatment means differed significantly.

The highest germination was from 15°C to 30°C and ranged from 93% to 96%. The treatment means from 15°C to 30°C were not significantly different. The total germination percentages decreased below and above 25°C. At 10°C and 5°C, the total germination percentages were 77% and 1% respectively. At 35°C and 37°C the percentages were 71% and 10% respectively. Germination was not observed at 3°C and 40°C.

The most rapid germination occurred at 30°C, where 28% was attained in 1 day. At 20°C, 25°C and 35°C, germination was also observed in 1 day but the percentages were lower. At 15°C germination was observed after 2 days. From 15°C to 35°C germination was completed in approximately 5 to 8 days. At 10°C germination was observed on the 3rd day and was completed on the 13th day with 77% germination. At 5°C germination percentage of 1% was obtained on day 28 and there was no further germination. Germination was observed at 37°C on the 4th day and was completed on day 6 with only 4% germination.

Germination Rate

Germination index values presented in Figure 7 varied with temperature. The germination was most rapid from 15°C to 30°C with the lowest value (2.19) corresponding to the high rate of germination at 30°C. The index value was higher at 15°C (3.90) and much higher at 10°C (7.34) and 5°C (28.00) indicating slower rate of germination as temperature decreased. The index increased at 35°C (3.09) and 37°C (5.35). The index was infinite at 3°C and 40°C because there was no germination.

The minimum germination temperature for variety Span was approximately 5°C (Appendix Table 5). The maximum germination temperature was less than 40°C (Appendix Table 5). High germination percentages and low germination indexes representing rapid germination rates were obtained from 15°C to

30°C and from 20°C to 30°C respectively. On the basis of high germination percentages and high germination rates, the optimum temperature for germination of variety Span is from 20°C to 30°C (Figure 7 and Appendix Table 21).

Brassica campestris variety Torch

Germination Percentage

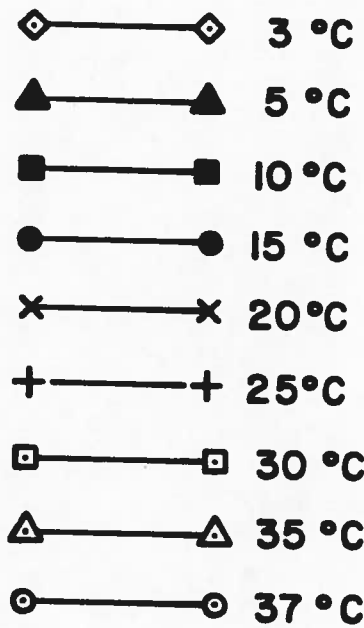
Germination percentages presented in Figures 8 and 9 increased as the incubation temperature increased up to an optimum range and then decreased as temperature increased further. Analysis of variance (Appendix Table 13) and Duncan's Multiple Range Test for germination percentages (Appendix Table 22) showed that temperature effect was highly significant and treatment means differed significantly.

The percentages were high and not significantly different from 10°C to 35°C and ranged from 97% to 100%. Germination percentage decreased below 10°C and above 35°C. At 5°C and 3°C, the percentage was 46% and 16% respectively. At 37°C germination percentage was 64%. No germination was observed at 40°C.

The number of days required for germination to begin and to be completed varied with temperature (Figure 8). From 10°C to 37°C, except at 15°C, germination was observed after 1 day. The highest percentage of 86% was obtained after 1 day at 30°C. At 15°C germination was observed on the 2nd

FIGURE 6. Germination of Brassica campestris variety Span at nine temperatures.

Legend:



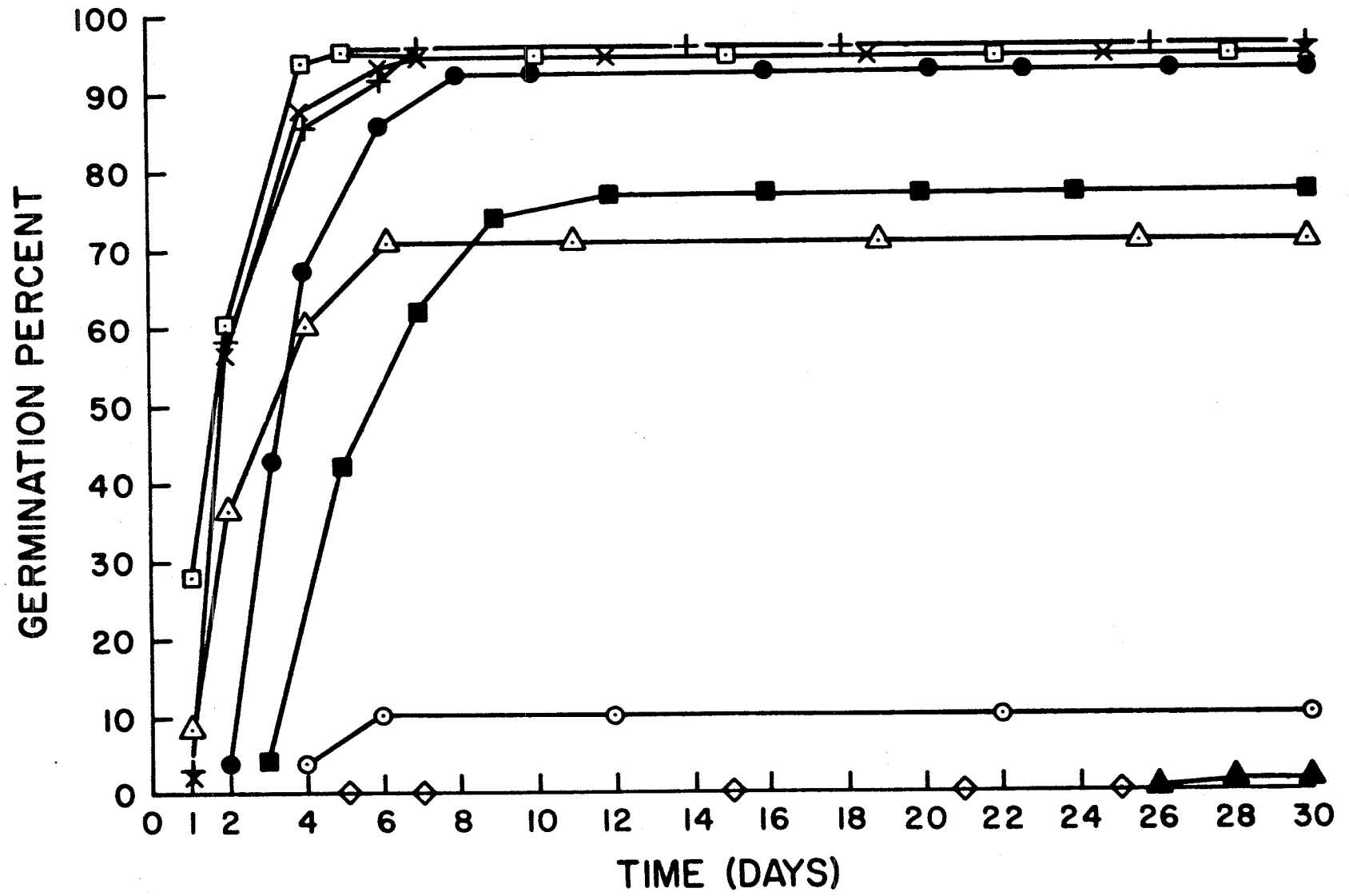
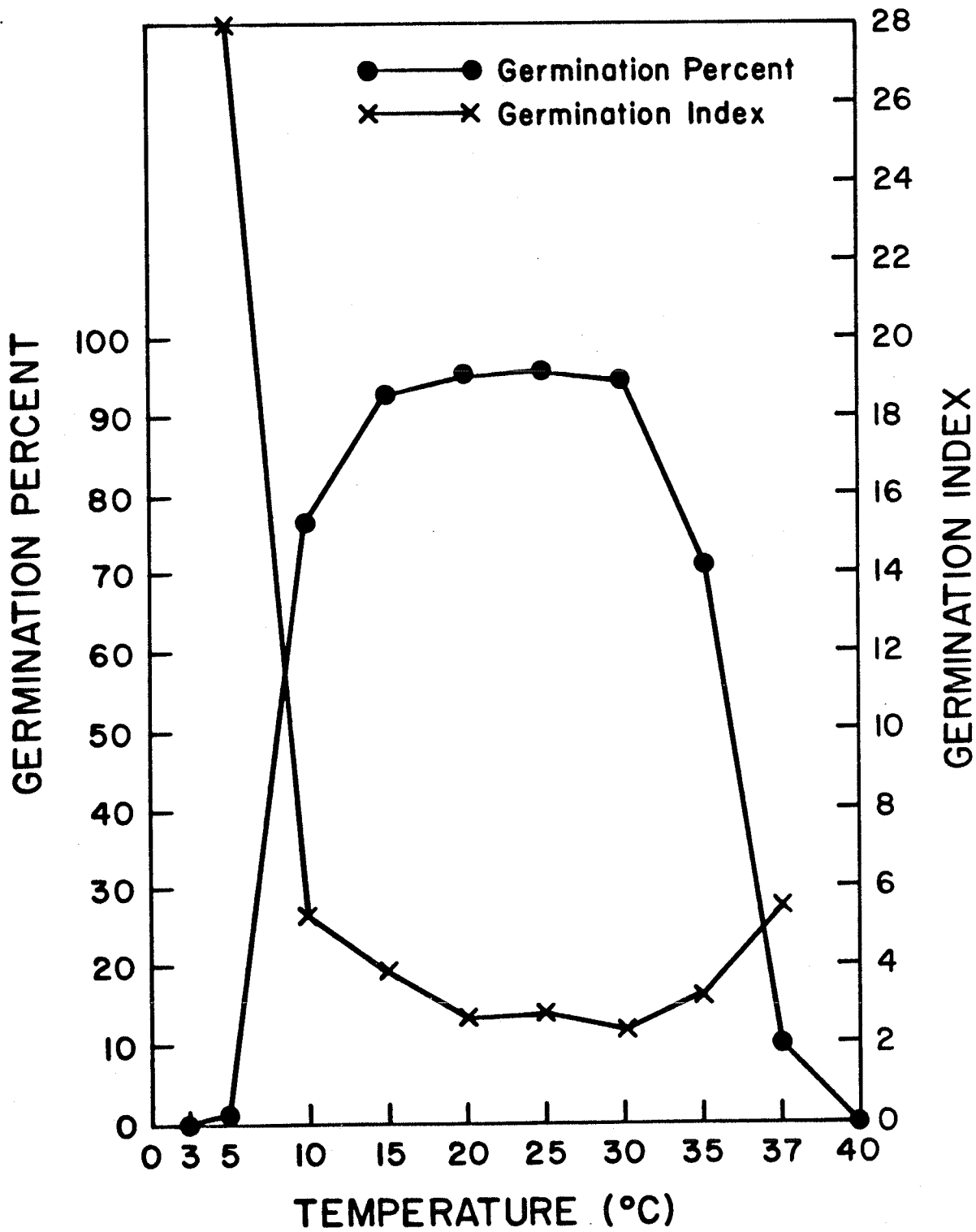


FIGURE 7. Effect of temperature on germination percentage and germination index of Brassica campestris variety Span.



day. From 10°C to 37°C, germination was completed in approximately 4 to 8 days. Germination was first observed at 5°C on the 7th day and was completed on the 16th day with a percentage of 46%. At 3°C germination was observed on the 14th day and was completed on day 28 with a total of 16%. At 37°C, 64% of the seeds had germinated by the 7th day and there was no further germination.

Germination Rate

Germination index values are shown in Figure 9. The values varied with temperature. Analysis of variance for germination index (Appendix Table 13) showed that temperature effect was highly significant. Duncan's Multiple Range Test (Appendix Table 22) showed that there were significant differences between treatment means. Germination was rapid at temperatures 15°C to 35°C, became slower at temperatures below 15°C and above 35°C. The most rapid rate with an index value of 1.17 was at 30°C. At 10°C, 5°C and 3°C germination indexes were 4.23, 15.50 and 21.08 respectively, indicating reduced rate of germination as temperature decreased. At 37°C the index value increased to 2.41. At 40°C the index was infinite since none of the seed germinated.

The minimum germination temperature for variety Torch was below 5°C (Appendix Table 6). The maximum temperature for germination was less than 40°C (Appendix Table 6). High germination percentage was obtained from 10°C to 35°C (Figure 9).

Lowest germination index values representing the most rapid germination rate were at 20°C to 35°C (Figure 9). On the basis of highest germination percentages and most rapid germination rates, the optimum temperature for variety Torch is from 20°C to 35°C (Figure 9 and Appendix Table 22).

Brassica campestris variety Candle

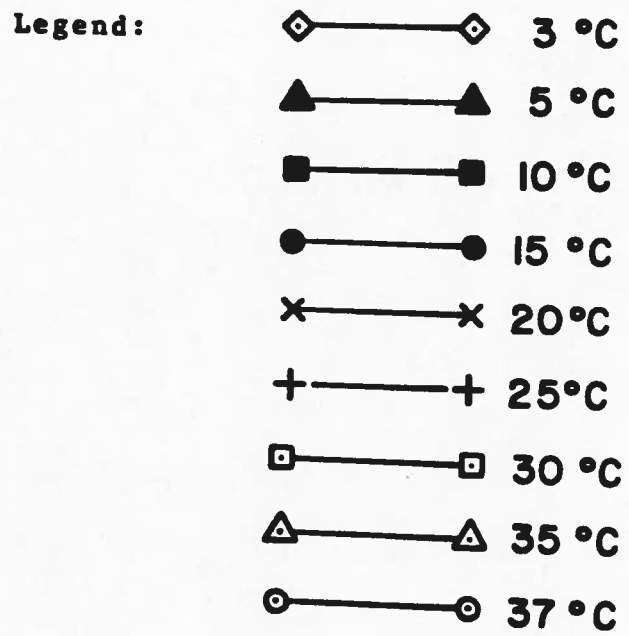
Germination Percentage

Germination percentage varied with temperature (Figure 10 and 11). The percentage increased as incubation temperature increased up to an optimum range, then decreased. Germination percentage was high from 15°C to 30°C with the highest germination percentage of 97% at 20°C. The percentages were not significantly different at 15°C to 30°C. Germination percentage declined below 15°C and above 30°C. At 10°C, 5°C and 3°C, germination percentages were 90%, 51% and 10% respectively. At 35°C and 37°C, germination percentages were 85% and 34% respectively. No germination was observed at 40°C.

Analysis of variance (Appendix Table 14) indicated that temperature effect was highly significant. Duncan's Multiple Range Test showed that there were significant differences between treatment means.

The most rapid germination occurred at 30°C. At this temperature 66% of the seed had germinated in 1 day. At

FIGURE 8. Germination of Brassica campestris variety Torch at ten temperatures.



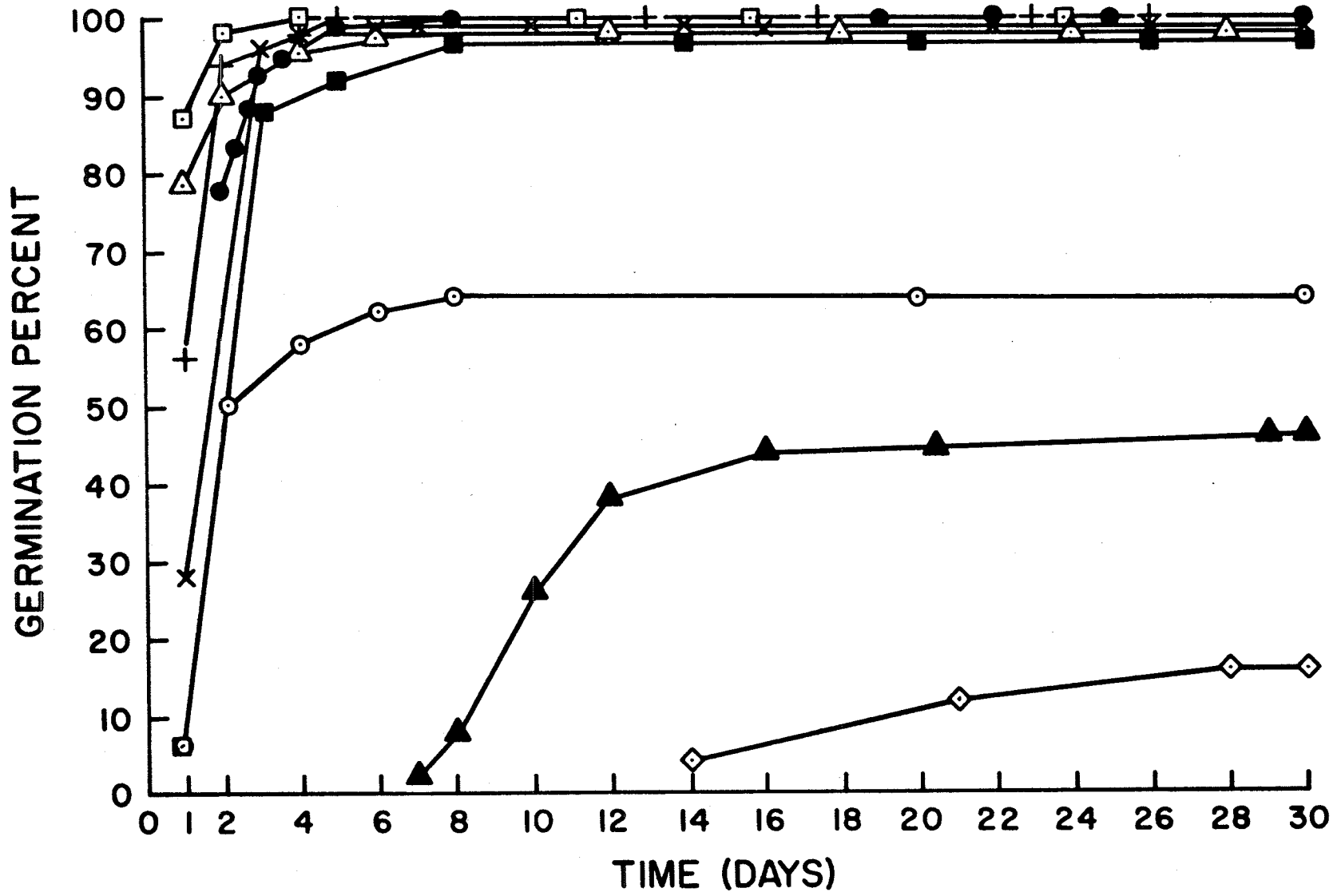
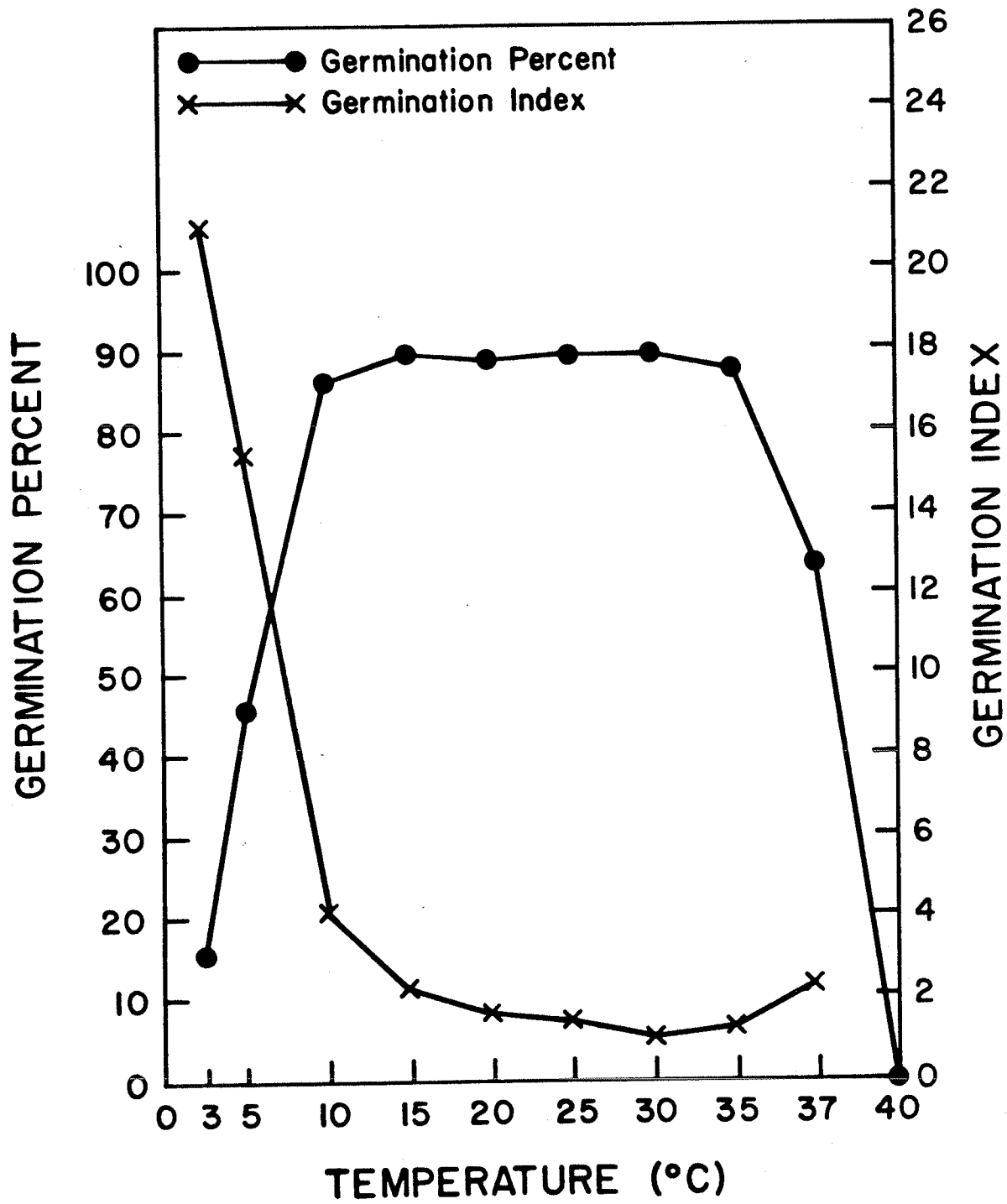


FIGURE 9. Effect of temperature on germination percentage and germination index of Brassica campestris variety Torch.



temperatures 10°C, 20°C, 25°C, 35°C and 37°C, germination was also observed after 1 day but percentages were lower. From 10°C to 37°C germination was completed in approximately 4 to 9 days. At 5°C and 3°C germination was observed on day 7 and 14 respectively and was completed on day 21 and 24 respectively. At 5°C, 51% of the seed germinated, while at 3°C, 10% of the seed germinated. No germination was observed at 40°C.

Germination Rate

Germination index values varied with temperature (Figure 11). The temperature effect was highly significant (Appendix Table 14). There were significant differences between treatment means as determined by Duncan's Multiple Range Test (Appendix Table 23). The lowest germination indexes (1.51) corresponding to most rapid germination were from 25°C to 35°C. Germination index values were not significantly different from 15°C to 35°C (Appendix Table 23).

The rate became slower below 15°C as shown by increases in germination index values. The values were 4.37, 15.90 and 19.91 at 10°C, 5°C and 3°C respectively. The index at 37°C was 3.36 indicating slower rate at high temperature. The index was infinite at 40°C because no seeds germinated.

The minimum temperature for germination of variety Candle was below 5°C (Appendix Table 7). The maximum temperature for germination was less than 40°C (Appendix

Table 7). Germination percentage was high from 15°C to 35°C (Figure 11). Low germination indexes representing rapid germination rate occurred from 15°C to 35°C (Figure 11). On the basis of high germination percentages and high germination rates, the optimum temperature for germination of variety Candle is from 15°C to 30°C (Figure 11 and Appendix Table 23).

Brassica juncea variety Lethbridge 22A

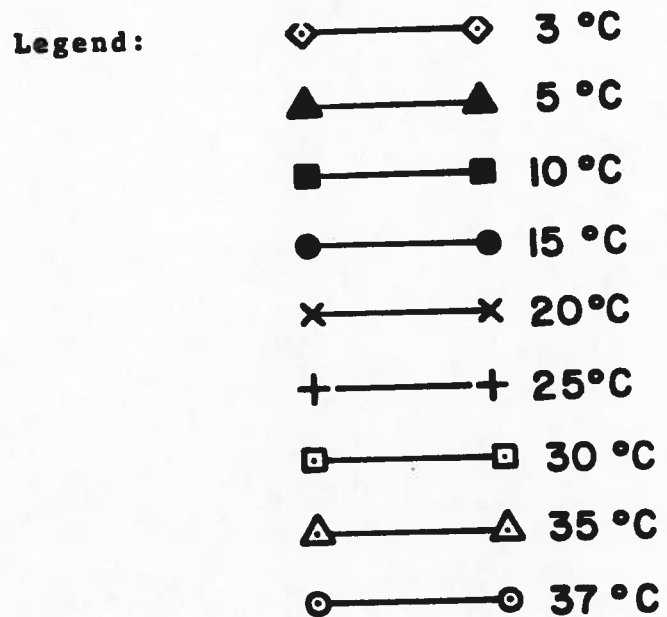
Germination Percentage

Germination percentage varied with temperatures (Figures 12 and 13). The percentage increased as temperature increased up to an optimum range, then declined. Total germination percentage was high and not significantly different from 10°C to 25°C and ranged from 95% to 96%. The percentage was lower at 5°C (48%) and much lower at 3°C (2%). At 30°C, 35°C and 37°C, germination percentages were 86%, 76% and 47% respectively. No germination was observed at 40°C.

Analysis of variance for germination percentage (Appendix Table 15), and Duncan's Multiple Range Test (Appendix Table 24) showed that the temperature effect was highly significant and treatment means differed significantly.

At 25°C and 30°C germination was observed after 1 day with the most rapid germination at 30°C. At 15°C, 20°C, 35°C and 37°C germination was observed on the 2nd day. From 15°C

FIGURE 10. Germination of Brassica campestris variety Candle at ten temperatures.



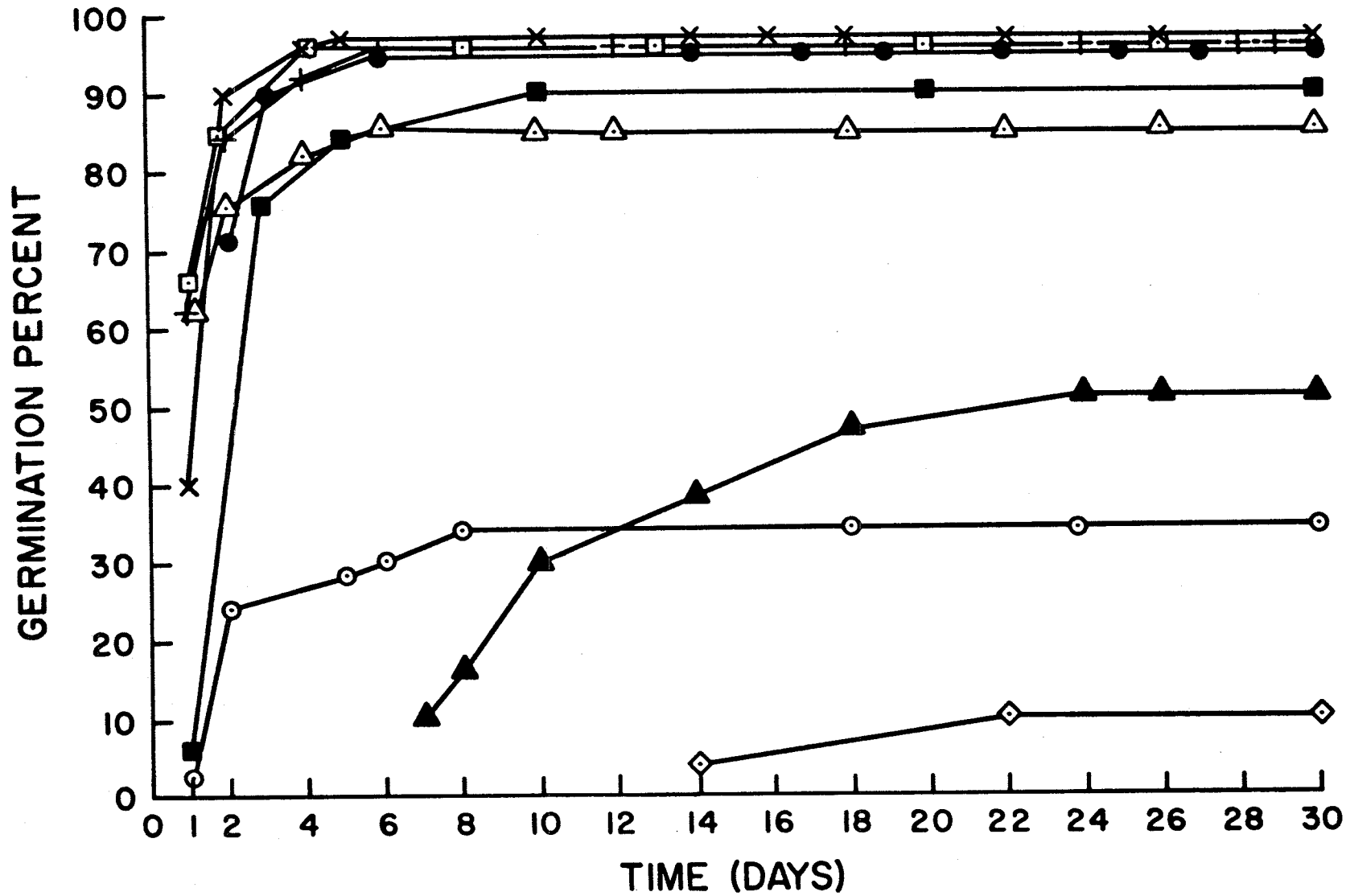
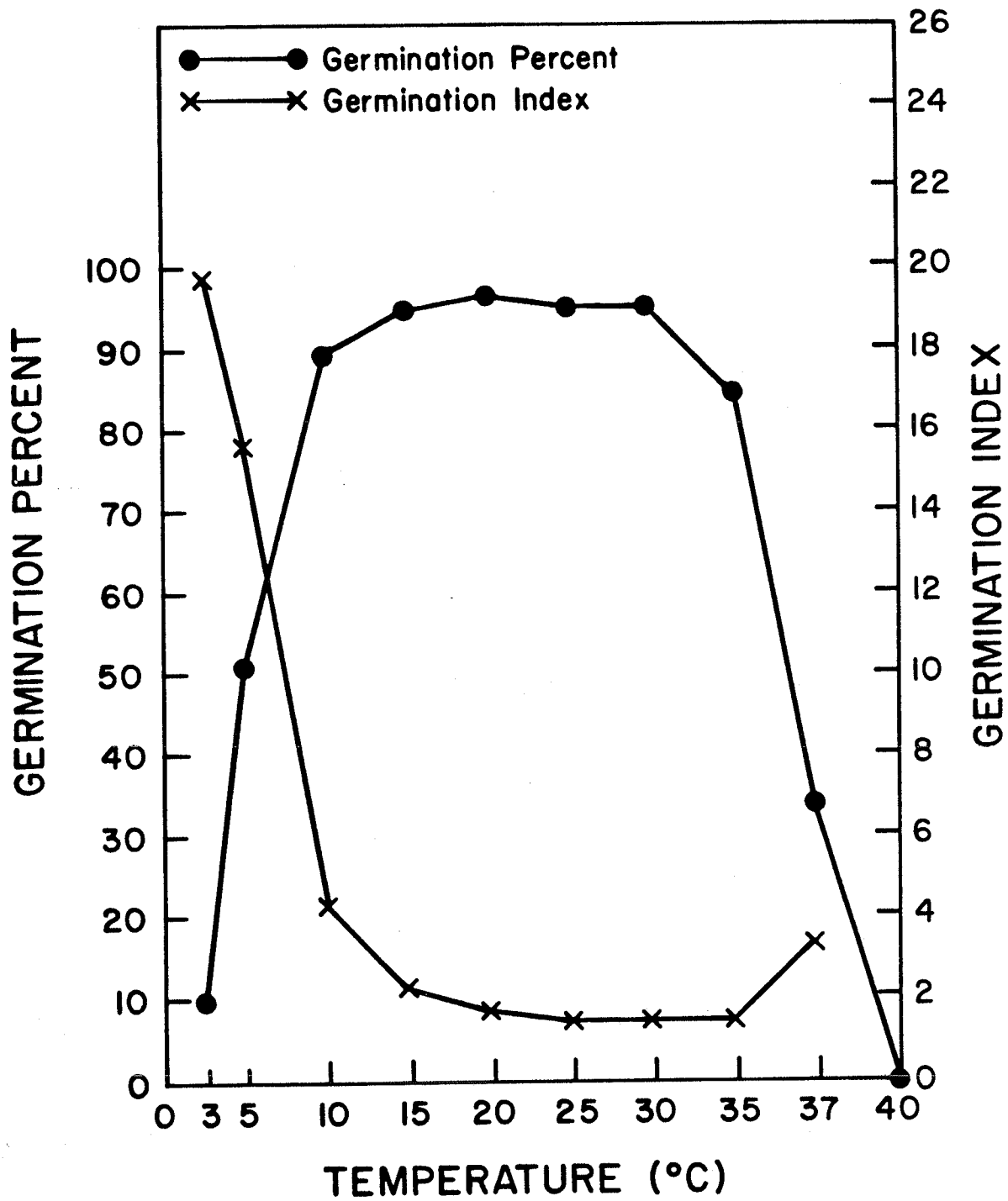


FIGURE 11. Effect of temperature on germination percentage and germination index of Brassica campestris variety Candle.



to 37°C germination was completed in approximately 5 to 8 days. At 10°C germination was observed on the 3rd day and was completed on day 13 with a total percentage of 96%. At 5°C, germination was observed on day 9 and was completed on day 29. The percentage attained was 48%. At 3°C germination was only observed on day 29 and only 2% of the seed germinated. At 30°C, 35°C and 37°C the germination percentages were 86%, 76% and 47% respectively.

Germination Rate

Germination index values are shown in (Figure 13). The values varied with temperature. Analysis of variance for germination index (Appendix Table 15) showed that temperature effect was highly significant. Treatment means differed significantly as determined by Duncan's Multiple Range Test.

The lowest germination index (2.30) was at 30°C. The index increased significantly below and above 30°C. From 25°C to 15°C the index varied from 2.68 to 4.28 indicating slower germination rate. At 10°C, 5°C and 3°C the index values were 6.64, 25.03 and 29.30 respectively, reflecting a much slower rate of germination as temperature decreased. At 37°C the index value was 4.07 and at 40°C, it was infinite because no seed germinated.

The minimum germination temperature for variety Lethbridge 22A was below 5°C (Appendix Table 8). The maximum germination temperature was less than 40°C (Appendix Table 8).

High germination percentage was obtained from 10°C to 25°C (Figure 13). Low germination index values representing most rapid germination rates occurred from 20°C to 30°C (Figure 13). On the basis of high germination percentages and rapid germination rates, the optimum temperature for germination of variety Lethbridge 22A is from 20°C to 25°C (Figure 13 and Appendix Table 24).

Sinapis alba variety Ochre

Germination Percentage

Germination percentages at different temperatures are shown in Figures 14 and 15. The percentages varied with temperature. Total germination percentage was high from 3°C to 25°C and ranged from 99% to 100%. Above 25°C germination declined, and reached 0% at 40°C. At 30°C, 35°C and 37°C germination percentages were 90%, 82% and 28% respectively. Analysis of variance for germination percentage (Appendix Table 16) showed that temperature effect was highly significant. Duncan's Multiple Range Test showed that there were significant differences between treatment means.

The days required for germination to begin and to be completed varied with temperature. From 15°C to 35°C, germination was observed after 1 day with the highest percentage of 50% at 30°C. At 10°C and 37°C germination was observed on the 2nd day. Between temperatures 10°C and 37°C germination was

FIGURE 12. Germination of Brassica juncea variety Lethbridge 22A at ten temperatures.

Legend:

◇ — ◇ 3 °C

▲ — ▲ 5 °C

■ — ■ 10 °C

● — ● 15 °C

× — × 20 °C

+ — + 25 °C

□ — □ 30 °C

△ — △ 35 °C

○ — ○ 37 °C

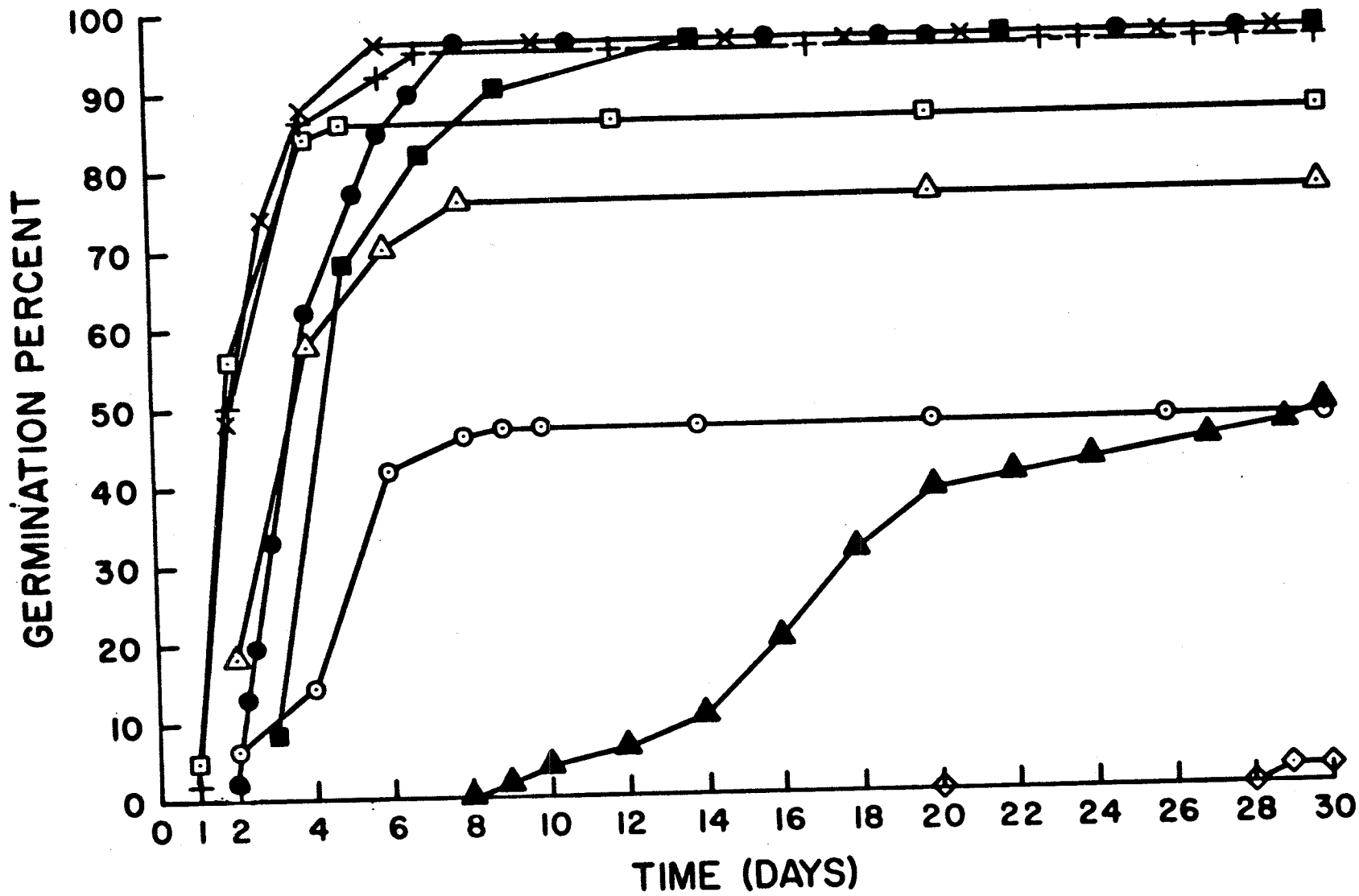
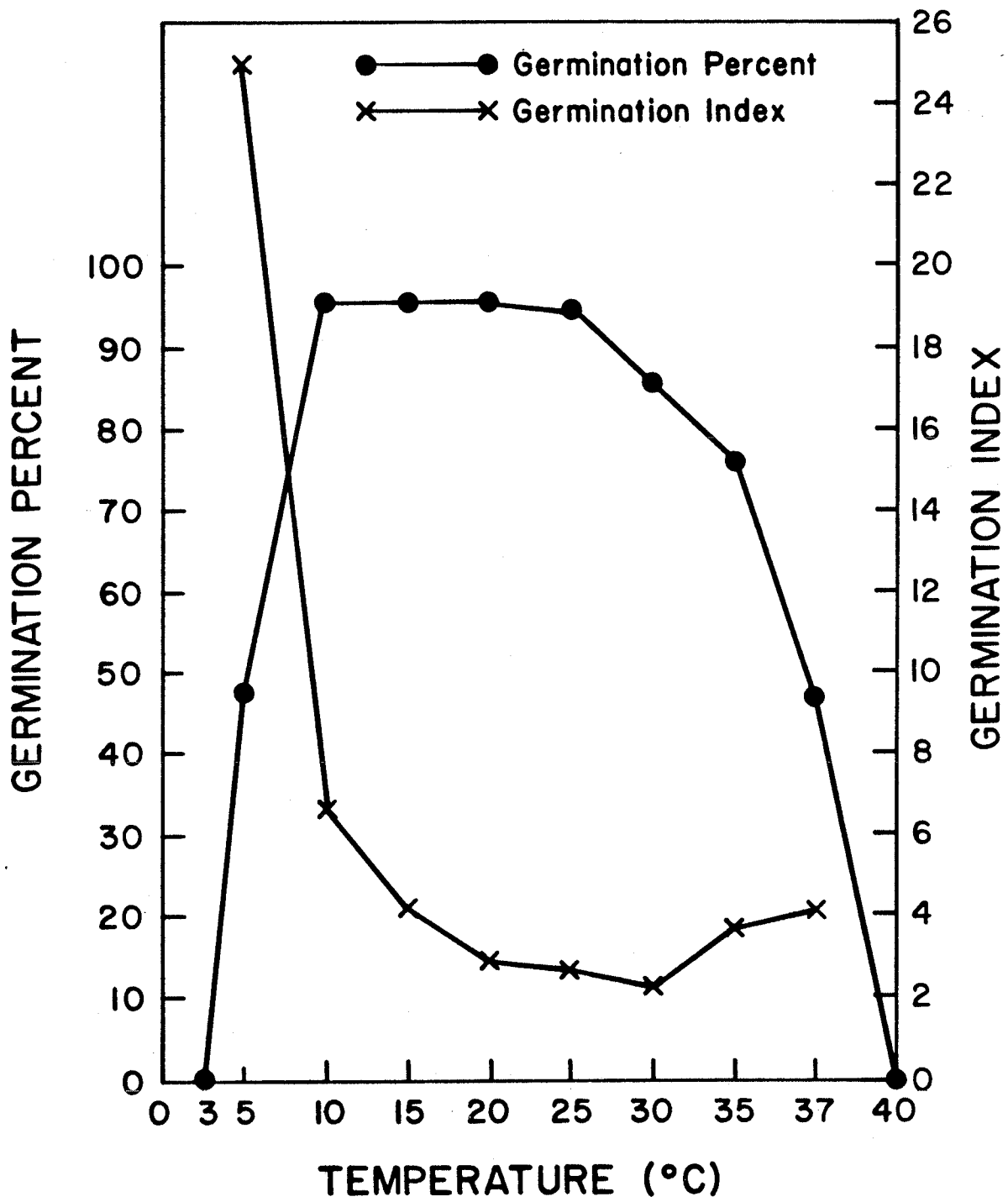


FIGURE 13. Effect of temperature on germination percentage and germination index of Brassica juncea variety Lethbridge 22A.



completed in approximately 3 to 7 days. At 5°C and 3°C germination was first observed on day 5 and 7 respectively and was completed on day 12 and 21 respectively.

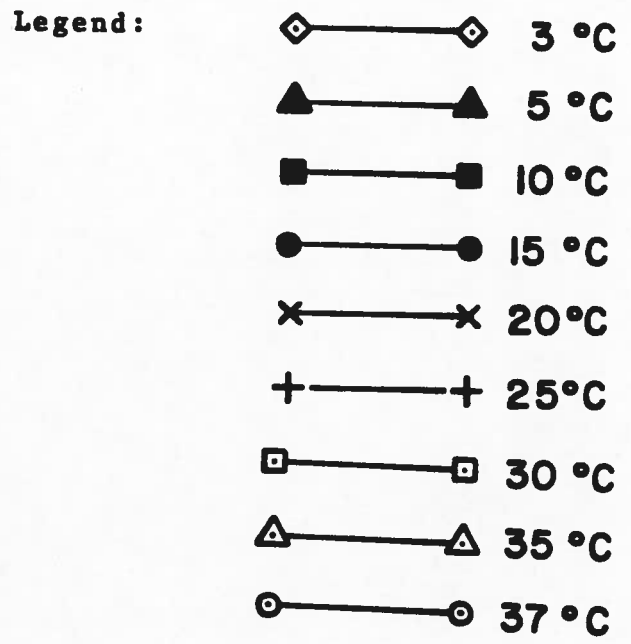
Germination Rate

Germination index values are presented in Figure 15. The values varied with temperature. The lowest index value (1.48) was obtained at 20°C but the value did not differ significantly from the value (1.76) obtained at 25°C. There was an increase in germination index from 10°C (2.01) to 37°C (3.65) reflecting slower germination rate below and above 20°C. Germination index was high (7.67) at 5°C and much higher (13.45) at 3°C indicating further reduction in germination rate as temperature decreased. At 40°C the index was infinite because no seed germinated.

Analysis of variance (Appendix Table 16) and Duncan's Multiple Range Test showed significant temperature effect and significant differences between treatment means.

The minimum germination temperature for variety Ochre was below 3°C (Appendix Table 9). The maximum germination temperature was less than 40°C (Appendix Table 9). High germination percentages were obtained from 3°C to 25°C (Figure 15). The lowest germination index values representing most rapid germination rates were obtained from 10°C to 30°C (Figure 15). On the basis of high germination percentages and rapid germination rates, the optimum temperature for germination of variety Ochre is from 10°C to 25°C (Figure 15 and Appendix Table 25).

FIGURE 14. Germination of Sinapis alba variety Ochre at ten temperatures.



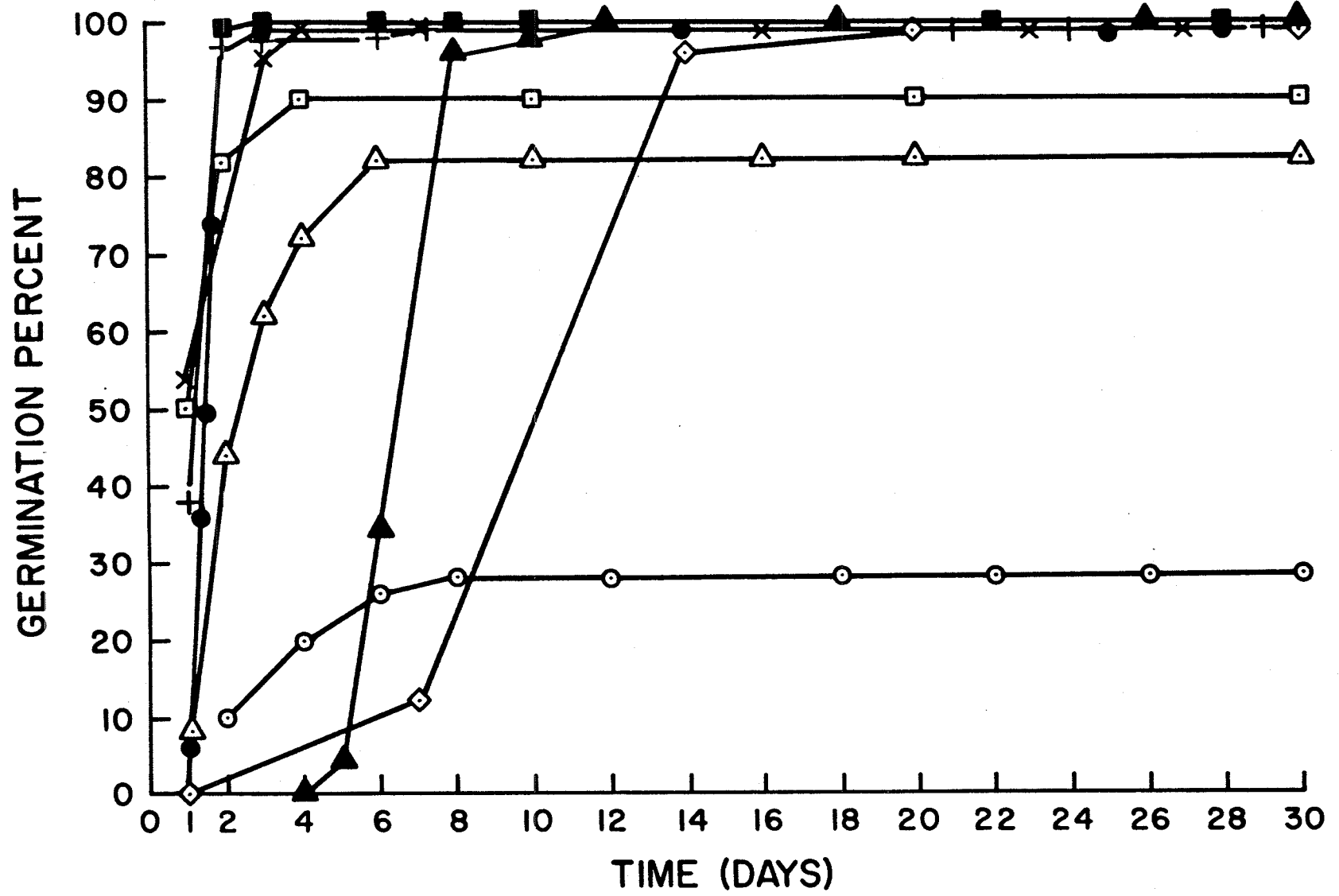
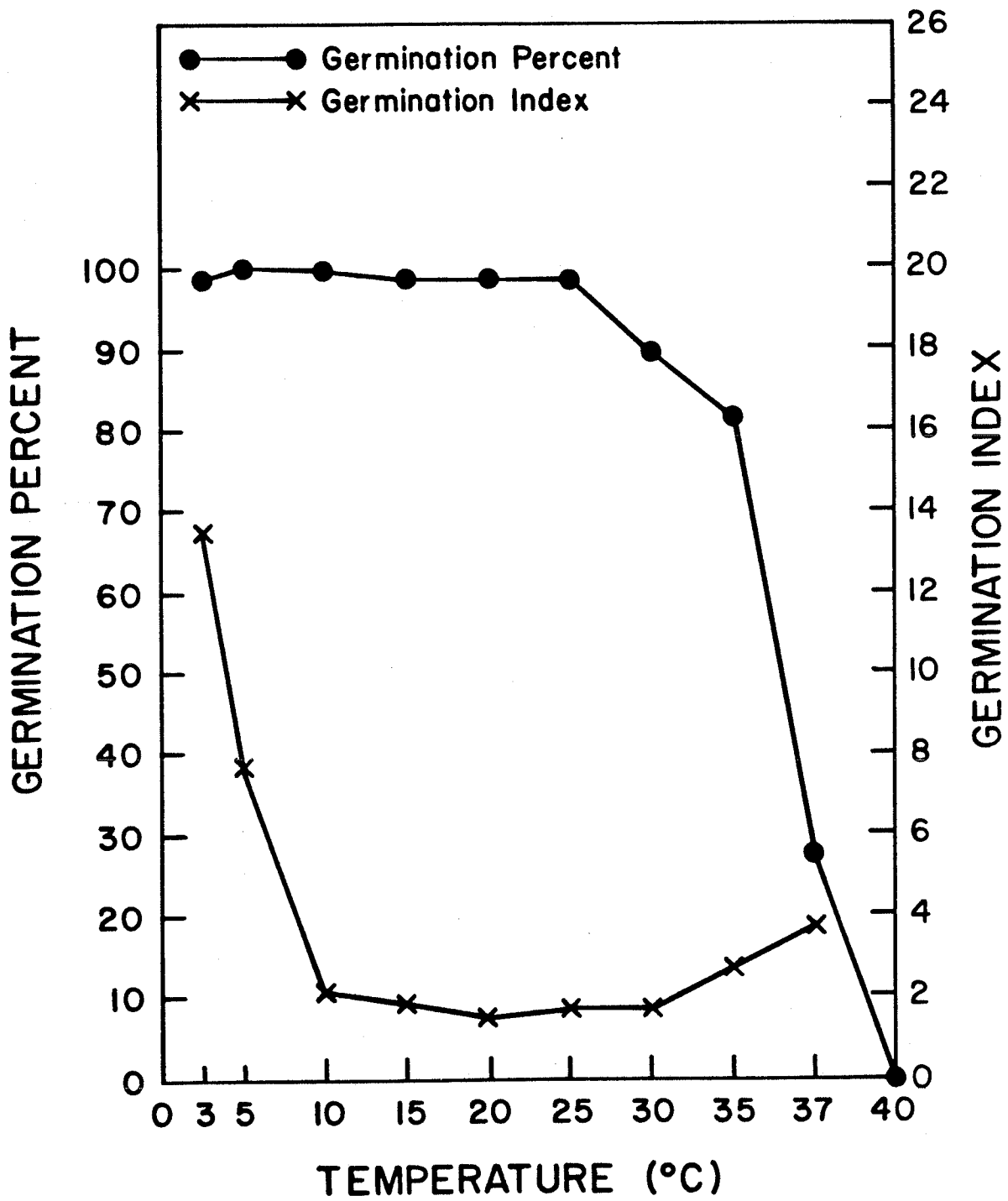


FIGURE 15. Effect of temperature on germination percentage and germination index of Sinapis alba variety Ochre.



Germination of seven varieties at ten temperatures

Germination Percentage

Mean germination percentages of the seven varieties at ten temperatures are shown in Table 1. Germination percentage was high for all the varieties from 10°C to 30°C. Germination percentage decreased below 10°C and above 30°C. No germination was obtained at 40°C for any of the varieties.

Analysis of variance for germination percentage (Appendix Table 17) at each temperature for the seven varieties showed that varieties' effect was highly significant at all temperatures where germination was observed. Duncan's Multiple Range Test (Table 1) indicated that some treatment means at each temperature differed significantly.

Analysis of variance of all the germination percentage data (Appendix Table 1) showed that there were significant differences between temperatures, varieties and the varieties x temperatures interaction (Table 2). The mean squares and F values due to temperature were greater than those contributed by the varieties, and the interaction effect was the smallest.

An examination of the interaction between varieties and temperatures (Figure 16) indicate that, while all varieties attained high germination percentages from 10°C to 30°C, some varieties attained higher percentages than others at low (5°C and 3°C) and high temperature (35°C and 37°C). At 5°C the

germination percentages for varieties Ochre (100%), Reston (97%) and Regent (90%) were higher than those of other varieties. At 3°C the germination percentage for Ochre (99%) and Reston (81%) were quite high while no germination was observed for variety Span.

The germination percentage of varieties Torch (64%), Lethbridge 22A (47%) and Candle (34%) were the highest at 37°C. The germination percentages of these varieties were low at low temperatures (3°C and 5°C). The germination percentages of varieties Span, Regent and Reston at 37°C were 10%, 4% and 3% respectively.

Germination Rate

Mean germination index values representing germination rates of the seven varieties at ten temperatures are shown in (Table 3). The low germination indexes for all varieties were from 15°C to 35°C with a tendency of lowest indexes at 30°C. The index values increased more above 35°C and much more below 10°C. The indexes were infinite at 40°C for all varieties, and at 3°C for variety Span, since no seed germinated.

Analysis of variance for germination index (Appendix Table 18) showed that effects in germination index due to varieties were highly significant at each temperature. Duncan's Multiple Range Test showed that some of the treatment means of varieties at each temperature differed significantly (Table 3).

Table 1. Means of germination percentage for seven varieties of Brassica species at ten temperatures.

Variety	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
Regent	44 c ^Y	90 b	99 a	97 abc	98 ab	98 abc	97 b	72 de	3 f	0
Reston	81 b	97 a	98 a	97 abc	91 c	96 bc	93 c	68 e	4 f	0
Span	0	1 d	77 c	93 c	95 b	96 bc	95 bc	71 de	10 e	0
Torch	16 d	46 c	97 a	100 a	99 ab	100 a	100 a	98 a	64 a	0
Candle	10 d	51 c	90 b	95 bc	97 ab	96 bc	96 bc	85 b	34 c	0
Lethbridge 22A	2 e	48 c	96 a	96 bc	96 ab	95 c	86 e	76 cd	47 b	0
Ochre	99 a	100 a	100 a	99 a	99 a	99 a	90 d	92 bc	28 d	0
CV	13.88	6.53	3.73	2.68	2.24	2.04	1.88	6.03	11.32	

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's multiple range test.

Table 2. Analysis of variance of the germination percentage for seven varieties of Brassica species at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
Replications	3	6.02	2.01	0.19	3.01	4.72
Temperatures	8	170,907.46	31,363.38	2,004.05**	2.36	3.36
Error	24	255.84	10.66			
Varieties	6	17,695.11	2,949.19	288.62**	3.67	6.88
Varieties x Temperatures	48	69,828.32	1,442.26	111.80**	1.46	1.72
Error	162	2,089.14	12.90			
Total	251	260,181.89				

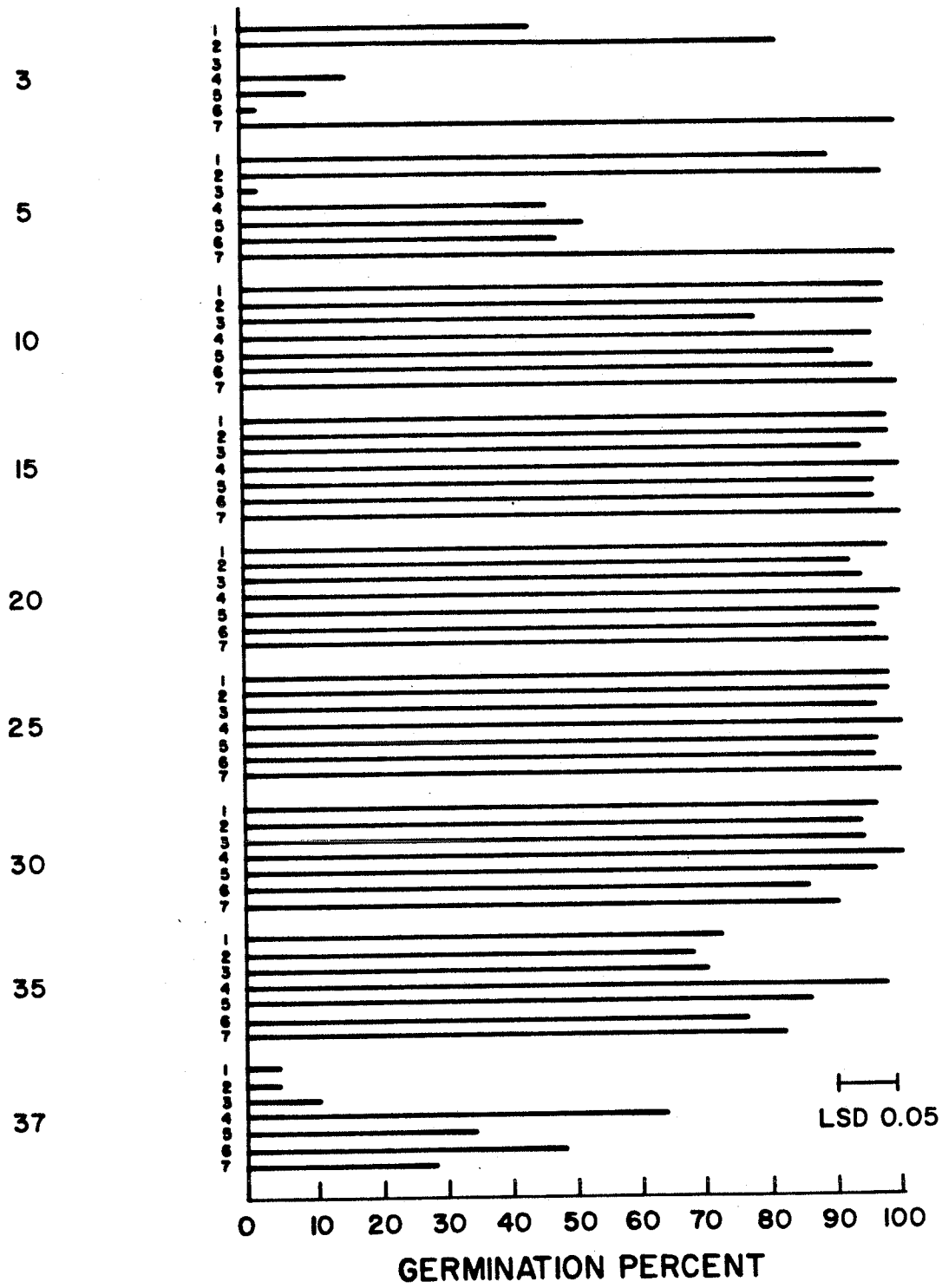
**Significant at p=0.01 level.

FIGURE 16. Germination percentage for seven varieties of Brassica species at nine temperatures.

Legend:

- 1 = Regent**
- 2 = Reston**
- 3 = Span**
- 4 = Torch**
- 5 = Candle**
- 6 = Lethbridge 22A**
- 7 = Ochre**

TEMP (°C) VARIETY



The overall analysis of the data (Appendix Table 2) on germination index indicated significant differences between temperatures, varieties and varieties x temperatures interactions (Table 4). The mean squares and F values due to temperature were greater than those contributed by the varieties. The interaction effect was the smallest.

An examination of the interaction between varieties and temperatures (Figure 17) indicated that while some varieties germinate more rapidly than others at low temperatures, all varieties germinate more slowly at low temperatures (3°C and 5°C) than at temperatures ranging from 10°C to 35°C. The rate of germination for all varieties decreased above 35°C (ie. 37°C). However, some varieties germinated more rapidly than others at high temperatures.

At low temperatures (3°C and 5°C) varieties Ochre, Reston and Regent germinated more rapidly than other varieties. At high temperatures (35°C and 37°C) varieties Torch and Candle germinated more rapidly than other varieties.

Temperature effect and varietal response

Temperature

Germination percentage. The germination percentage means for temperatures are shown in Table 5 and are presented in Figure 18. Germination percentage was high from 10°C to 30°C and ranged from 93.6% to 97.1%. Germination percentage was

Table 3. Means of germination index for seven varieties of Brassica species at ten temperatures.

Variety	Germination Index									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
Regent	22.25 b ^Y	15.65 c	4.79 c	2.76 d	2.08 c	2.02 c	1.63 b	3.07 b	5.75 a	∞
Reston	20.45 bc	15.43 c	4.39 d	3.16 c	2.15 c	2.33 b	1.68 b	2.81 b	4.95 a	∞
Span	∞	28.00 a	7.34 a	3.90 b	2.69 b	2.80 a	2.19 a	3.09 b	5.35 a	∞
Torch	21.08 bc	15.50 c	4.23 d	2.37 e	1.74 d	1.55 d	1.17 c	1.34 c	2.41 c	∞
Candle	19.91 c	15.90 c	4.37 d	2.33 e	1.71 d	1.51 d	1.51 bc	1.51 c	3.36 b	∞
Lethbridge 22A	29.30 a	25.03 b	6.64 b	4.88 a	2.88 a	2.68 a	2.30 a	3.71 a	4.07 b	∞
Ochre	13.47 d	7.67 d	2.01 e	1.97 f	1.48 e	1.76 cd	1.79 b	2.67 b	3.65 b	∞
CV	6.36	6.68	5.62	4.44	4.48	8.75	13.88	11.63	11.93	

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's multiple range test.

∞ = Infinity

Table 4. Analysis of variance of the germination percentage for seven varieties of Brassica species at nine temperatures.

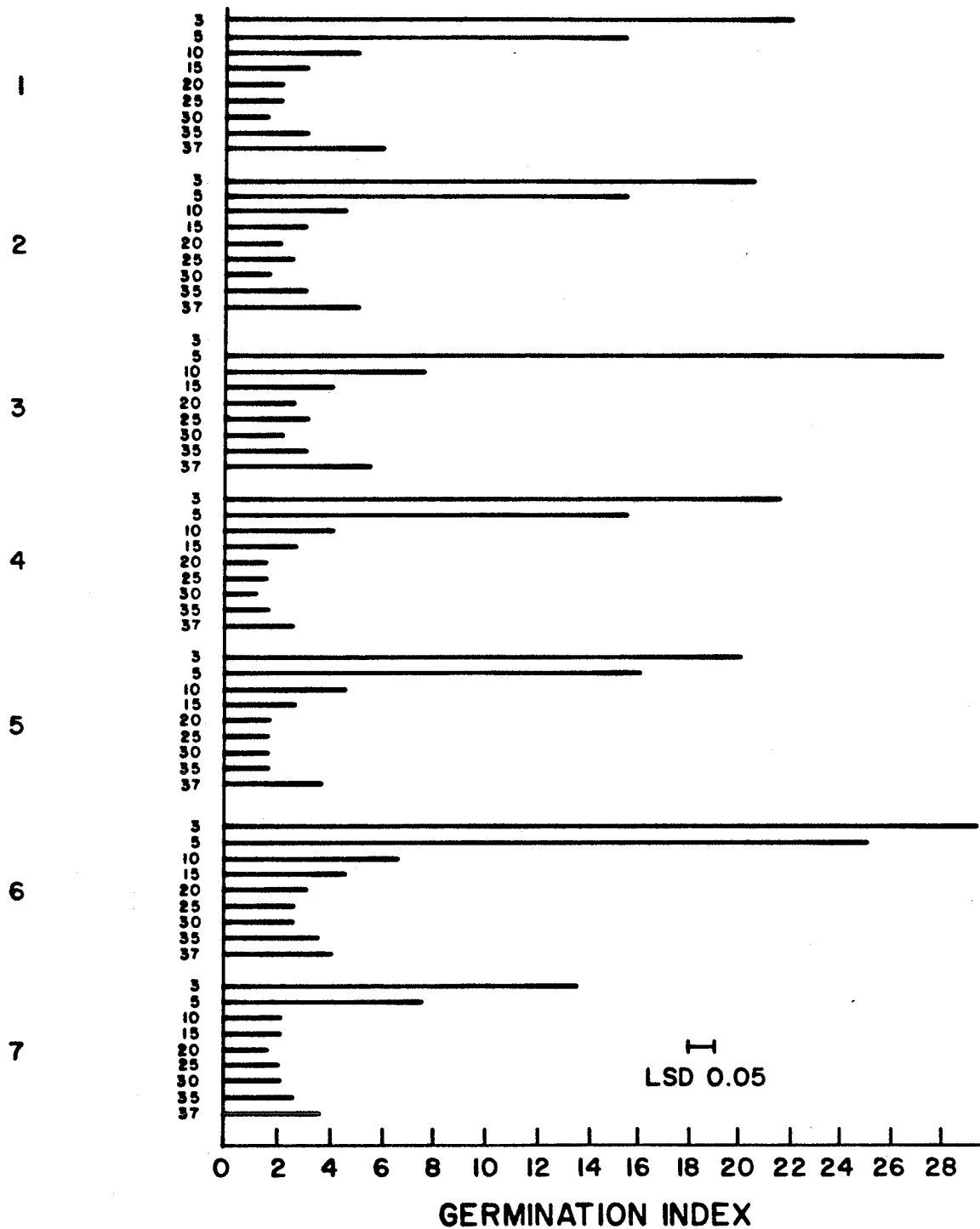
<u>Analysis of Variance</u>						
Source of Variation	DF	SS	MS	F	5%	1%
Replications	3	2.89	0.96	0.49	3.01	4.72
Temperatures	8	8,727.95	1,090.99	551.01**	2.36	3.36
Error	24	47.54	1.98			
Varieties	6	432.59	72.10	225.31**	2.10	2.80
Varieties x Temperatures	47	854.85	18.18	56.82**	1.36	1.55
Error	154	48.55	0.32			
Total	242	10,114.37				

**Significant at p=0.01 level.

FIGURE 17. Germination index for seven varieties of Brassica species at nine temperatures.

- Legend:**
- 1 - Regent**
 - 2 - Reston**
 - 3 - Span**
 - 4 - Torch**
 - 5 - Candle**
 - 6 - Lethbridge 22A**
 - 7 - Ochre**

VARIETY TEMP. (°C)



highest (97.1%) at 25°C. The percentage decreased below 10°C and above 25°C. At 5°C and 3°C the mean percentage were 61.8% and 36.0% respectively, indicating that the percentage decreased as temperature decreased. At 35°C and 37°C the percentages were 78.9% and 27.0% respectively reflecting that germination percentage declined as temperature increased above the optimum temperature range. No germination was observed for any varieties at 40°C. Duncan's Multiple Range Test showed that treatment means differed significantly (Table 5).

Germination Rate. The mean germination index values for varieties are shown in Table 5 and are presented in Figure 18. The index values were low from 10°C to 35°C and ranged from 1.75 at 30°C to 4.82 at 10°C. The index values increased below and above 30°C indicating slower rate of germination as temperature decreased below 30°C and increased above 30°C. At 5°C germination index (16.80) was higher and at 3°C it was much higher (20.00), showing that rate of germination decreased as incubation temperature decreased further. At 37°C the index was 4.22 indicating slow rate at this temperature. At 40°C the index was infinite indicating no germination occurred probably due to damage from too high a temperature.

The treatment means were significantly different as determined by Duncan's Multiple Range Test.

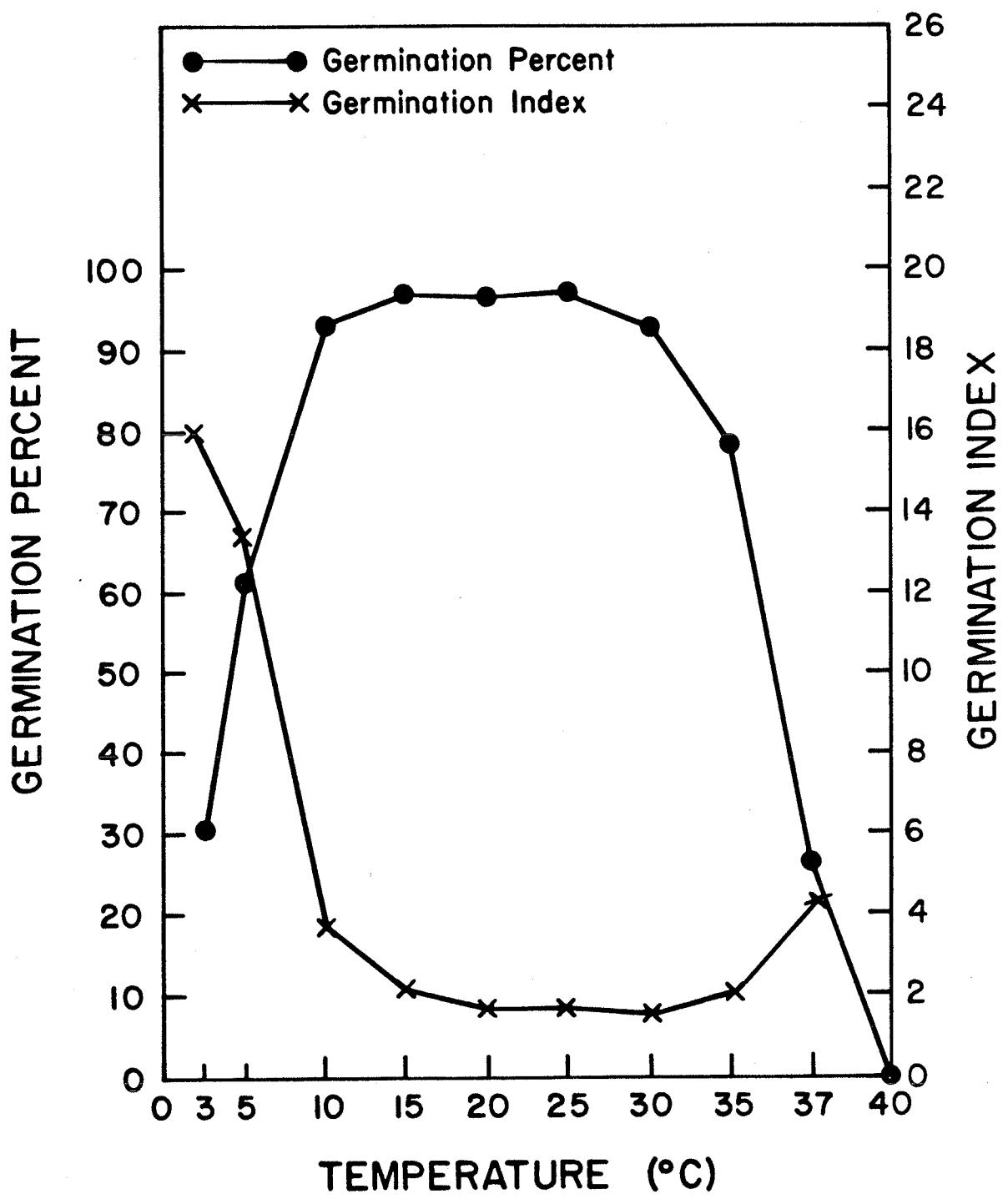
Table 5. Effect of temperature on germination percentage and germination index for seven varieties of Brassica species at ten temperatures.

Temperature (°C)	Germination Percentage	Germination Index
3	36.0 e ^Y	20.00 a ^Y
5	61.9 d	16.80 b
10	98.6 b	4.82 c
15	96.7 a	2.97 e
20	96.4 a	2.10 f
25	97.1 a	2.81 f
30	93.9 b	1.75 f
35	78.9 c	2.60 e
37	27.0 f	4.22 d
40	0.0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's multiple range test.

∞ = infinity

FIGURE 18. Effect of temperature on germination percentage and germination index for seven varieties of Brassica species at ten temperatures.



Varieties

Germination percentage. The mean germination percentages of varieties are shown in Table 6 and are illustrated in Figure 19. The percentages ranged from 58.9% for variety Span to 88.4% for variety Ochre. Duncan's Multiple Range Test showed that treatment means differed significantly. However, the percentage for variety Reston (80.6%) was not significantly different from the percentage for variety Torch (80.0%). Also, the percentage for variety Candle (72.7%) did not differ significantly from the percentage for variety Lethbridge 22A (71.3%).

Germination rate. The mean germination index values are shown in (Table 6) and are illustrated in (Figure 19). The index values ranged from 4.05 for variety Ochre to 7.14 for variety Lethbridge 22A indicating that variety Ochre had the most rapid rate of germination over all temperatures, while variety Lethbridge 22A had the slowest rate of germination. Duncan's Multiple Range Test indicated that there were significant differences between the treatment means. Variety Regent (6.67) did not differ significantly from variety Lethbridge 22A (7.14). Varieties Regent (6.67), Reston (6.37) and Torch (6.32) did not differ significantly in their mean germination rates. Also, varieties Reston (6.37), Torch (6.38) and Candle (5.79) did not differ significantly.

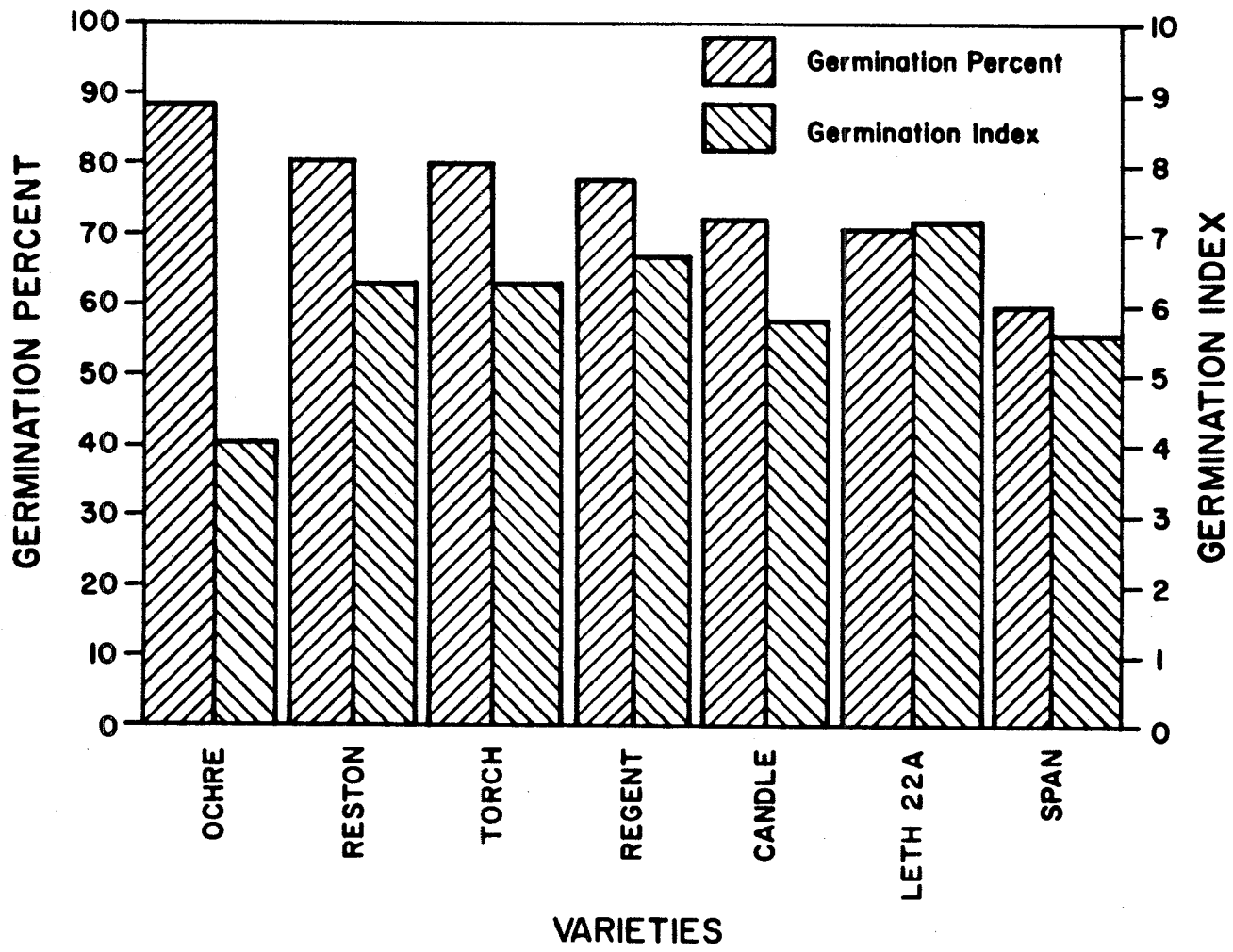
Table 6. Mean germination percentage and mean germination index for seven varieties of Brassica species at ten temperatures.

Variety	Germination Percentage	Germination Index
Ochre	88.2 a ^Y	4.05 e ^Y
Reston	80.6 b	6.37 bc
Torch	80.0 b	6.32 bc
Regent	77.6 c	6.67 ab
Candle	72.7 d	5.79 cd
Lethbridge 22A	71.3 d	7.14 a
Span	59.8 e	5.51 d

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

FIGURE 19. Germination percentage and germination index for seven varieties of Brassica species at ten temperatures.

Leth 22A = Lethbridge 22A



Discussion on Experiment 1

The effect of temperature on germination indicated that varieties responded differently to various temperature treatments. As shown in Figures 2, 4, 6, 8, 10, 12 and 14, varieties differed in number of days required for germination to begin and to be completed at different temperatures. On an average, varieties required 12 days at 3°C, 7 days at 5°C, approximately 4 to 9 days at 10°C to 35°C and approximately 3 to 7 days at 37°C. At the low temperature (3°C) variety Span did not germinate showing that it is sensitive to very low temperature. The other varieties which germinated, required a longer incubation period (days), for germination to begin at low temperature. Similar observations were made by Harrington (1921) and also stated by Edward (1932) in his review. Kretschmer (1975a) working with lettuce noted that the more sensitive the variety to the cool temperature, the longer was the period required to initiate germination. In this study it was also observed that varieties sensitive to low temperature required longer periods of incubation for germination to begin. This study also showed that, period of incubation decreased as temperature increased.

As noted above, germination was slow at low temperature but increased with increase in temperature. In addition to slow germination, germination percentage was low at low temperatures, except for the variety Ochre. The percentage

increased with increase in temperature for all the varieties. Germination percentage increased up to a peak then declined. No germination was observed at 40°C. The range in germination percentage varied with the varieties at various temperatures. The maximum germination attained however, was above 90% for all varieties. The percentages observed at various temperatures between the optimum range and 40°C varied with varieties. Thus, varieties do not react in the same manner to various temperatures. This is in conformity of the report of Coffman (1923).

DeCandole (1886) stated that each species has a minimum temperature at which it germinates. Germination observations in this study also indicated that germination depended on temperature and varied with variety. Generally however, minimum temperature was found to be below 5°C except for variety Ochre which had high germination (99%) even at 3°C. These results are in agreement with studies of Tokumasu and Kato (1980) who noted that the minimum germination temperature for some Brassica species was below 5°C. They also found that the optimum temperature for germination of B. napus was from 15°C to 25°C. On the basis of germination percentage (Table 5), this study showed that high levels of germination were obtained in the range from 10°C to 30°C. Their study further indicated 45°C as the maximum temperature for germination, but the present study indicates that the maximum temperature for varieties tested is between 35°C and

40°C. The differences in varietal response to temperature could be due to genotypic differences or provenance (Mayer 1975). The effect of seed source is discussed in Experiment 4.

The rate of germination expressed as germination index was found to vary with temperature and variety (Table 3 and Appendix Table 18). Germination index was infinite at temperature where no germination was observed. The germination index patterns (Figures 3, 5, 7, 9, 11, 13 and 15) varied with temperature and variety. Higher values indicated slow rate of germination while low values indicated a rapid rate of germination. At low temperatures (3°C and 5°C) the values were large indicating a slow rate. Germination index values were low within temperature range of 10°C to 30°C indicating fast germination. The values increased when temperature increased above the optimum showing slow rate of germination.

Even though specific sensitivity of varieties differed; the illustration of germination indexes (Figure 17) show that the general trends for all varieties were similar, indicating general effect of temperature on germination rate.

The mean germination percentages and germination indexes for the temperatures, and for varieties are shown in Tables 5 and 6 and Figures 18 and 19. Germination percentage for all varieties except Ochre was low at low temperatures but increased as temperature increased (Table 5).

The increase was up to a peak at an optimum temperature and then declined to 0% as temperature increased above the optimum temperature. The results showed that low (3°C) and high (37°C) temperature gave the lowest germination percentages. The lowest mean germination percentage (27%) was at 37°C. The highest germination percentage (97.1%) was obtained at 25°C. This indicated that 25°C is the optimum temperature for germination percentage varieties studied. The results also showed that low and high temperatures affect germination capacity.

The mean germination index was also affected by temperature (Table 5). The index was high at low (3°C, 5°C and 10°C) and high (37°C and 40°C) temperatures and low at temperatures from 10°C to 35°C. This indicated that germination rate was slow at low and high temperatures. The mean index decreased as temperature increased from low to optimum temperature range, then increased as temperature increased above the optimum range (10°C to 35°C).

The results interestingly showed that as the temperature increased, germination index decreased indicating that germination rate increased. The increase in percentage reached its peak at 25°C. While the differences of germination indexes between 20°C and 30°C were not significant, the lowest germination index was at 30°C. However as temperature increased above 25°C the germination percentage declined but the index increased above 30°C showing that germination rate was becoming slower.

Previous researchers have reported similar effects of temperatures. Kumar and Alka (1977) working with Brassica campestris reported that temperature up to 30°C favourably affected germination but above 30°C, germination was reduced. Harrington (1963) using vegetable seeds also found that temperature had marked effect on total germination and rate.

This study showed that mean germination index was not at its lowest value when mean germination percentage reached its peak (25°C), though mean percentages at 15°C to 25°C did not differ significantly. Similar observation was made by Gordon (1971).

The germination percentage decreased to 0% over a short temperature range (35°C to 40°C). A similar observation was also made by Reynolds (1973) on lettuce. He suggested that the abrupt change from optimum to no germination over a very short temperature span could be due to a switch on trigger mechanism. He proposed that structures maintained by hydrogen bonds that are sensitive to temperature could be responsible. The abrupt change noted in this study could be due to effect of temperature on enzymes that play a major role in germination as noted by James (1946).

Enzymes are protein compounds. Ching (1975) found that protein synthesizing ability was proportional to temperature. Since proteins are affected by high temperatures, this could have resulted in the effect of temperature on germination.

There were significant differences between varieties for germination percentage and germination index (Tables 5 and 6). This indicated that varieties responded differently to temperature treatments. However, the ranking of the varieties according to germination percentage was not the same as for germination index and hence rate, though the variety Ochre had the highest germination percentage (88.4%) and lowest germination index (4.05). The other varieties did not follow the same pattern. The differences in varietal response could be due to genotypic differences. Similar results were obtained by Achaya et al. (1983) on Brassica genotypes.

Significant differences were found between temperatures, varieties and varieties x temperatures interactions for both germination percentage and germination index (Table 2 and 4). Similar observations were made by Townsend and McGinnies (1972) on forages. The temperature effect on both germination percentage and germination index was the largest in this study. This shows that of the variables, temperature had the greatest influence on germination. Since varietal effects are significant, selection could be applied to develop seed with better germination as suggested by Achaya et al. (1983).

The results in this study indicate that Brassica napus varieties germinate better at lower temperatures than Brassica campestris varieties. This was also noted by

Achaya et al. (1983). At high temperatures Brassica campestris varieties are more tolerant than B. napus. This possibly explains why germination problems have been encountered with variety Span (B. campestris) at low temperature.

Results published from warmer countries (Kumar and Alka, 1977) also confirm that B. campestris varieties tend to germinate at high temperature.

Results

Experiment 2. Effect of exposure to low temperature (3°C) for various lengths of time (days) on germination percentage and germination rate at 25°C.

Germination Percentage.

The germination percentages obtained after transfer from low (3°C) to higher temperature (25°C) generally decreased as the exposure period (days) at low temperature increased from 10 to 30 days (Table 7).

The varieties responded differently to various durations of exposure. Variety Ochre was the least affected by the low temperature exposure. Almost all the seeds capable of germinating, germinated within 10 days at 3°C. The seeds exposed for 20 and 30 days germinated by the end of exposure period. The rest of the varieties (Regent, Reston, Span, Torch and Candle) except Lethbridge 22A were almost equally affected during the first 10 days of exposure. Germination percentages of these varieties was above 90%. However, as exposure period was extended to 20 and 30 days, the responses varied differently. The germination percentages for varieties Regent, Reston, Span, Torch, Candle and Lethbridge 22A after 30 days of exposure were 55%, 81%, 72%, 79%, 83%, and 80% respectively.

Germination Rate.

Germination index values representing germination rates increased as duration of exposure to low temperature (3°C) increased for all varieties except for varieties Lethbridge 22A and Torch (Table 7). The maximum increase in germination index differed with varieties reflecting different responses to low temperature exposure. Germination index for variety Ochre was least affected. Germination index for this variety obtained after 10 days of exposure was 1.34 and no germination index was calculated after 20 and 30 days of exposure because all seeds germinated before they were transferred. The germination index (3.41) for variety Regent was the largest after 30 days of exposure.

Experiment 3. Effect of exposure to high temperature (40°C) for various lengths of time (days) on germination percentage and germination rate at 25°C.

Germination Percentage

The exposure of seeds to 40°C for various lengths of time (days) affected germination percentage of all varieties germinated at 25°C (Table 8). Germination percentage declined to 0% as duration of exposure increased. However, varieties showed different degrees of tolerance to the high temperature treatment.

Table 7. Germination percentage and germination index for seven varieties of Brassica species started at 3°C and transferred to 25°C for ten days.

Variety	Days at 3°C	No. Germinated at Transfer	No. Not Germinated After Transfer	No. Germinated After Transfer	Germination Percentage After Transfer	Germination Index After Transfer
Regent	10	1	49	48	98	1.79
	20	15	35	29	83	2.60
	30	20	30	16.5	55	3.41
Reston	10	3	47	44	94	1.68
	20	34.5	15	11.5	74	3.24
	30	42	8	6.5	81	2.20
Span	10	0	50	48	96	2.96
	20	0	50	37	74	3.24
	30	0	50	36	72	3.07
Torch	10	0	50	48	96	1.41
	20	5.5	44.5	41	92	1.72
	30	14.5	35.5	28	79	1.36
Candle	10	0	50	48	96	1.46
	20	13.5	36.5	29.5	81	1.51
	30	17.5	32.5	27	83	1.90
Lethbridge 22A	10	0	50	44.5	89	2.62
	20	2	48	44	92	2.86
	30	1	49	44	80	2.64
Ochre	10	47.5	2.5	2	80	1.34
	20	50	0	0	0	0
	30	50	0	0	0	0

Germination did not occur for variety Ochre, even after one day of exposure. Germination was observed only after 1 day for variety Candle, and the percentage was 43%. Variety Torch was most tolerant to high temperature exposure. The germination percentage obtained after 1 day of exposure was 100%. However, the percentage decreased as duration of exposure increased and no germination occurred when samples were exposed for 16 days. Germination percentages obtained after 1 day were also high for varieties Regent (94%), Lethbridge 22A (93%) and Reston (88%) but the percentage decreased to 0% as the exposure periods were extended to 12, 5, and 6 days respectively. The germination percentage for variety Span after 1 day of exposure was 52%. The percentage decreased to 0% on day 8.

Germination Rate

The germination index values obtained at 25°C varied with variety and duration (days) of exposure to 40°C (Table 8). Germination indexes were infinite where germination did not occur. The indexes for variety Ochre were infinite for all periods of exposure because germination did not occur even after 1 day. The index values increased as exposure period increased. The index (1.65) was lowest for variety Torch after 1 day of exposure but increased to infinity on day 16 when germination did not occur.

Table 8. Germination percentage and germination index for seven varieties of Brassica species at 25°C for ten days after exposure to 40°C for various lengths of time (days).

Variety	Germination Percentage and Germination Index	Days at 40°C ^g										
		1	2	3	4	5	6	8	10	12	14	16
Regent	Germination percentage	94	80	56	38	36	37	32	22	0	0	0
	Germination index	2.21	2.28	3.98	5.39	5.86	6.81	7.09	7.18	∞	∞	∞
Reston	Germination percentage	82	62	68	37	28	0	0	0	0	0	0
	Germination index	2.74	3.11	3.80	5.59	5.78	∞	∞	∞	∞	∞	∞
Span	Germination percentage	52	24	27	25	25	26	0	0	0	0	0
	Germination index	3.75	4.40	3.92	6.04	6.36	7.33	∞	∞	∞	∞	∞
Torch	Germination percentage	100	92	92	41	40	38	35	32	14	3	0
	Germination index	1.65	1.65	1.89	3.26	4.45	4.60	4.90	5.00	7.20	8.13	∞
Candle	Germination percentage	43	0	0	0	0	0	0	0	0	0	0
	Germination index	2.60	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Lethbridge 22A	Germination percentage	93	45	18	9	0	0	0	0	0	0	0
	Germination index	3.32	4.57	6.88	7.00	∞	∞	∞	∞	∞	∞	∞
Ochre	Germination percentage	0	0	0	0	0	0	0	0	0	0	0
	Germination index	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞

^gNo germination at 40°C.

∞ = infinity

Germination of three lines of *B. campestris* variety Toria, *B. napus* variety Regent and *S. alba* variety Ochre at four (5°C, 25°C, 40°C and 45°C) temperatures.

Germination percentages for lines or varieties germinated at 5°C, 25°C, 40°C and 45°C are shown in Table 9. Germination percentages were lower at 5°C except for variety Ochre which was 100%. At 5°C the germination percentage for variety Regent, which was 88%, was higher than for the three lines of variety Toria. At 5°C the germination percentage for Toria 1422 (81%) was higher than for Toria 1424 (69%) and Toria 1421 (61%).

At 25°C germination percentage was excellent; it ranged from 99% for variety Regent to 100% for variety Ochre and Toria lines.

The germination of all varieties was affected at 40°C. The Canadian varieties (Ochre and Regent) did not germinate at 40°C. This was in agreement with the results previously obtained in this study. However, the lines of Toria germinated at 40°C. At 40°C the germination percentage of line Toria 1421 which had the lowest germination percentage (61%) at 5°C was the highest (82%). The germination percentages of other lines were, 71% for Toria 1424 and 69% for Toria 1422.

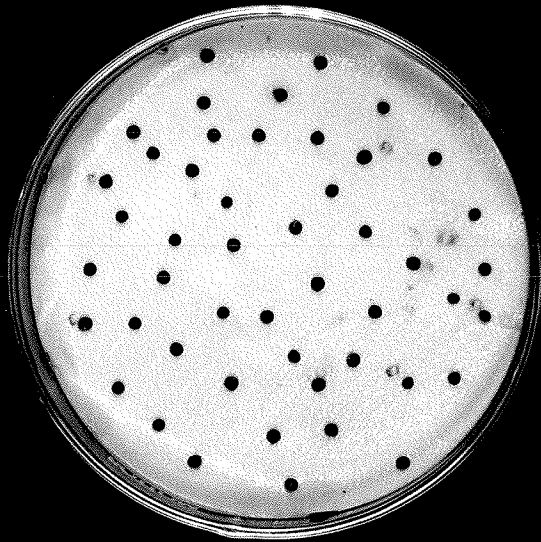
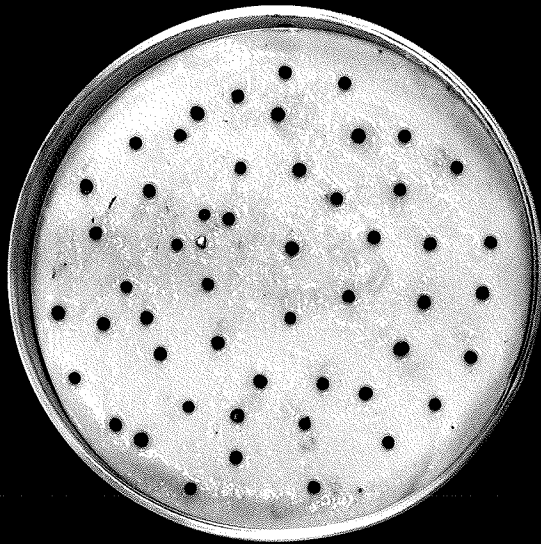
To determine whether an exposure for 10 days to 45°C was lethal, the seeds were transferred to 25°C after 10 days at 45°C. Germination counts were not taken but some germination

occurred for Toria lines while none of the seeds of Regent or Ochre germinated as shown by an example in Figure 20. Thus exposure to 45°C for 10 days was lethal for the Canadian varieties but only sub-lethal for lines of Toria originally from India.

Table 9. Germination percentage for three lines of Brassica campestris variety Toria, Brassica napus variety Regent and Sinapis alba variety Ochre at four temperatures.

Variety	Germination Percentage			
	Temperature			
	5°C	25°C	40°C	45°C
Toria 1421	61	100	82	0
Toria 1422	81	100	69	0
Toria 1424	69	100	71	0
Ochre	100	100	0	0
Regent	88	99	0	0

FIGURE 20. Germination of Brassica napus variety Regent and Brassica campestris variety Toria at 25°C for ten days after exposure to 45°C for ten days.



Brassica napus L.
Var. Regent

Brassica campestris L.
Var. Toria

Discussion on Experiments 2, 3 and variety Toria

Germination percentage was reduced as duration (days) of exposure increased at low temperature. Germination index values increased as incubation period at low temperature was extended. This indicated that germination rate was reduced as exposure period increased. Varieties differed in their responses to low temperature exposure. Some varieties, for example Span, did not germinate at 3°C while others for example Ochre, germination percentage reached 99% within 10 days. Morinaga (1926) working with seeds that included Brassica thunbergii found that, seeds germinated at higher temperatures (27°C to 38°C) after exposure to 5°C for 30 days. Pasha and Salehuzzaman (1978) working with B. campestris variety Toria to find a possible screening technique before cultivation, also found that germination rate was delayed as exposure period increased.

Several researchers have advanced a hypothesis to explain the effect of low temperature on germination. Mayer (1975) stated that water imbibed in seed activates the enzymes that digest stored food to form soluble products, that are translocated to growing point of embryo to be utilized in growth. James (1946) suggested that low temperature inactivates enzymes. This inactivation could have been responsible for differences in germination percentage and index observed

in this study. Bryan et al. (1973) put forward an assumption that inhibitors are formed by germinating seeds, and rate of formation increases with decrease in temperature. This inhibitor could be abscisic acid (ABA) that has been found to inhibit germination (Fountain and Bewley, 1976).

Low temperature has been reported to reduce germination capacity (Margaris and Fiakow, 1974). The response of varieties has been reported to differ when germinated at low temperature (Achaya et al. 1983). Torfanson and Nonneke (1957) reported that varieties responded differently as duration of exposure to temperature increased.

The effect of low temperature observed in this study could have been due to effect of temperature on enzymes, inhibitor production or some other physiological, biochemical or metabolic effects. These factors could have been affected differently as exposure periods were extended and hence affecting germination percentage and rate. Differences in response at various durations of exposure could have been due to genotypic differences.

As in low temperature treatment, germination percentage and germination index were affected by exposure to high temperatures. Germination percentage was reduced as days of exposure increased. After exposure of seeds to 40°C for 16 days, no germination was obtained after transfer to 25°C.

This indicated that seeds were killed by exposure to high temperature. Germination index also, like at low temperature increased as duration of exposure increased. Varieties were found to differ in germination response and also in days for which they could be exposed before they were killed.

The inhibitory effect of high temperature on germination could have been due to induced anaerobiosis leading to thermodormancy, a situation where at a high temperature, secondary dormancy is induced because of insufficient oxygen required for high respiratory activity of germinating embryo (Come and Tissoui 1972).

This possibly induced dormancy was broken when seeds were transferred to a lower temperature (25°C). The differences in genotypes could have been responsible for the variation observed in germination percentage and germination index. Toole and Hollowed (1939) and Knight (1965) working with Crimson Clover found that dormancy was induced by high temperature but the dormancy was broken by transferring seed from high to low temperature.

The seeds were killed as exposure period was prolonged possibly due to change in physiological processes. Physiological processes are involved in germination, in which enzymes mediated steps take place (Koller 1972). The reactions rate change with temperature. The reactions may cease completely due to thermal denaturation of enzymes (Harrington 1963, Koller 1972) resulting in killing of the seed.

Gray (1977) stated that it is possible for cell damage in an embryo to be enhanced by exposure to temperature higher than the lowest needed to maintain thermodormancy. This could have contributed to seeds being killed as was observed in this study. The varieties differed in their tolerance to high temperature. These differences are probably genetically controlled.

The test on lines of variety Toria, with varieties Regent and Ochre as controls, showed that variety Toria germinated at 40°C, and also exposure to 45°C for 10 days was not quite lethal. Variety Toria is originally from India but varieties Regent, Ochre and any other varieties used in this study were selected in Canada. India is a warmer geographical region than Canada. The ability of B. campestris variety Toria to germinate at high temperature was probably due to variety Toria having been developed in a warmer climatic region.

Results in this study and previously reported by Kumar and Alka (1977) indicate that B. campestris genotypes germinate at high temperature. However, the results reported by Kumar and Alka indicate that germination occurred at 50±2°C, but in this study germination of all Canadian varieties did not occur at 40°C while germination did not occur at 45°C for lines of Toria. The difference in response between genotypes used by Kumar and Alka and in this study could possibly be that the genotypes used by Kumar and Alka are more tolerant to high temperatures.

On the other hand Canadian varieties germinated better than Toria at low temperature probably because in development of Canadian Varieties, varieties with cold resistance were selected. The higher germination at lower temperature (5°C) for varieties Regent and Ochre (Canadian varieties) support this contention.

Results

Experiment 4. Effect of temperature on germination percentage and germination rate of five varieties grown at six locations.

Germination Percentage at 5°C and 25°C

Varieties

Germination percentage was more affected at 5°C than at 25°C as expected, except for variety Ochre (Table 10). At 5°C and at 25°C there were significant differences between treatment means as determined by Duncan's Multiple Range Test. The mean germination percentages ranged from 56.5% for variety Candle to 95% for variety Ochre at 5°C; but germination percentages for varieties Ochre (95.5%), Regent (94.5%) and Lethbridge 22A (93.7%) did not differ significantly. At 25°C germination percentages ranged from 94% for variety Ochre to 98.5% for variety Candle. The percentages at 25°C for varieties Candle (98.5%), Torch (98.2%) and Lethbridge 22A (97.8%) were not significantly different. The percentages for varieties Lethbridge 22A (97.8%) and Regent (96.8%) did not also differ significantly at 25°C.

Locations

The mean germination percentages for locations are shown in Table 11. There were significant differences between treatment means at 5°C and 25°C as determined by Duncan's

Table 10. Mean germination percentage at 5°C and 25°C for five varieties of Brassica species grown at six locations.

Location	Germination Percentage	
	Temperature	
	5°C	25°C
Regent	94.5 a ^Y	96.8 b ^Y
Ochre	95.0 a	94.0 c
Torch	61.5 b	98.2 a
Lethbridge 22A	93.7 a	97.8 ab
Candle	56.5 c	98.5 a

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

Multiple Range Test. The germination percentages were lower at 5°C than at 25°C. At 5°C the percentages ranged from 68.0% for Irricana to 86.8% for Morden. Germination percentages for locations, Morden (86.8%) and Winnipeg (85.6%) were not significantly different while percentages for locations Indian Head (82.0%), Melfort (79.6%) and Scott (79.4%) also did not differ significantly.

The germination percentages at 25°C ranged from 92.8% for Irricana to 98.8% for Winnipeg. Locations, Winnipeg (98.8%), Indian Head (98.4%) and Scott (98.6%) did not differ significantly, and locations Morden (97.4%) and Melfort (96.8%) were also not significantly different.

The analysis of variance for germination percentages (Appendix Table 26) at 5°C (Table 12) and at 25°C (Table 13) showed that locations, varieties and varieties x locations interaction were highly significant. The mean squares and F values for varieties were larger than for locations at 5°C (Table 12) but at 25°C, the mean squares and F value for locations were larger than for varieties (Table 13). Interaction effects were smaller at both 5°C and 25°C (Tables 12 and 13).

The germination of five varieties from six locations at two temperatures (5°C and 25°C) is illustrated in Figure 21 and Figure 22. These Figures permit observation of the nature of the interaction between varieties and locations.

Table 11. Mean germination percentage at 5°C and 25°C for locations where five varieties of Brassica species were grown.

Location	Germination Percentage	
	Temperature	
	5°C	25°C
Melfort	79.6 b ^Y	96.8 b ^Y
Irricana	68.0 c	92.8 c
Morden	86.8 a	97.4 b
Indian Head	82.0 b	98.4 a
Scott	79.4 b	98.6 a
Winnipeg	85.6 a	98.8 a

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

Table 12. Analysis of variance of germination percentage at 5°C for five varieties of Brassica species grown at six locations.

Source of Variation	DF	SS	MS	F	5%	1%
Replications	2	49.16	24.58	1.64	1.64	7.56
Locations	5	3,622.76	724.55	48.37**	3.33	5.64
Error	10	149.78	14.98			
Varieties	4	25,989.78	6,497.45	233.22**	2.58	3.76
Locations x Varieties	20	4,684.36	234.22	8.41**	1.80	2.30
Error	48	1,337.07	27.86			
Total	89	35,832.91				

**Significant at p=0.01 level.

Table 13. Analysis of variance of germination percentage at 25°C for five varieties of Brassica species grown at six locations.

Source of Variation	DF	SS	MS	F	5%	1%
Replications	2	1.16	0.58	0.28	4.10	7.56
Locations	5	373.82	74.76	36.64**	3.33	5.64
Error	10	20.44	2.04			
Varieties	4	183.82	45.96	22.31**	2.58	3.76
Locations x Varieties	20	656.29	32.82	15.93**	1.80	2.30
Error	48	99.07	2.06			
Total	89	1,334.60				

**Significant at p=0.01 level.

At 5°C, while the seeds for varieties Lethbridge 22A, Ochre and Regent germinated reasonably well, seeds of varieties Candle and Torch showed poorer germination percentages except for seeds of variety Torch from Indian Head. At 25°C the seeds of all varieties from all locations attained germination percentages of above 90% except for seeds of variety Ochre from Irricana that showed a germination percentage of 79% (Appendix Table 26).

Germination Rate at 5°C and 25°C

Varieties

The mean germination index values representing germination rate for varieties are shown on Table 14. There were significant differences between treatment means at 5°C and 25°C as determined by Duncan's Multiple Range Test. Germination index values were higher at 5°C than at 25°C indicating slower rates of germination at 5°C.

The index values at 5°C ranged from 8.24 for variety Ochre to 13.81 for variety Candle. The germination indexes for varieties Torch (12.88) and Candle (13.21) did not differ significantly at 5°C. At 25°C germination index values ranged from 1.17 for variety Candle to 1.41 for variety Regent. The indexes for varieties Candle (1.17), Lethbridge 22A (1.19) and Torch (1.21) did not differ significantly (Table 14).

FIGURE 21. Germination percentage at 5°C for five varieties of Brassica species grown at six locations.

Legend: 1 = Melfort
2 = Irricana
3 = Morden
4 = Indian Head
5 = Scott
6 = Winnipeg

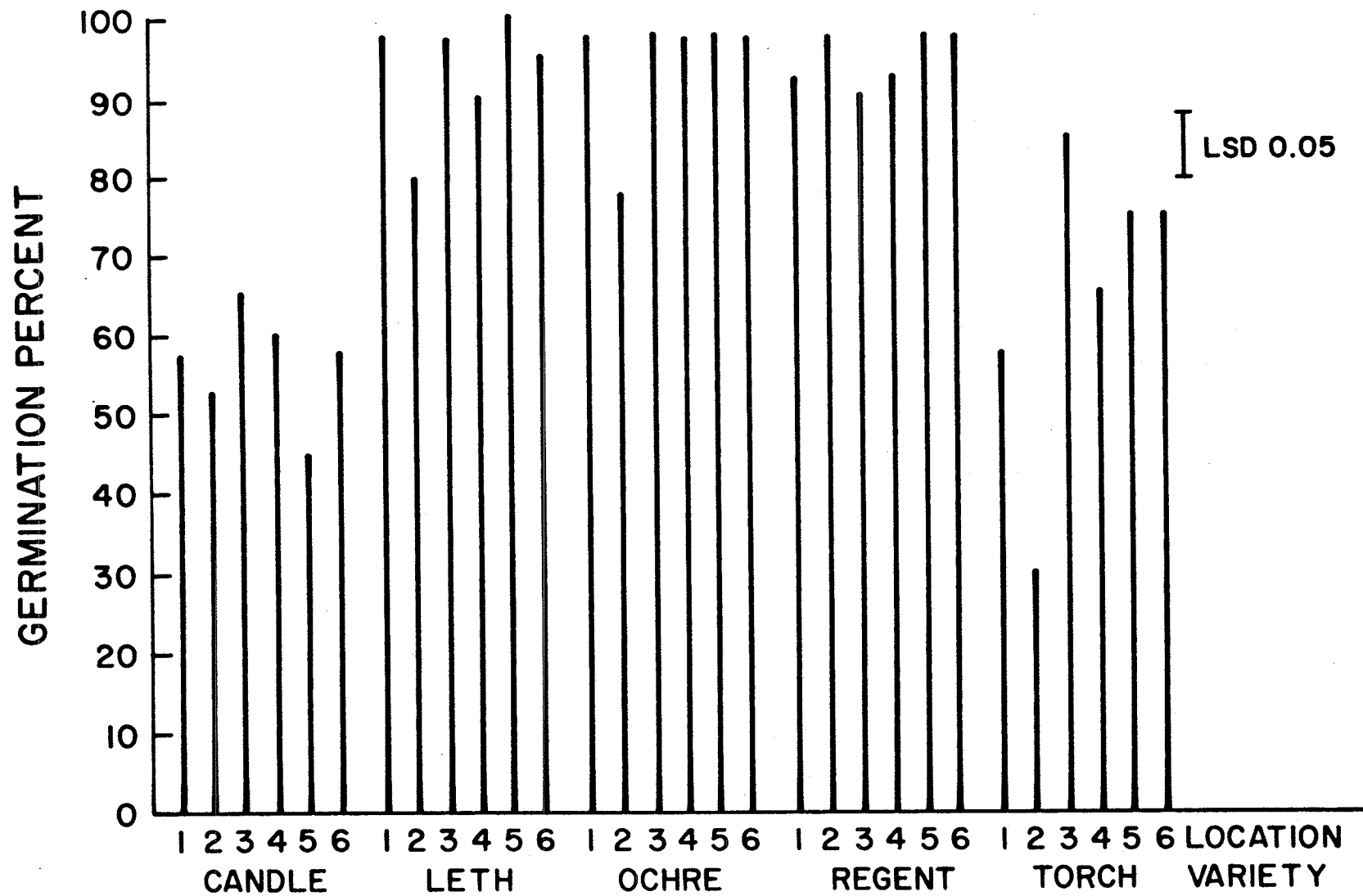
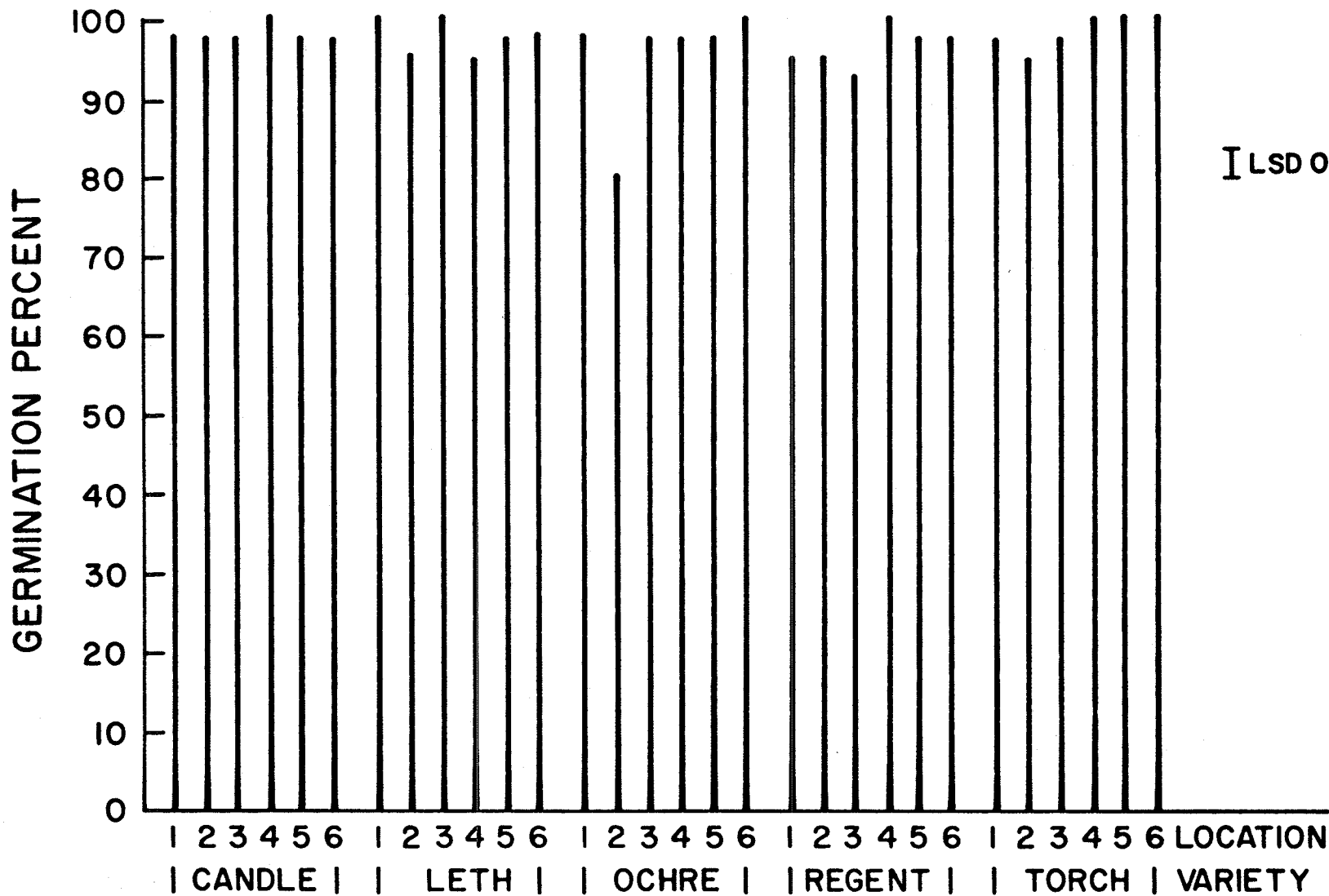


FIGURE 22. Germination percentage at 25°C for five varieties of Brassica species grown at six locations.

Legend: 1 = Melfort
 2 = Irricana
 3 = Morden
 4 = Indian Head
 5 = Scott
 6 = Winnipeg



Locations

The mean germination index values for locations at 5°C and 25°C differed significantly as determined by Duncan's Multiple Range Test (Table 15). The index values were higher at 5°C than at 25°C. At 5°C germination indexes ranged from 10.57 for Morden to 11.79 for Winnipeg. The indexes for Morden (10.57) and Scott (10.71) did not differ significantly, while indexes for Melfort (11.70), Scott (10.71), Irricana (11.75) and Winnipeg (11.79) did not also differ significantly.

Germination index values at 25°C varied from 1.07 for Winnipeg to 1.51 for Irricana. The indexes for Indian Head (1.18) and Scott (1.21) were not significantly different at 25°C.

The analysis of variance for germination index values (Appendix Table 27) at 5°C (Table 16) and 25°C (Table 17) showed that locations, varieties and locations x varieties interaction were highly significant. The mean squares and F value were larger for varieties than for locations at 5°C but at 25°C the mean squares and F value were larger for locations than for varieties. Interaction effects were smaller at both 5°C and 25°C (Table 16 and 17).

The germination indexes of five varieties from six locations at two temperatures (5°C and 25°C) are illustrated in Figures 23 and 24. These Figures permit the observation of

the nature of the interaction between locations and varieties. An examination of Figures 23 and 24 show that although germination indexes were lower at 25°C reflecting faster rate of germination, germination indexes and hence germination rates varied with the source of seed for all varieties. However, at 5°C (Figure 23) germination indexes for variety Ochre were the lowest at all locations indicating that germination rate was most rapid.

Table 14. Mean germination index at 5°C and 25°C for five varieties of Brassica species grown at six locations.

Variety	Germination Index	
	Temperature	
	5°C	25°C
Regent	11.93 b ^Y	1.41 a ^Y
Ochre	8.24 d	1.35 b
Torch	12.88 a	1.21 c
Lethbridge 22A	10.36 c	1.19 c
Candle	13.21 a	1.17 c

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

Table 15. Mean germination index at 5°C and 25°C for locations where five varieties of Brassica species were grown.

Location	Germination Index	
	Temperature	
	5°C	25°C
Melfort	11.70 a ^Y	1.36 b ^Y
Irricana	11.75 a	1.51 a
Morden	10.57 b	1.28 c
Indian Head	11.41 a	1.18 d
Scott	10.71 b	1.21 d
Winnipeg	11.79 a	1.07 e

^YMeans at each temperature followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

Table 16. Analysis of variance of germination index at 5°C for five varieties of Brassica species grown at six locations.

Source of Variation	DF	SS	MS	F	5%	1%
Replications	2	6.87	3.44	6.62*	4.10	7.56
Locations	5	22.13	4.43	8.51**	3.33	5.64
Error	10	5.21	0.52			
Varieties	4	304.03	76.01	75.25**	2.58	3.76
Locations x Varieties	20	66.67	3.33	3.30**	1.80	2.30
Error	48	48.67	1.01			
Total	89	453.58				

**Significant at p=0.01 level.

Table 17. Analysis of variance of germination index at 25°C for five varieties of Brassica species grown at six locations.

Source of Variation	DF	SS	MS	F	5%	1%
Replications	2	0.03	0.015	2.143	4.10	7.56
Locations	5	1.80	0.360	51.429**	3.33	5.64
Error	10	0.07	0.007			
Varieties	4	0.82	0.205	41.000**	2.58	3.76
Locations x Varieties	20	0.48	0.025	5.000**	1.80	2.30
Error	48	0.24	0.005			
Total	89	3.44				

**Significant at p=0.01 level.

FIGURE 23. Germination index at 5°C for five varieties of Brassica species grown at six locations.

Legend: 1 = Melfort
 2 = Irricana
 3 = Morden
 4 = Indian Head
 5 = Scott
 6 = Winnipeg

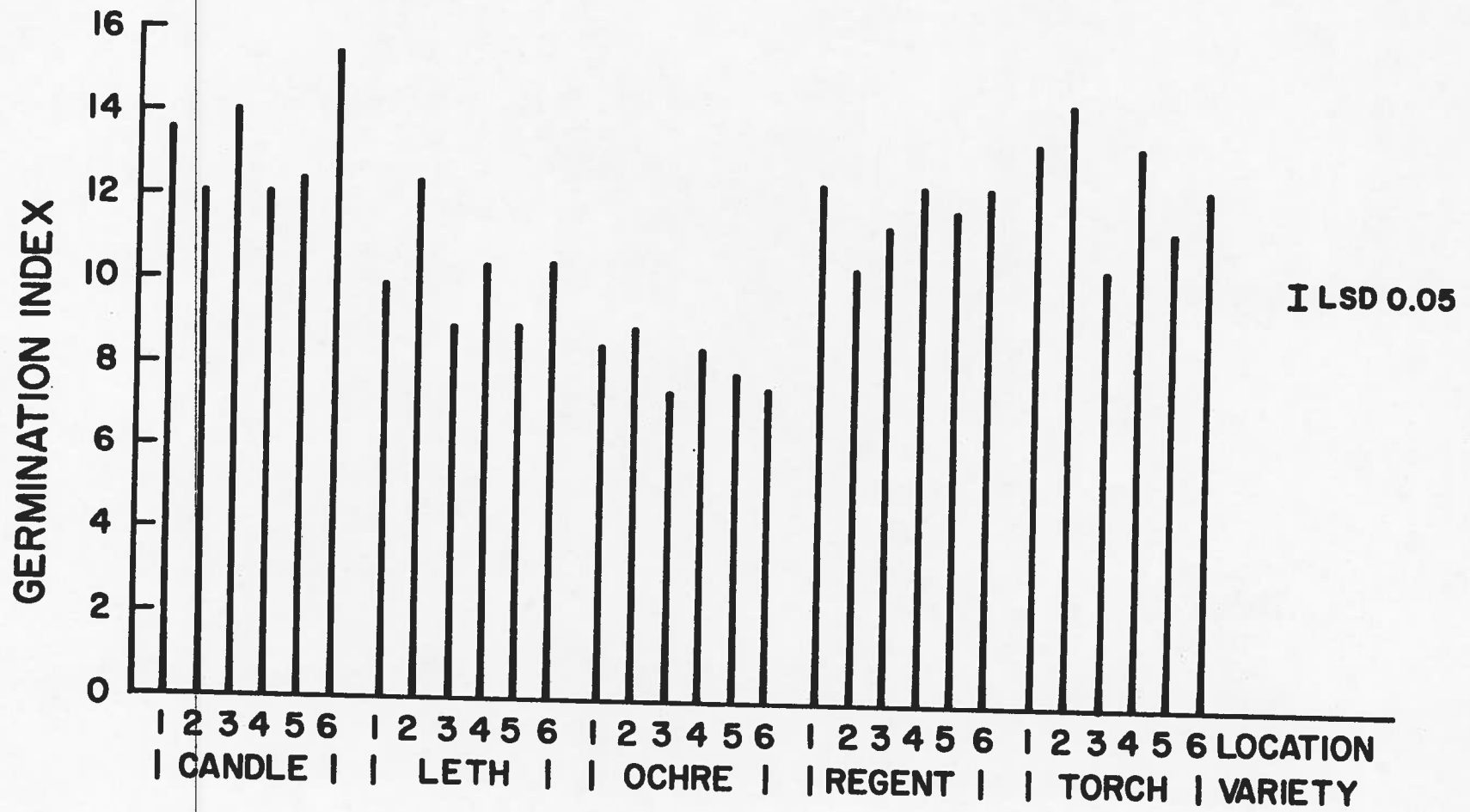
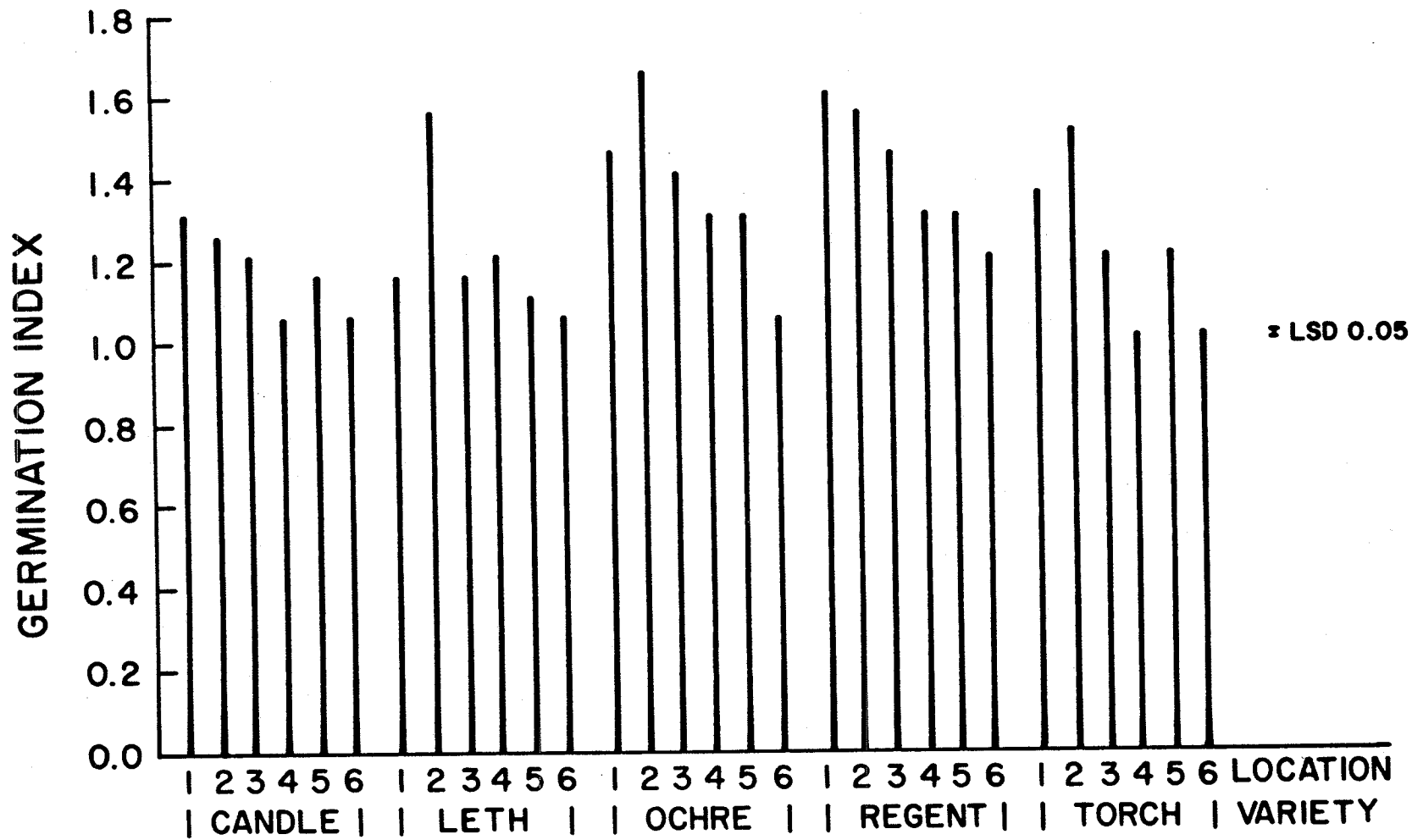


FIGURE 24. Germination index at 25°C for five varieties of Brassica species grown at six locations.

- Legend:
- 1 = Melfort
 - 2 = Irricana
 - 3 = Morden
 - 4 = Indian Head
 - 5 = Scott
 - 6 = Winnipeg



Discussion on Experiment 4

Germination percentages and germination index values for the varieties over all the locations were lower at 5°C than at 25°C (Appendix Table 26 and 27). There were significant differences between varieties, locations and the locations x varieties interaction for both germination percentage and germination index at 5°C and 25°C (Tables 12, 13, 16 and 17). At 5°C variety effect was greater than locational effect but at 25°C location effect was greater than varietal effects. This shows that temperature effect is greater at lower temperature than at higher temperature. Also at lower temperature, germinating seeds show greater variability than at higher temperature.

At higher temperature (25°C), locational effect was greater indicating that environmental effect was expressed more. The results showed varietal and seed source effects were greater at low temperature than at a more moderate temperature. Variation shown indicated that at the two temperatures, germination percentage and germination index were affected by genotypic and environmental differences. This is supported by the fact that there were significant differences between variety and location means. The varietal differences were probably due to genetic differences while environmental differences could have been a result of climatic and soil differences at locations where

seed parents were grown. For example the daily, maximum and minimum temperatures and also soil temperatures vary at locations tested (Temperature and precipitation for 1941 - 1970, estimated months normals of soil temperatures 1975). Locations x varieties interaction was significant indicating that germination percentage and germination index of varieties was influenced by location where the seed parents were grown.

Harrington (1952) working with lettuce seeds reported that the region where seed was grown had a significant effect on germination. Similar results were reported by Witcombe and Whittington (1971) on cultivated rape. They found interaction between genotype and environment. Gordon (1971) studying germination resistance (germination rate) reported that cultivar x location interaction was significant. Environmental effect on characters determining germinability was also reported by Achaya et al. (1983) on canola (rapeseed) cultivars. They suggested from their heritability studies that, the characters have complex inheritance (possibly polygenic) and are very strongly influenced by environment.

The studies reported here, and those published by several researchers indicate that germination is influenced by genetic differences and the environment in which seed was produced. This indicates that genotypes can be tested and selected for good germinability. Selection can be done in the laboratory or in the field. Studies by Hegarty (1971) on

carrots showed that there was a relationship between field establishment and laboratory germination. Results from this study suggest that selection for rapid high levels of germination can be used on rapeseed and the mustards to develop genotypes better adapted to low or high temperatures.

SUMMARY AND CONCLUSIONS

The effect of 10 temperatures (3°C, 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C, 37°C, 40°C) on the germination of 7 Canadian varieties (Regent, Reston, Span, Torch, Candle, Lethbridge 22A and Ochre) of Brassica species was investigated.

Seeds of the 7 varieties were also exposed to a low temperature (3°C) for varying periods of time (10 to 30 days) and then transferred to a moderate temperature (25°C) for 10 days.

Seeds of the 7 varieties were exposed to a high temperature (40°C) for varying length of time (1 to 16 days) and then transferred to a moderate temperature (25°C) for 10 days.

On the basis of results obtained from the study on Canadian varieties and results reported by previous researchers, 3 lines of B. campestris variety Toria originally from India, and two Canadian varieties (Regent and Ochre) as controls were tested at four temperatures (5°C, 25°C, 40°C and 45°C). After 10 days at 45°C the samples were transferred to moderate temperature (25°C) for 10 days.

Seeds from five varieties (Regent, Reston, Torch, Lethbridge 22A and Ochre) grown at six locations (Melfort, Irricana, Morden, Indian Head, Scott and Winnipeg) in Western Canada were germinated at 5°C and 25°C for 30 and 10 days respectively.

The germination percentages and rates of germination were low at low (3°C to 5°C) and high (35°C to 40°C) temperatures with the exception of variety Ochre whose germination percentage (99%) and rate (13.47) were high at 3°C and 5°C.

Germination percentages and germination rates were high from 15°C to 30°C. Differences between varieties were greatest at low and at high temperatures. The germination percentage for Ochre was high (99%) at 3°C while Span did not germinate at 3°C. The germination percentage for Span was only 1% at 5°C. At high temperature (37°C) the germination percentage for variety Torch was 64% while those of Regent and Reston were 3% and 4% respectively. Varieties Span and Lethbridge 22A had the slowest germination rates at 3°C and 5°C while variety Ochre had the most rapid rate. At high temperature (37°C) the rate of germination for variety Regent was the slowest while rate of germination for variety Torch was most rapid.

None of the Canadian varieties germinated at 40°C or 45°C while lines of Toria originally from India germinated at 40°C but did not germinate at 45°C.

The minimum temperature for germination ranged from 5°C (Span) to less than 3°C (Ochre). The maximum germination temperature for Canadian varieties was less than 40°C and less than 45°C for lines of Toria from India.

The temperature which resulted in the highest mean germination percentage for all varieties was at 25°C. The means of 15°C, 20°C and 25°C did not differ significantly.

The lowest mean germination index indicating rapid germination rate was for the temperature of 30°C, but this value did not differ significantly from the indexes for 20°C and 25°C.

Thus, on the basis of high germination percentage and high rate of germination, the optimum temperature for the germination of the varieties tested appears to be from 20°C to 30°C.

The exposure of seeds to low (3°C) and high (40°C) temperatures followed by a moderate temperature (25°C) showed that germination percentage decreased and germination index representing rate of germination increased as exposure time (days) increased. Exposure to 40°C for 16 days was lethal for seeds from all Canadian varieties while exposure to 45°C for 10 days was not quite lethal for seeds of Toria lines from India.

The germination of seeds from 5 varieties grown at six locations indicated that seed source (location) could influence the germination percentage and germination rate of seeds of Brassica species.

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Appendix Table 1. Effect of temperature on germination percentage for seven varieties of Brassica species at ten temperatures.

Temperature (°C)	Variety	Replication				Mean
		1	2	3	4	
3	Regent	52	46	36	42	44
	Reston	86	94	68	76	81
	Span	0	0	0	0	0
	Torch	10	18	22	14	16
	Candle	10	6	6	18	10
	Lethbridge 22A	0	0	0	8	2
	Ochre	98	100	100	100	99
5	Regent	88	94	86	92	90
	Reston	100	100	94	94	97
	Span	0	2	0	2	1
	Torch	38	50	54	42	46
	Candle	52	46	56	50	51
	Lethbridge 22A	48	50	44	48	48
	Ochre	100	100	98	100	100
10	Regent	98	100	100	96	99
	Reston	98	94	100	100	98
	Span	74	72	76	86	77
	Torch	98	96	100	92	97
	Candle	86	86	92	94	90
	Lethbridge 22A	96	98	94	94	96
	Ochre	100	100	100	100	100
15	Regent	94	98	96	100	97
	Reston	96	98	98	96	97
	Span	96	98	88	90	93
	Torch	100	100	100	100	100
	Candle	96	94	98	92	95
	Lethbridge 22A	94	94	98	96	96
	Ochre	98	100	98	100	99
20	Regent	98	96	100	96	98
	Reston	94	86	94	90	91
	Span	98	92	94	94	95
	Torch	98	100	98	100	99
	Candle	100	94	98	94	97
	Lethbridge 22A	96	98	96	94	96
	Ochre	96	100	98	100	99

.....continued

Appendix Table 1 continued

Temperature (°C)	Variety	Replication				Mean
		1	2	3	4	
25	Regent	98	98	98	98	98
	Reston	96	96	95	98	96
	Span	96	94	100	94	96
	Torch	100	100	100	100	100
	Candle	96	98	94	96	96
	Lethbridge 22A	100	92	94	94	95
	Ochre	98	98	100	100	99
30	Regent	96	96	98	96	97
	Reston	92	92	94	94	93
	Span	94	94	96	94	95
	Torch	100	100	100	98	100
	Candle	92	98	98	94	96
	Lethbridge 22A	84	88	88	82	86
	Ochre	88	90	88	92	90
35	Regent	74	70	72	72	72
	Reston	64	74	64	68	68
	Span	68	74	64	76	71
	Torch	100	96	96	98	98
	Candle	80	78	90	92	85
	Lethbridge 22A	82	76	74	70	76
	Ochre	80	84	84	80	82
37	Regent	2	2	4	4	3
	Reston	2	6	4	4	4
	Span	14	8	10	10	10
	Torch	62	58	64	70	64
	Candle	34	32	34	34	34
	Lethbridge 22A	52	48	40	48	47
	Ochre	28	24	28	32	28
40	No germination for all the varieties.					

Appendix Table 2. Effect of temperature on germination index for seven varieties of Brassica species at ten temperatures.

Temperature (°C)	Variety	Replication				Mean
		1	2	3	4	
3	Regent	21.91	22.67	22.31	22.10	22.25
	Reston	20.10	20.69	20.77	20.24	20.45
	Span	∞	∞	∞	∞	∞
	Torch	22.40	22.22	21.70	20.00	21.58
	Candle	18.20	23.33	18.67	19.44	19.91
	Lethbridge 22A	∞	∞	∞	29.30	29.30
	Ochre	13.57	13.58	13.14	13.58	13.47
5	Regent	15.60	17.50	14.50	15.00	15.65
	Reston	15.00	15.50	14.60	16.60	15.43
	Span	∞	28.00	∞	28.00	28.00
	Torch	17.20	15.20	14.60	15.00	15.50
	Candle	14.20	19.00	13.90	16.50	15.90
	Lethbridge 22A	25.90	23.90	25.30	25.00	25.03
	Ochre	7.80	7.98	7.30	7.60	7.67
10	Regent	5.06	4.64	5.08	4.38	4.79
	Reston	4.59	4.08	4.56	4.32	4.39
	Span	7.95	7.00	7.47	6.93	7.34
	Torch	4.74	3.92	4.16	4.09	4.23
	Candle	4.23	4.05	4.57	4.64	4.37
	Lethbridge 22A	6.67	6.78	6.32	6.77	6.64
	Ochre	2.00	2.00	2.00	2.00	2.01
15	Regent	2.72	2.67	2.67	2.97	2.97
	Reston	3.40	3.00	2.96	3.27	3.16
	Span	3.88	3.63	3.96	4.13	3.90
	Torch	2.20	2.46	2.26	2.56	2.37
	Candle	2.28	2.45	2.25	2.35	2.33
	Lethbridge 22A	4.34	4.19	4.12	4.48	4.28
	Ochre	1.98	1.98	1.96	1.96	1.97
20	Regent	2.14	2.20	1.96	2.00	2.08
	Reston	2.19	2.12	2.19	2.09	2.15
	Span	2.57	2.83	2.70	2.66	2.69
	Torch	1.60	1.74	1.79	1.82	1.74
	Candle	1.72	1.74	1.67	1.70	1.71
	Lethbridge 22A	3.10	2.28	2.71	2.82	2.88
	Ochre	1.52	1.50	1.41	1.50	1.48

....continued

Appendix Table 2 continued

Temperature (°C)	Variety	Replication				Mean
		1	2	3	4	
25	Regent	2.14	2.08	1.96	1.94	2.02
	Reston	2.31	2.65	2.28	2.08	2.33
	Span	3.14	2.55	2.82	2.70	2.80
	Torch	1.56	1.58	1.42	1.62	1.55
	Candle	1.72	1.62	1.36	1.35	1.51
	Lethbridge 22A	2.68	2.86	2.87	2.30	2.68
	Ochre	1.59	1.83	1.76	1.86	1.76
30	Regent	1.48	1.81	1.71	1.52	1.63
	Reston	1.62	1.63	1.81	1.64	1.68
	Span	1.98	2.15	2.48	2.15	2.19
	Torch	1.10	1.18	1.22	1.16	1.17
	Candle	1.44	1.80	1.53	1.26	1.51
	Lethbridge 22A	2.52	2.34	2.34	2.00	2.30
	Ochre	2.52	1.71	1.47	1.46	1.79
35	Regent	2.87	3.49	3.03	2.92	3.07
	Reston	2.47	2.43	3.18	3.14	2.81
	Span	3.06	2.95	3.53	2.81	3.09
	Torch	1.48	1.14	1.50	1.25	1.34
	Candle	1.33	1.69	1.62	1.39	1.51
	Lethbridge 22A	3.32	3.71	3.95	3.86	3.71
	Ochre	2.90	2.31	2.40	3.08	2.67
37	Regent	5.00	6.00	6.00	5.00	5.75
	Reston	5.00	4.30	6.00	4.50	4.95
	Span	5.14	5.25	6.00	5.00	5.35
	Torch	2.32	2.76	2.34	2.20	2.41
	Candle	3.94	3.56	3.29	2.65	3.36
	Lethbridge 22A	4.35	4.21	4.35	4.38	4.07
	Ochre	4.43	4.67	3.00	3.50	3.65
40	Germination index was infinite.					

∞ = infinity

Appendix Table 3. Germination percentage of Brassica napus variety Regent at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	2	0	8	8	46	4	0	0
2	0	0	2	39	90	94	92	46	0	0
3	0	0	52	93	96	96	92	52	0	0
4	0	0	94	95	96	98	94	59	0	0
5	0	0	94	97	96		96	60	0	0
6	0	0	94	97	98		97	66	3	0
7	0	2	99					70		0
8	0	12						72		0
9	0	26								0
10	0	50								0
11	0	61								0
12	0	72								0
13	0	78								0
14	6	84								0
15	6	86								0
16	6	86								0
17	6	86								0
18	6	86								0
19	6	86								0
20	6	86								0
21	28	86								0
22	28	86								0
23	28	86								0
24	28	86								0
25	28	86								0
26	28	90								0
27	28									0
28	40									0
29	40									0
30	44									0
Final Germination Percentage	44	90	99	97	98	98	97	72	3	0

Appendix Table 4. Germination percentage of Brassica napus variety Reston at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	2	0	8	6	42	4	0	0
2	0	0	2	20	80	84	86	48	0	0
3	0	0	86	84	82	88	88	50	2	0
4	0	0	86	90	86	90	92	54	2	0
5	0	0	94	92	91	94	93	58	2	0
6	0	0	94	92		96		64	4	0
7	0	2	96	92				66		0
8	0	8	96	94				68		0
9	0	28	98	96						0
10	0	60		97						0
11	0	78								0
12	0	82								0
13	0	86								0
14	14	90								0
15	14	90								0
16	14	92								0
17	14	92								0
18	14	92								0
19	14	94								0
20	14	94								0
21	68	94								0
22	68	94								0
23	68	94								0
24	68	94								0
25	68	94								0
26	68	94								0
27	68	94								0
28	81	96								0
29		96								0
30		97								0
Final Germination Percentage	81	97	98	97	91	96	93	68	4	0

Appendix Table 5. Germination percentage of Brassica campestris variety Span at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	0	0	2	2	28	8	0	0
2	0	0	0	4	56	58	60	36	0	0
3	0	0	2	50	76	78	84	48	0	0
4	0	0	2	68	88	86	94	60	4	0
5	0	0	42	81	92	88	95	64	6	0
6	0	0	42	86	94	92		71	10	0
7	0	0	62	90	95	96				0
8	0	0	62	93						0
9	0	0	74							0
10	0	0	74							0
11	0	0	76							0
12	0	0	76							0
13	0	0	77							0
14	0	0								0
15	0	0								0
16	0	0								0
17	0	0								0
18	0	0								0
19	0	0								0
20	0	0								0
21	0	0								0
22	0	0								0
23	0	0								0
24	0	0								0
25	0	0								0
26	0	0								0
27	0	0								0
28	0	1								0
29	0									0
30	0									0
Final Germination Percentage	0	1	77	93	95	96	95	71	10	0

Appendix Table 6. Germination percentage of Brassica campestris variety Torch at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	6	0	28	56	86	78	6	0
2	0	0	6	78	96	94	98	90	50	0
3	0	0	88	93	98	96	98	94	58	0
4	0	0	88	97	98	98	100	96	58	0
5	0	0	92	99	98	100		96	60	0
6	0	0	97	99	98			98	62	0
7	0	2		99	99				64	0
8	0	8		100						0
9	0	22								0
10	0	26								0
11	0	34								0
12	0	38								0
13	0	38								0
14	4	38								0
15	4	42								0
16	4	44								0
17	4									0
18	4									0
19	4									0
20	4									0
21	12									0
22	12									0
23	12									0
24	12									0
25	12									0
26	12									0
27	12									0
28	16									0
29										0
30										0
Final Germination Percentage	16	46	97	100	99	100	100	98	64	0

Appendix Table 7. Germination percentage of Brassica campestris variety Candle at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	6	0	40	62	66	62	2	0
2	0	0	6	71	90	86	84	76	24	0
3	0	0	76	90	94	92	88	80	24	0
4	0	0	76	92	96	94	96	82	24	0
5	0	0	84	95	97	96		84	28	0
6	0	0	84					85	30	0
7	0	10	88						32	0
8	0	16	88						34	0
9	0	26	90							0
10	0	30								0
11	0	36								0
12	0	36								0
13	0	38								0
14	4	38								0
15	4	40								0
16	4	40								0
17	4	44								0
18	4	46								0
19	4	46								0
20	4	46								0
21	10	46								0
22		48								0
23		50								0
24										0
25										0
26										0
27										0
28										0
29										0
30										0
Final Germination Percentage	10	51	90	95	97	96	96	85	34	0

Appendix Table 8. Germination percentage of Brassica juncea variety Lethbridge 22A at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	0	0	0	2	6	0	0	0
2	0	0	0	2	48	50	56	18	6	0
3	0	0	8	33	74	76	78	44	14	0
4	0	0	8	62	88	86	84	58	14	0
5	0	0	68	76	92	90	86	64	36	0
6	0	0	68	85	96	92		70	42	0
7	0	0	82	89		95		74	44	0
8	0	0	82	96				76	46	0
9	0	2	90						47	0
10	0	4	90							0
11	0	6	94							0
12	0	6	94							0
13	0	6	96							0
14	0	10								0
15	0	16								0
16	0	20								0
17	0	26								0
18	0	26								0
19	0	34								0
20	0	38								0
21	0	40								0
22	0	40								0
23	0	42								0
24	0	42								0
25	0	42								0
26	0	42								0
27	0	44								0
28	0	44								0
29	2	46								0
30		48								0
Final Germination Percentage	2	48	96	96	96	95	86	76	47	0

Appendix Table 9. Germination percentage of Sinapis alba variety Ochre at ten temperatures.

No. of Days in Test	Germination Percentage									
	Temperature									
	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C
1	0	0	0	6	54	38	50	8	0	0
2	0	0	99	96	96	96	82	44	10	0
3	0	0	100	99	98	96	88	62	18	0
4	0	0			99	98	90	74	20	0
5	0	4				98		82	24	0
6	0	34				98			26	0
7	12	94				99			28	0
8	12	96								0
9	12	96								0
10	12	98								0
11	12	98								0
12	12	100								0
13	12									0
14	96									0
15	96									0
16	96									0
17	96									0
18	96									0
19	96									0
20	96									0
21	99									0
22										0
23										0
24										0
25										0
26										0
27										0
28										0
29										0
30										0
Final Germination Percentage	99	100	100	99	99	99	90	82	28	0

Appendix Table 10. Analysis of variance of the germination percentage and germination index for Brassica napus variety Regent at nine temperatures.

<u>Analysis of Variance</u>						
Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	6.56	2.19	0.22	3.01	4.72
Temperatures	8	34,755.56	4,344.44	440.98**	2.36	3.36
Error	24	236.44	9.85			
Total	35	34,998.56				
<u>Germination Index</u>						
Replications	3	3.61	1.20	2.48	3.01	4.72
Temperatures	8	1,714.50	214.31	443.07**	2.36	3.36
Error	24	11.61	0.48			
Total	35	1,729.72				

**Significant at p=0.01 level.

Appendix Table 11. Analysis of variance of the germination percentage and germination index for Brassica napus variety Reston at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	71.56	23.85	1.03	3.01	4.72
Temperatures	8	29,710.89	3,713.86	159.61**	2.36	3.36
Error	24	558.44	23.27			
Total	35	30,340.89				
<u>Germination Index</u>						
Replications	3	0.30	0.10	0.47	3.01	4.72
Temperatures	8	1,461.66	182.71	872.17**	2.36	3.36
Error	24	5.03	0.21			
Total	35	1,466.99				

**Significant at p=0.01 level.

Appendix Table 12. Analysis of variance of the germination percentage and germination index for Brassica campestris variety Span at eight temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	59.38	19.79	2.04	3.07	4.87
Temperatures	7	12,625.88	1,803.70	186.02**	2.49	3.64
Error	21	203.63	9.70			
Total	31	12,888.89				
<u>Germination Index</u>						
Replications	3	0.66	0.22	0.99	3.07	4.87
Temperatures	7	1,519.85	217.12	989.14**	2.49	3.64
Error	21	4.61	0.22			
Total	31	1,525.12				

**Significant at p=0.01 level.

Appendix Table 13. Analysis of variance of the germination percentage and germination index for Brassica campestris variety Torch at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	59.00	19.67	1.47	3.01	4.72
Temperatures	8	30,190.22	3,773.78	283.03**	2.36	3.36
Error	24	320.00	13.33			
Total	35	30,569.22				
<u>Germination Index</u>						
Replications	3	1.64	0.55	1.81	3.01	4.72
Temperatures	8	1,716.87	214.61	712.11**	2.36	3.36
Error	24	7.23	0.30			
Total	35	1,725.74				

**Significant at p=0.01 level.

Appendix Table 14. Analysis of variance of the germination percentage and germination index for Brassica campestris variety Candle at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	86.22	28.74	1.99	3.01	4.72
Temperatures	8	33,992.89	4,249.11	294.93**	2.36	3.36
Error	24	345.78	14.41			
Total	35	34,424.89				
<u>Germination Index</u>						
Replications	3	7.93	2.64	2.37	3.01	4.72
Temperatures	8	1,572.39	196.55	176.01**	2.36	3.36
Error	24	26.80	1.12			
Total	35	1,607.12				

**Significant at p=0.01 level.

Appendix Table 15. Analysis of variance of the germination percentage and germination index for Brassica juncea variety Lethbridge 22A at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	59.38	19.79	2.04	3.08	4.67
Temperatures	8	17,012.60	2,126.58	219.24**	2.37	3.41
Error	21	203.63	9.70			
Total	32	17,275.61				
<u>Germination Index</u>						
Replications	3	0.66	0.22	1.00	3.08	4.67
Temperatures	8	1,988.99	248.62	1,130.09**	2.37	3.41
Error	21	4.61	0.22			
Total	32	1,994.26				

**Significant at p=0.01 level.

Appendix Table 16. Analysis of variance for germination percentage and germination index for Sinapis alba variety Ochre at nine temperatures.

Analysis of Variance

Source of Variation	DF	SS	MS	F	5%	1%
<u>Germination Percentage</u>						
Replications	3	15.56	5.59	2.00	3.01	4.72
Temperatures	8	17,590.00	2,198.75	845.67	2.36	3.36
Error	24	62.44	2.60			
Total	35	17,668.00				
<u>Germination Index</u>						
Replications	3	0.56	0.19	2.38	3.01	4.72
Temperatures	8	522.70	65.34	816.75**	2.36	3.36
Error	24	1.88	0.08			
Total	35	525.14				

**Significant at p=0.01 level.

Appendix Table 17. Mean squares of germination percentage for seven varieties of Brassica species at nine temperatures.

Source of Variation	DF	Mean Squares								
		Temperature								
		3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C
Replications	3	42.13	7.24	9.71	2.05	11.07	1.29	7.62	3.81	16.14
Varieties	6	615.40**	5148.62**	259.14**	22.91**	29.91**	12.91**	86.81**	434.48**	210.81**
Error	18	48.13	16.24	12.16	6.71	5.04	3.95	3.06	22.48	9.37
CV		13.88	6.53	3.73	2.68	2.24	2.04	1.88	6.05	11.30

** Significant at p=0.01 level.

Appendix Table 18. Mean squares of germination index for seven varieties of Brassica species at nine temperatures.

		Mean Squares								
		Temperature								
Source of Variation	DF	3°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C
Replications	3	0.93	1.93	0.21	0.07	0.01	0.06	0.01	0.09	0.68
Varieties	6	47.75**	185.15**	12.18**	2.96*	1.08**	1.10*	0.61**	3.03*	5.21**
Error	18	1.53	1.38	0.07	0.02	0.01	0.03	0.06	0.09	0.25
CV		6.36	6.68	5.62	4.44	4.48	8.75	13.88	11.63	11.99

*, ** Significant at p=0.5, 0.01 levels respectively.

Appendix Table 19. Effect of temperature on germination percentage and germination index of Brassica napus variety Regent.

Temperature (°C)	Germination Percentage	Germination Index
3	44 d ^Y	22.25 a ^Y
5	90 b	15.65 b
10	99 a	4.79 c
15	97 a	2.76 d
20	98 a	2.08 de
25	98 a	2.02 de
30	97 a	1.63 e
35	72 c	3.07 d
37	3 e	5.75 c
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 20. Effect of temperature on germination percentage and germination index of Brassica napus variety Reston.

Temperature (°C)	Germination Percentage	Germination Index
3	81 b ^Y	20.45 a ^Y
5	97 a	15.43 b
10	98 a	4.39 c
15	97 a	3.16 d
20	91 a	2.15 ef
25	96 a	2.33 ef
30	93 a	1.68 f
35	68 c	2.81 de
37	4 d	4.95 c
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 21. Effect of temperature on germination percentage and germination index of Brassica campestris variety Span.

Temperature (°C)	Germination Percentage	Germination Index
3	0	
5	1 d ^Y	28.00 a ^Y
10	77 b	7.34 b
15	93 a	3.90 c
20	95 a	2.69 d
25	96 a	2.80 d
30	95 a	2.19 e
35	71 b	3.09 d
37	10 c	5.35 c
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 22. Effect of temperature on germination percentage and germination index of Brassica campestris variety Torch.

Temperature (°C)	Germination Percentage	Germination Index
3	16 d ^Y	21.08 a ^Y
5	46 d	15.50 b
10	97 a	4.23 c
15	100 a	2.37 d
20	99 a	1.74 de
25	100 a	1.55 de
30	100 a	1.17 e
35	98 a	1.34 c
37	64 b	2.41 d
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 23. Effect of temperature on germination percentage and germination index of Brassica campestris variety Candle.

Temperature (°C)	Germination Percentage	Germination Index
3	10 f ^Y	19.91 a ^Y
5	51 d	15.90 b
10	90 bc	4.37 c
15	95 a	2.33 de
20	97 a	1.71 e
25	96 a	1.51 e
30	96 a	1.51 e
35	85 c	1.49 e
37	34 e	3.36 cd
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 24. Effect of temperature on germination percentage and germination index of Brassica juncea variety Lethbridge 22A.

Temperature (°C)	Germination Percentage	Germination Index
3	2 e ^Y	29.30 a ^Y
5	48 d	25.03 b
10	96 a	6.64 c
15	96 a	4.28 d
20	96 a	2.88 e
25	95 a	2.68 e
30	86 b	2.30 e
35	76 c	3.71 d
37	47 d	4.07 d
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 25. Effect of temperature on germination percentage and germination index of Sinapis alba variety Ochre.

Temperature (°C)	Germination Percentage	Germination Index
3	99 a ^Y	13.47 a ^Y
5	100 a	7.67 b
10	100 a	2.01 e
15	99 a	1.97 e
20	99 a	1.48 f
25	99 a	1.76 ef
30	90 b	1.79 e
35	82 b	2.67 d
37	28 c	3.65 c
40	0	∞

^YMeans in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test.

∞ = infinity

Appendix Table 26. Mean germination percentage at 5°C and 25°C for five varieties of Brassica species grown at six locations.

Temperature	Variety	Mean Germination Percentage						Mean
		Location						
		Melfort	Irricana	Morden	Indian Head	Scott	Winnipeg	
5°C	Regent	89	99	89	93	98	99	94.5
	Ochre	98	77	98	99	98	100	95.0
	Torch	57	31	85	66	56	74	61.5
	Lethbridge 22A	97	80	98	91	100	96	93.7
	Candle	57	53	64	61	45	59	56.5
	Mean	79.6	68.0	86.8	82.0	79.4	85.6	80.2
25°C	Regent	95	96	94	100	98	98	96.8
	Ochre	96	79	97	97	98	99	94.3
	Torch	96	96	98	100	99	100	98.2
	Lethbridge 22A	100	95	99	96	99	98	97.8
	Candle	97	98	99	99	99	99	98.5
	Mean	96.8	92.8	97.4	98.4	98.6	98.8	97.1

Appendix Table 27. Mean germination index at 5°C and 25°C for five varieties of Brassica species grown at six locations.

Temperature	Variety	Mean Germination Index						Mean
		Location						
		Melfort	Irricana	Morden	Indian Head	Scott	Winnipeg	
5°C	Regent	12.65	10.66	11.35	12.56	11.93	12.41	11.93
	Ochre	8.51	8.98	7.95	8.39	7.83	7.75	8.24
	Torch	13.58	14.67	10.73	13.44	12.15	12.73	12.88
	Lethbridge 22A	10.18	12.38	8.93	10.68	9.24	10.73	10.36
	Candle	13.58	12.07	13.91	12.00	12.39	15.31	13.21
	Mean	11.70	11.75	10.57	11.41	10.71	11.79	11.32
25°C	Regent	1.60	1.57	1.47	1.29	1.30	1.20	1.41
	Ochre	1.43	1.67	1.39	1.32	1.28	1.03	1.35
	Torch	1.33	1.52	1.19	1.02	1.21	1.01	1.21
	Lethbridge 22A	1.13	1.53	1.13	1.22	1.08	1.05	1.19
	Candle	1.30	1.26	1.21	1.03	1.16	1.05	1.17
	Mean	1.36	1.51	1.28	1.18	1.21	1.07	1.27