SOME EFFECTS OF COLD TEMPERATURE ON SEEDSTALK PRODUCTION IN CARROTS

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SEEDSTALK PRODUCTION IN CARROTS

By
MICHAEL HUGH DICKSON

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
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MASTER OF SCIENCE

Department of Horticulture

Approved C. E. Peterson

ABSTRACT

M. H. DICKSON

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SEEDSTALK PRODUCTION IN CARROTS

The effects of cold storage on seedstalk induction in mature carrot roots and on seedling carrots were studied. Mature roots were harvested from Muck and Loam soils, stored for periods of 1, 2, 4 and 8 weeks at temperatures from 32-50° F. The stored roots were subsequently grown in the greenhouse at temperatures of 55-60° F. and 65-70° F. The mature carrot roots when stored for 4 or 8 weeks at temperatures between 32 and 50° F. and then grown in the greenhouse at 55-60° F. produced 90-100 percent seedstalks. Roots grown at 65-70° F. after eight weeks of cold storage also produced 90-100 percent seedstalks, but three months later than those grown in the greenhouse at 55-60° F. Those stored four weeks and then grown at 65-70° F. produced between 33 and 90 percent seedstalks and they were likewise later than those grown in the cool greenhouse after four weeks of storage at 32-50° F.

Roots harvested on August 30 and stored for eight weeks and then grown in the warm house produced fewer bolters and the seedstalks developed more slowly than those harvested October 3.

Mature roots harvested October 3 produced seed earliest and in the most reliable manner when subjected to 8 weeks of storage at 40° F. followed by growing the plants at a greenhouse night temperature of 55-60° F. until the seedstalks began to elongate. After the seedstalks became apparent the temperature should be raised to 70° F. to obtain rapid growth and flower development.

ABSTRACT

M. H. DICKSON

Seedling carrots between 0 and 56 days old were not induced to bolt when subject to 28 days at 40° F. and then grown at 60-70° F.

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INTRODUCTION

The recent discovery of male sterility in carrots has encouraged a plant breeding program for the development of male sterile lines, similar to those available in onions. Carrots being very heterozygous vary widely in shape, internal structure and composition, even within a particular strain of one variety. With an open pollinated crop using mass selection improvement is very slow. Also to cross pollinate carrot plants by hand is very difficult and tedious as the small flowers only produce two seeds. When male sterile plants were found a new opportunity for exacting carrot breeding in contrast to mass selection became available.

With our present knowledge completion of the life cycle within a year using the greenhouse in the winter is a somewhat unreliable process. It was felt that further investigation into the flowering habit of carrots was required with a view to obtaining a reliable procedure for seed production during the winter months.

Although the accepted method of inducing flowering in carrots is by a period of cold exposure, the minimum length of cold induction necessary for 100 percent seedstalk production in the shortest time has not been found. In order to study the optimum temperature for induction, and the necessary minimum thermoperiod an experiment was designed to find a reliable method of post harvest induction to insure rapid seed production.

In most commercial plantings there is a small percentage of early bolters in various stages of development which must be rogued before harvest to insure a high quality processed product. Steckling stocks from which early seeders have been removed still contain roots with a tendency to bolt and are the source of commercial seed. An investigation of conditions under which early initiation occurred was necessary. Therefore, an experiment was designed to see if any carrot seedling induction would occur under normal conditions and to determine the effect of day length and temperature of growth after cold induction process. If a reliable test could be found for promoting induction of susceptible carrots in the first season more adequate rogueing could be made with eventual elimination of the early bolters. At the same time a means to induce premature seeding would be useful in a plant breeding program to hasten back crossing and testing for male sterility.

REVIEW OF LITERATURE

Effects of cold on flower induction in various plants.

Gassner (8) was among the first to investigate the effects of cold treatment on flowering and seed formation. He observed that beets held in a cool greenhouse from January to April went to seed the following Summer, while those held at 20° C. did not. Also that cabbage, rutabaga and carrots seemed to depend generally for their flower formation upon the influence of low temperatures.

Boswell (2) reported that in onions flower primordia differentiation was almost entirely inhibited by storing for 8 months at 32° F., while storage at 50° F. produced a much higher percentage of flowers. However, 6½ months at 32° F. followed by 7 weeks at 50° F. greatly increased the flowering percentage compared with bulbs stored 8 months at 32° F. He also observed that the lower the storage temperature below 50° F. the greater the inhibiting effect on flower primordia development and that the large bulbs produced higher percentages of seeders.

Thompson and Smith (29) working with onion sets state that large sets of 13/16-1 1/8 inch diameter produced much higher percentages of seedstalks than did medium 5/8-3/4 inch diameter or small sets 3/8-5/8 in diameter. They observed that sets stored at 40-50° F. produced the highest percentages of seedstalks as well as the fewest marketable bulbs. Sets stored at 32° F. produced the best bulbs, and while sets stored at 60-70° F. also produced few flower stalks the bulbs were much shriveled. When sets were stored under conditions unfavorable for seedstalk production large sets produced the best yields, but also the most splits and doubles. For seed production a growing temperature of 50-60° F. was found to be best, while at 70-80° F. seedstalks did not develop. When sets in storage at 32° F. were moved to 40-50° F., seedstalk production increased compared to those held at 32° F. all the time. Moving sets in storage from 40-50° to 60-70° F. decreased seedstalk production and moving them from 60-70° F. to 50° F. or 32° F. increased seeding. Increasing the photoperiod by five hours over the normal winter day length hastened seedstalk development, but under high temperatures of 70-80° F. seedstalks did not develop under normal day length or under long days.

Jones (11) and Jones and Emsweller (12) working with the Ebenezer variety of onion found that bulbs stored at 46° F. and 53° F. always produced the earliest seedstalks while those stored at 86° F. produced the latest, and also that high temperature produced vegetative bulbs and few seedstalks. Bulbs stored at 53° F. always produced the largest seed yields.

Starring (25) in Montana working on celery, found that a check in growth due to cool weather alone unfailingly caused seed production. He also found that at longer periods of cold temperature the percentage of bolters increased. Thompson (26) stated that a serious check in growth delays seedstalk development in celery and may prevent it entirely. In young seedlings after 2 weeks or more at 40-50° F. premature seeding is likely, also plants grown in the greenhouse for 2½ months or more at 50° F. are likely to produce seedstalks in the first season. However, a 70° F. temperature after 30 days of cold prevented seeding unless the seedstalk was started before subjection to this temperature. For the best seed production he recommended growing the celery at 55-60° F. after the cold induction until the seedstalks had started to grow, then completing growth at 60-70° F. He also stated that when conditions are favorable for rapid growth for a few weeks following the cold treatment, the percentage of seedstalks are much higher than when conditions are unfavorable for good growth. This applied to beets as well as celery.

Pawar and Thompson (15) investigating the effects of age and size of plant at time of exposure to low temperature, observed that older celery plants at the time of cold treatment went to seed faster, but that the total time from seed to seed was shortest when 2 month old plants were treated. However, plants treated at any age would bolt eventually. The age of the plant was the important factor, and size had no effect on the rate of flowering.

In studies on premature flower formation in wintered-over cabbage, Boswell (3) found that below a stem diameter of 6mm the increases in seeding with increasing size of plant are small. At a diameter of 6-7mm there is a sharp increase in the percentage of seeders, above which the increase is still more marked. Earlier planting in the fall produced increased bolting even if the over-wintered plants were the same size. This appeared to be due to the older plants being physiologically more mature. Low temperature is effective in promoting reproduction only after the plants have accumulated a sufficient weight of reserve foods.

Miller (13) found that cabbage plants bolted a month earlier when grown at 60-70° F. than at 50-60° F. after 2 months at 40° F., but that 15 and 30 days at 40° F. only produced a very few bolters. He also found that increasing the day length did not enhance seedstalk development.

Chroboezek (6) observed that garden beets became vegetative at high temperatures even after the flower stem had grown to full height and the buds had developed. It was shown that the crown or growing point was the vital area, which had to be given cold treatment to induce bolting. He was able to produce bolting by winding a small rubber tube around the base of the petioles and circulating cold water at 43.8° F. If the tubing was wound around the base of the root no seedstalk production occurred. He also noted that germination at low temperature did not induce flowering in beets which were later grown at high temperatures. Thirty days at 40-50° F. for young plants induced flowering when grown later at 60-70° F., but 70-80° F. nullified the cold treatment. However, if the plants were grown for 60-90 days at 40-50° F. the nullifying effect of high temperature was not evident. Extra light helped seed production at high temperatures but under cool conditions 8 hours was enough. However, at high temperatures very few plants went to seed even with extra light. The most plants bolted when they were grown at 50-60° F. and under 15 hours light. Plants grown at 50-60° F. under continuous light produced seed stalks 53 days after planting.

Naylor (14) stated that by using continuous light of 1000-1400 ft. candles flowers were produced in 31 days in garden beets and 40 days after seeding in dill. At 500 ft. candles seed stem elongation in 60 days was observed in dill, but none with this light in biennial beets. The intensity of the light proportionately speeded bolting in dill. Cold suppressed the flowering responses under continuous light. Annual beets would not flower if more than 10-11 hours of darkness were given in 24 hours, but 13 days of continuous light resulted in bolting even on returning to short days. Annual beets required over 700 ft. candles for flowering.

In studies on premature seeding in beets Smith (23) found that when mature beets were grown in the dark at 55° F. no flower primordia were formed, but if in the light 100 percent flowered. However, two weeks in the dark at 50° F. followed by continuous light at 55° F., produced more bolting than growth in continuous light at 55° F. Plants grown at 50° F. for 2 weeks and then moved to a growing temperature of 55° F. and continuous light produced the most seedstalks. Thirty-seven to forty-seven day old plants responded better than older or younger plants.

Carolus (4) stored beets and turnips at 32-40° F. and also 55-65° F. in common storage. The cold storage temperarily delayed seedstalk elongation compared to common storage; however, the resultant flower stalks were longer and more vigorous from the cold stored plants. For each month of storage the rate of seedstalk elongation was increased on removing the plants from storage. Thus, beets stored 3 months reached 90% elongation ahead of those stored 2 or 1 months, although planted 1 and 2 months earlier, and all reached 100% at the same time. While in turnips, 2 weeks after planting, plants stored 3 months were ahead of those stored 2 months, although the latter had been planted 6 weeks.

Peto (16) reported flowering in turnips was inhibited by temperatures above 65° F. in plants which had shown incipient bolting, and that plants grown continuously at high temperatures produced vegetative growth, while low temperatures favor sexual reproduction. Sakr (21) reported that when turnip plants one month old were subjected to 30 days at 40-50° F. subsequent exposure to 50-60° F. was more favorable for seedstalk production than 60-70° F. or 70-80° F. After 60 days of cold storage at 40-50° F. any growing temperature gave a high percentage of bolters. He found that increased light in November and December speeded seed production at higher growing temperatures. He also found that seed vernalized for one month at 37° F. produced 64 percent bolters if it had germinated during vernalization, but only 3 percent if it had not germinated. Plants put into the cold when just germinated tended to bolt more than those put into the cold when one month old. A temperature of 53° F. and continuous light on germinating seedlings gave incipient bolting in 71 days. In mature plants 30 days at 40-50° F. followed by growing at 50-60° F. gave the most seeders. If the temperature following exposure to 40-50° F. for 30 days was 65° F. or above bolting was inhibited to some extent.

Sakr (22) reported that no bolting occurred in seedling parsnip plants grown 33 days at 60-70° F. followed by 15, 30 or 60 days at 40-50° F. and then returned to a temperature of 60-70° F. However, 100 percent bolting resulted when 4 month old plants were subjected to 35 or 49 days in cold storage at 40-50° F. and subsequently grown at 60-70° F.

Chesnokov (5) stated that in turnips, cabbage and carrots young seedlings, rather than slightly germinated seed, chilled 50 days gave a higher percentage of seedstalks. He found with beet plants that 80-90 percent bolted the first Summer when young seedlings were chilled 50 days.

Verkerk (30) reported that the first signs of the generative stage were visible in disected growing tips of brussels sprouts after 4 weeks at 5 or 7° C.

Vlàtes and Meudt (31) in investigations on vernalization and photoperiodism in spinach observed that seed vernalized at 2° C. for two weeks produced up to 25 percent bolters at any photoperiod above 8 hours. After 8 weeks of vernalization at 2° C. all the plants flowered in 35 days when grown under 12 hours photoperiod as compared with only 8 percent flowering among plants grown from seed held at 25° C.

It was shown by Thompson and Knott (28) that high temperatures also have a role in flower induction. Lettuce grown at 70-80° F. went to seed without forming heads, while similar plants grown at 60-70° F. formed heads and then went to seed. Cochran (7) working with peppers found that blossom buds developed at 60-100° F., but at 90-100° F. they dropped off without setting fruit. Pepper plants at 55° F. fail to develop flower buds, but if plants with buds were grown at 55° F. all developed fruit parthenocarpically.

In studies on vernalization Gregory and Purvis (10) and Purvis and Gregory (17, 18) observed that a short period of high temperatures (30° C.) devernalized rye grain, but that it could be revernalized in a shorter time than the original vernalization. The degree of devernalization varied inversely with the duration of the previous vernalization. Three days at 35° C. after 4 weeks vernalization at 1° C. resulted in 55 percent devernalization. After 6 weeks only 16 percent devernalization occurred and after 12 weeks none occurred. Also, the vernalized condition was stabilized against reversal if a period of growth at 15° C. immediately preceded the high temperature.

With mature carrots Sakr and Thompson (19) found that storage at 40° F. resulted in a higher percentage of bolters than storage at 35° F. or 50° F. Roots stored 15 days at 40° F. and then grown in the greenhouse at 50-60° F. produced 100 percent bolters, while 30 days storage at 35° F. and 60 days at 50° F. were required to produce 100 percent bolting at the 50-60° F. growing temperature. Storage for 60 days at 40° F. was required to produce 100 percent bolting when plants were grown in the greenhouse at 60-70° F. He also found a slight advantage in using natural day length of about 10 hours during the winter rather than continuous light. The check plants grown continuously at 50-60° F. without a previous cold treatment produced as many bolters as those stored 30 days at 50° F. and then grown at 50-60° F. He decided that a growing temperature of 50-60° F. was the most favorable for seedstalk development, except after a long period of 80 days or more at 40° F. when even at the higher temperatures all plants went to seed.

Carrot seedlings (Sakr 20) subjected to one month at 40-50° F. starting 17 days after planting produced more bolters at a growing temperature of 50-60° F. than when grown at 60-70° F. and 70-80° F., but in all treatments the percentages were low. When seedling plants were grown for 135 days at 40-50° F. then moved to 50-60° F., 54 percent bolted, while those grown at 60-70° F. following the same treatment produced 43 percent bolters. Light increased vegetative growth at low temperatures, but made less difference at high temperatures; it made no difference on seedstalk production.

EXPERIMENTAL

General

Flower induction was investigated for two types of carrots. One involved mature carrots harvested in the fall, stored for varying periods at different temperatures and then grown in the greenhouse. The other involved seedlings of different ages subjected to a cold treatment and then grown at different temperatures and photoperiods.

Materials and Methods of Procedure

The Effect of Cold Storage on Flower Stalk Induction in Mature Carrots

Carrots grown at the Muck Farm. Carrots of the variety Long Chantenay were seeded at the Experimental Muck Farm on May 3, 1955. Mature roots were harvested on August 30 and selected for trueness to type. The tops were cut off about one-half inch above the crown and the roots were then dipped for approximately 30 seconds in an antibiotic solution*.

A total of 600 roots were selected and placed in shallow wire-bottomed trays in moist sphagnum moss, 120 roots being stored at each of five temperatures, 32, 40, 45, 50° F. and the check lot at room temperature, approximately 70° F.

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* Agri-mycin 100, formulated by the Pfizer Company, was used at a concentration of 150 ppm as recommended. It contained Streptomycin 15% and oxytetracycline 1.5% as the active ingredients.

Storage periods of 1, 2, 4, and 8 weeks were used. At the end of each period 20 carrot roots were removed from the trays in each temperature and planted in the greenhouse in 6 inch pots. Thus, the plants with the longer storage periods were planted later. For the first planting the soil was rather heavy and there was about 50 percent loss during the following month mostly due to bacterial soft rot. The second and all the following plantings were grown in a mixture of equal parts of loam, sand and muck. The third lot was planted in a core of Arasan and sand in an effort to prevent rotting, but after a period of two weeks this was found to inhibit root development so they were repotted in the soil mixture without a sand-Arasan core. Carrots for the fourth planting were rolled in Arasan or Spergon and then potted.

Until November 25 the greenhouse night temperature was 70° F. and often reached 90° F. by day. From November 25 to the end of the experiment it was possible to hold the greenhouse temperature near 65° F. at night and 70° F. by day. Due to an accident the temperature reached 100° F. during the night of November 21.

<u>Carrots grown at the Horticulture Farm</u>. These carrots were seeded on a sandy loam on May 11, 1955, at the Michigan State University Horticulture Farm. On October 3 mature roots were hand harvested. The tops were cut off one inch above the crown, as it was felt that slightly longer tops might better protect the apical bud. They were dipped in the same anti-biotic solution as roots harvested at the Muck Farm, then placed in moist sphagnum moss in shallow wire-bottomed trays and kept in storage for periods of 1, 2, 4, and 8 weeks at 32, 40, 45, 50° F. The check lots were stored at a temperature of about 70° F. for corresponding periods of time.

On being taken out of storage the roots were rolled in Arasan or Spergon and then potted in the loam, sand and muck mixture. They were then divided into two lots, one lot to be grown at a night temperature of 55° F. and the other at 65° F. It was not possible to achieve the 65° F. intended until November 25, prior to that date the temperature was 70° F. The cool house was not available until October 18 so the plants stored for 1 week were placed outside in the cold frame. As a result they received some further cold treatment since the outdoor temperature averaged a little below 50° F. Until the end of October, the cool house had a night temperature of 60° F. after which it was fairly constant at 55° F. except for November 24-29 when it was at 65° F. During the day the cool house was at 55-60° F., except on 7 bright days in February when it reached 70° F.

No check was used with the roots stored 4 or 8 weeks as the crowns were eaten by mice during the storage period. Primordia as indicated in Tables II and III were based on a visual inspection made by cutting the carrot through the crown on March 3 when the experiment was terminated. Figure I illustrates the stages observed in the development of Primordia.

The Effect of Cold Induction on Seedling Carrots

Seedling Carrots Growing in Greenhouse

Carrots of the variety Red Cored Chantenay were seeded on September 23, October 7, October 21, November 4, November 18 and December 12, 1955, directly into 2½ inch pots in a soil composed of equal parts of loam, sand and muck. Thirty-six pots were seeded on each date. On November 18 the seedling plants were all placed in cold storage at 40° F. until December 16. The seedlings had roots of about .5 to .7 centimeters in diameter. The check was seeded on December 12 and received no cold storage. On being taken out of storage the pots were divided into two groups, one being put in a greenhouse at a night temperature of 65° F. and the other at a night temperature of 60° F. The temperature of the warm house during the day was usually around 75-80° F., while the cool house seldom exceeded 65° F. The plants were repotted in 4-inch pots when their size required it.

In each house there were three further divisions, with one lot receiving 8-9 hours, the second 12-13 hours and the third lot 16-17 hours of light in each period of 24 hours.

The natural light from December 16 to February was very dull and this may have further retarded growth of the 8 hours lot which had no supplementary light.

Results

Carrots grown at the Muck Farm. The plants which had had 8 weeks of storage irrespective of temperature (see Table I) had produced about 34% bolters by January 19. However, for all practical purposes the maximum storage period of 8 weeks was inadequate to produce rapid bolting under the subsequent growing conditions of an average temperature of 70° F. Roots which had been stored for 1 or 2 weeks were discarded in early December when it appeared that they had become senescent and were not bolting. Roots stored for 4 or 8 weeks were discarded on January 19. Those plants which had bolted by October 29 must have been pre-induced in the field as they bolted almost immediately on being taken out of storage. Data for the second

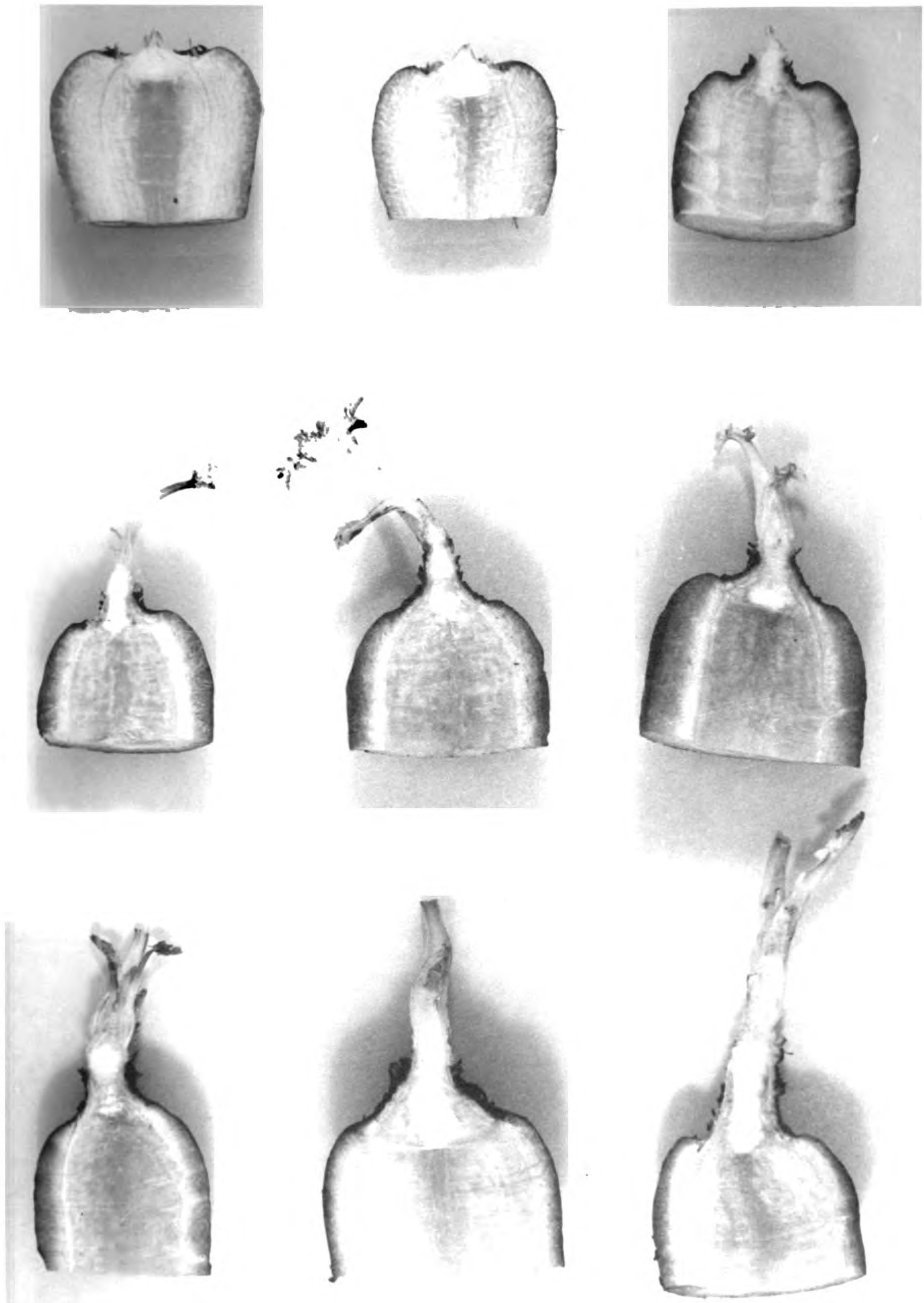

Figure I. Carrots showing development of seedstalk primordia. Top row left no primordia development; bottom row right, advanced primordia.

group of carrots harvested at the Horticulture Farm October 3, are presented in Tables II and III. These tables list the number of plants showing seedstalk elongation by each date to March 3, and the number showing some degree of flower primordia formation on March 3, when the experiment was terminated.

The most outstanding difference in bolting was that which was due to growing temperatures after the roots were taken out of storage. In every case the carrots grown at 55-60° F. after being taken out of cold storage bolted earlier and in a higher percentage than those grown at 65-70° F.

One week of cold storage was insufficient to induce bolting and the plants were discarded on January 21 (Table II and III). Two weeks in the cold storage induced an average of 60% bolting by March 3 in the cooler house and 35% in the warm house, if plants showing primordia are also included in the totals, but only 46% and 12% when only plants with visible seedstalks were included. Four weeks cold storage resulted in a high percentage of bolting in both houses. When all plants showing any degree of flower stalk development were included the bolting percentage was 95% in the 55-60° F. house and 67% in the 65-70° F. house. On the basis of visible seedstalks only, there were 85% in the cool house and only 36% in the warm house.

In both houses the plants given 8 weeks of cold storage produced almost 100% bolting if those showing flower primordia were included. Only 52% had visible seedstalks by March 3 in the warm house, while in the cool house all except one plant out of 38 had produced seedstalks.

TABLE I

THE EFFECT OF COLD STORAGE ON THE PRODUCTION OF SEEDSTALKS IN LONG CHANTENAY CARROTS GROWN IN MUCK SOIL, AND PUT IN COLD STORAGE ON AUGUST 30 AND SUBSEQUENTLY GROWN AT A NIGHT TEMPERATURE OF 65° F.

Weeks in storage	Storage temp. °F	No. of plants	Plants with visible seedstalks: Oct 29	Nov 12	Nov 26	Dec 9	Dec 24	Jan 7	Jan 21	Total	Total percentage
1	32	16	0	0	0	0				0	0
1	40	6	1	1	1	1				1	17
1	45	11	2	2	2	2				2	18
1	50	6	1	1	1	1				1	17
Mean		10								1	10
Control	70	9	1	1	1	1				1	11
2	32	5	2	2	2	2				2	40
2	40	5	0	0	0	0				0	0
2	45	9	1	1	1	1				1	11
2	50	7	1	1	2	2				2	28
Mean		7								1	27
Control	70	12	1	1	1	1				1	8
4	32	14	1	2	3	4	5	5	5	5	36
4	40	16	2	2	3	3	3	4	4	4	25
4	45	15	0	1	1	1	1	1	1	1	7
4	50	17	3	3	3	3	3	3	3	3	18
Mean		16								3	21
Control	70	11	0	0	0	0	0	0	0	0	0
8	32	14		1	3	3	3	3	3	3	21
8	40	13		1	1	3	3	3	3	3	23
8	45	14		1	1	2	2	4	5	5	36
8	50	17		0	1	2	4	6	9	9	53
Mean		15								5	34

TABLE II

THE EFFECT OF COLD STORAGE ON THE PRODUCTION OF SEEDSTALK IN LONG CHANTENAY CARROTS GROWN ON MINERAL SOIL, AND PUT IN COLD STORAGE ON OCTOBER 3 AND SUBSEQUENTLY GROWN AT A NIGHT TEMPERATURE OF 65° F.

Weeks in storage	Storage temp. °F	No. of Plants	Plants with visible seedstalks Dec 9	Dec 24	Jan 7	Jan 21	Feb 4	Feb 18	Mar 3	Total percentage	Primordia	Grand Total Percentage
1	32	7	0	0	0	0				0	0	0
1	40	6	0	0	0	0				0	0	0
1	45	5	0	0	0	0				0	0	0
1	50	10	0	0	0	0				0	0	0
Mean		7								0	0	0
Control	70	8	0	0	0	0				0	0	0
2	32	8	1	1	1	1	1	1	1	12	1	25
2	40	8	1	1	1	1	1	1	1	12	3	50
2	45	10	0	0	1	1	1	1	1	10	1	20
2	50	8	0	0	1	1	1	1	1	12	3	50
Mean		8								12	2	35
Control	70	8	0	0	0	0	0	0	0	0	1	12
4	32	9	0	0	0	0	0	0	4	44	3	78
4	40	10	0	1	2	4	5	5	6	60	3	90
4	45	9	0	0	0	0	0	1	1	11	2	33
4	50	8	1	1	1	1	2	2	2	25	3	62
Mean		9								36	3	67
8	32	10	0	0	0	1	3	3	4	40	6	100
8	40	10	0	0	0	3	3	4	5	50	5	100
8	45	10	0	1	3	4	4	6	6	60	4	100
8	50	10	0	1	4	5	5	6	6	60	4	90
Mean		10								52	4	97

TABLE III

THE EFFECT OF COLD STORAGE ON THE PRODUCTION OF SEEDSTALKS IN LONG CHANTENAY CARROTS GROWN IN MINERAL SOIL, AND PUT IN COLD STORAGE ON OCTOBER 3 AND SUBSEQUENTLY GROWN AT A NIGHT TEMPERATURE OF 55° F.

Weeks in storage	Storage temp. °F	No. of plants	Plants with visible seedstalks							Total Percentage	Pri-mordia	Grand Total Percent-age
			Dec 9	Dec 27	Jan 7	Jan 21	Feb 7	Feb 18	Mar 3			
1	32	7	1	1	1	1				14	0	14
1	40	7	1	1	1	1				14	0	14
1	45	10	2	2	2	2				20	0	20
1	50	8	0	0	0	0				0	0	0
Mean		8								12	0	12
Control	70	7	0	0	0	0				0	0	0
2	32	8	0	0	0	0	0	2	4	50	2	75
2	40	9	0	0	0	0	1	1	1	11	2	33
2	45	9	1	1	1	1	1	3	4	44	1	44
2	50	9	1	1	1	2	2	4	7	78	1	90
Mean		9								46	1	60
Control	70	6	0	0	0	0	0	0	0	0	2	33
4	32	10	3	3	5	5	6	7	9	90	1	100
4	40	10	6	7	7	7	7	9	9	90	0	90
4	45	10	4	5	8	9	9	9	9	90	1	100
4	50	9	2	2	3	3	3	5	6	67	2	90
Mean		10								85	1	95
8	32	10			9	10	10	10	10	100	0	100
8	40	8			6	7	8	8	8	100	0	100
8	45	10			7	9	9	9	9	90	0	90
8	50	10			6	8	8	9	9	99	1	100
Mean		10								95	0	97

The real difference between the cool and the warm house is illustrated by the graphs in Figure II which show that bolting occurred in the cool house, approximately two months earlier than in the warm house.

The storage temperature, whether at 32, 40, 45 or 50° F. had no significant effect on the percentage of seedstalks produced (Table IV). However, the quality of roots stored at 50° F. after 4 or 8 weeks was poor compared with those stored at 32° F. or 40° F. and they were more susceptible to disease. They also tended to grow in storage which was undesirable. Sometimes the main terminal bud died and lateral buds produced a prolific growth. It appeared that this delayed flowering, as any plants where such damage had occurred produced seedstalks late.

The analysis of variance, (see Table IV), shows that the difference in seedstalk development owing to the duration of storage and greenhouse temperatures are both significant with probability values in excess of 1%. The differences due to temperature of storage are not significant. For the purpose of analysis the percentages of bolters were transformed to angles following the procedure outlined by Snedecor (24).

Effect of Cold Induction on Seedlings

Only one plant bolted among those subjected to cold induction treatment and it was in the group planted on November 18, germinated in cold storage, and subsequently grown in the cool house under 16-17 hours of light. The seedstalk elongation was first observed on March 10. When the experiment was terminated on April 28, one plant had

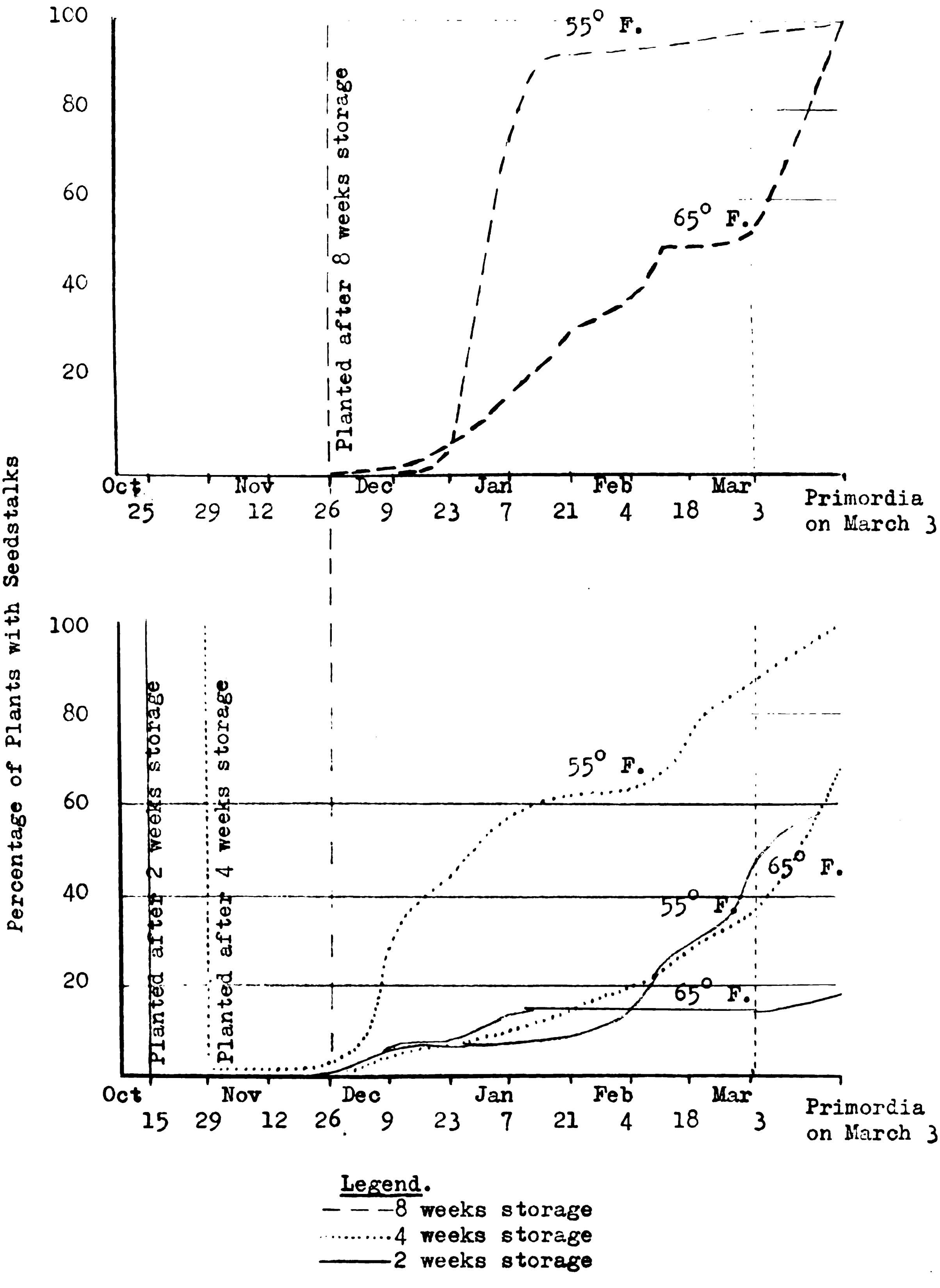

Figure II. Percentage of plants with seedstalks after different storage periods. Growing temperatures after storage periods are indicated.

TABLE IV

ANALYSIS OF VARIANCE TABLE OF PERCENTAGES OF SEEDSTALKS WHICH HAD FORMED BY MARCH 3, 1956, IN LONG CHANTENAY CARROTS AS INFLUENCED BY LENGTH AND TEMPERATURE OF STORAGE AND SUBSEQUENT GREENHOUSE GROWING TEMPERATURE

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F	
Only Including Visible Seedstalks					
Total	23	12,952.32			
Days in storage	2	4,900.32	2450.16	18.0	xx
Temp. of storage	3	132.65	44.22	0.3	NS
Greenhouse temp.	1	5,725.77	5725.77	41.9	xx
Days X temp. of storage	6	897.06	149.51	1.2	NS
Days X greenhouse temp.	2	293.63	146.81	1.1	NS
Greenhouse temp. X temp. of storage	3	184.09	61.36	0.4	NS
Error	6	818.81	136.46		
Including Visible Seedstalks and Flower Primordia					
Total	23	11,145.39			
Days in storage	2	6,811.67	2270.56	14.3	xx
Temp. of storage	3	397.98	132.66	0.8	NS
Greenhouse temp.	1	1,094.85	1094.85	6.9	x
Days X temp. of storage	6	672.81	112.13	0.7	NS
Days X greenhouse temp.	2	650.44	325.22	2.0	NS
Greenhouse temp. X temp. of storage	3	572.12	190.71	1.2	NS
Error	6				

xx Significant at 1% level

x Significant at 5% level

NS Not significant

developed seedstalk primordia. It was among those seeded on October 21, and grown under 12 hours of light in the cool house.

The plants seeded first had some bright sunlight during their first month and so obtained a better start, however, this effect disappeared by the end of the experiment.

In the warm house by April 28, the difference due to photoperiod appeared to have decreased considerably from what it was in early February, and the tops had less extreme variation in height. However, the style of growth remained unchanged being open with more and shorter leaves at 8-9 hours and fewer and longer leaves at 16-17 hours. In the cool house the change had not occurred. The 16-17 hour photoperiod produced the tallest plants irrespective of temperature. The plants in the cool house looked healthier than those in the warm house which was probably caused by hot weather in April. The difference in top growth between the warm and the cool house and between the day lengths is illustrated in Figure III for January 29, and Figure IV on April 28.

Roots grown in the warm house were somewhat blunter than those grown in the cool house. The length of photoperiod did not appear to effect their size appreciably although those grown under 8-9 hours were usually smaller than those grown under the longer photoperiods. The earliest plants also produced the largest roots, which may have been mainly due to their very good starts. Growing in 4-inch pots however, was not a good test of the effect of temperature and photoperiod on root shape.

Figure III. The effect of photoperiod and temperature on January 29, 1956. The three plants on the left at 65° F., the three on the right at 60° F. Reading from left to right, 16-17, 12-13, 8-9, 16-17, 12-13, and 8-9 hour photoperiods.

Figure IV. The effect of photoperiod and temperature on April 28, 1956. Three plants on the left grown at 70° F., the three on the right at 60° F. The center plants received 16-17 hours, the next two 12-13 hours and the outer two 8-9 hour photoperiods.

DISCUSSION AND CONCLUSION

Some Effects of Cold Induction on Seedstalk Development in Mature Carrot Roots

The effects of cold on induction of seedstalks in mature carrots depends mainly on duration of the cold period and upon subsequent growing temperatures after the plants are removed from cold storage.

There was a definite difference in the rate of seedstalk production when carrots were grown in the greenhouse at 55-60° F. compared to 65-70° F. or higher. This agreed with results of Sakr and Thompson (19). In the latter case after 8 weeks of cold storage almost 100% bolting eventually occurred, when those showing flower stalk primordia were included in the total. However, the plants were about two months later in flowering than those grown at 55-60° F. after storage.

This two-month period is of the greatest importance where a carrot breeding project is concerned and seed should be matured, dried, threshed and ready to seed by the middle of April. In the case of plants grown at the higher temperature this would not be possible with most of the plants.

It was noticed that other plants stored ten weeks and grown at 70° F. flowered in even less time than those stored for 8 weeks and grown at 55-60° F. Thus, it seems that what might be a minimum storage period to accomplish induction was not necessarily the most expedient method of seed production. This also agrees with work done in beets and turnips by Carolus (4). Using the minimum induction period also required extra labor and expense to produce seed because of the longer period in the greenhouse. Plants in the cool house grown from roots stored 4 weeks at temperatures ranging from 32-50° F. had produced 90-100% seedstalks by March 3. However, the graph in Figure II shows how much more slowly the carrots bolted if stored 4 weeks compared with those stored 8 weeks, in spite of having been potted a month earlier.

The date of harvest is also a factor as to how long the cold storage period should be. Carrots harvested on August 30 from the experimental Muck Farm and on October 1 from the Horticulture Farm were both stored for 8 weeks and then grown at 65° F. (night temperature). Three months after planting there was a higher percentage of bolters in those from the later harvest than in those harvested August 30. The early group when planted in the greenhouse had a higher temperature by a few degrees as it was impossible to keep down the temperature at first and this may have slightly retarded bolting. However, the date of harvest is important and should be recognized as a factor in considering how long to store the roots. Thus, if plants were harvested in August compared with the end of September two extra weeks of storage after the early harvest might be advisable. Sakr and Thompson (19), harvested their plants on October 1 and 20. During the month previous to harvest considerable cool weather probably occurred to favor initiation of flowering and percentages of seedstalks in their checksindicate this. Therefore, their conclusion that one month of cold storage is the minimum required for seedstalk induction applies only under specific conditions.

It appears that in all plants which require a period of cold exposure to induce seedstalk production, subsequent high temperatures of over 70° F. have an inhibiting effect. In almost all cases a growing temperature of 50–60° F. after the storage period produces bolting faster than growth at a higher temperature. This was shown in onions (Thompson and Smith 29), celery (Starring 25), beets (Chesnokov 5), turnips (Sakr 21), cabbage (Miller 13) and carrots (Sakr and Thompson 19). The degree of high temperature inhibition varies with the plants because beets (Chesnokov 5) become vegetative at high temperature even after flower stems had grown to full height and the buds had developed. Inhibition does not occur if a certain minimum storage period is given during which time the seedstalk initials are fully developed. Thus, in turnips (Sakr 21) after 60 days of cold storage at 40–50° F. any growing temperatures gave high percentages of bolters, and in carrots (Sakr and Thompson 19) after 80 days at 40–50° F. all plants went to seed even at high growing temperatures. Thus, there is a minimum period of cold storage which will induce bolting if plants are subsequently grown at a temperature below 60° F. If adequate storage was given, the seedstalks were already fully induced by the time the plants were taken out of cold storage and high temperature could not prevent seedstalk production in carrots, although it might delay the date of flowering.

The minimum storage time for induction has not been established precisely, but is of little importance from the standpoint of hastening seed production in a breeding program since minimum induction is not the most rapid or reliable method to obtain seed. There are also several factors which may have an influence, such as, field temperature during the period before entry into cold storage. However, it appears the method to obtain the most rapid production of seedstalks, in mature roots is storage at 40° F. for 8 or 10 weeks followed by growing the plants at 50-60° F. until the seedstalks elongate. After this the temperature should be raised to 70° F. to hasten the growth of the seedstalks, flowering and seed ripening. This is in contrast to the recommendation of Sakr and Thompson (19) who suggest one month at 40-50° F. followed by transferring plants to a temperature not above 70° F.

The temperature of storage does not appear to make too much difference provided it is between 32 and 50° F. From the Tables I, II, and III a storage temperature of 40° F. appears to give a slightly higher percentage of bolters when plants are grown subsequently at 50-60° F., while storage at 50° F. produces slightly more bolting if the growing temperature after storage is 65-70° F.. However, the data on this point is not conclusive. Fifty degrees Fahrenheit, if used for a storage temperature, results in growth in storage and reduction in vigor of the roots.

These results also agree with work done on onions (Thompson and Smith 29), beets (Chesnokov 5), turnips (Sakr 21), cabbage (Miller 13) and carrots (Sakr and Thompson 19), and almost all plants which require a cold storage induction period. A temperature of 40° F. in almost every case is optimal, below 40° F. growth being so slow that extra time is needed for the induction to be effective and above 40° F. the maximum benefit from the cool storage is not realized. Onions appear to respond most favorably if stored at 45-55° F. It is interesting that all the biennials after being taken out of cold storage appear to respond best to a period of cool growing temperature until the seedstalk starts to elongate, and then a higher temperature is advantageous, beets do better without the higher temperature as they may revert to a vegetative state. All the plants mentioned are insect pollinated except beets which are wind pollinated. Most insects require a temperature above 60° F. to be active in pollination.

Some Effects of Cold Induction and Photoperiod on Seedstalk Development in Young Carrots

Seedlings at different ages between 0 and 56 days were put into cold storage for 28 days. Only one plant subsequently bolted. This plant started growth in cold storage, but at the end of 28 days the cotyledons had not shown above the ground, as was the case with all the pots which were seeded the day they went into cold storage. This does not mean the seeds had not germinated during this time and been induced while in cold storage, as germination and growth at 40° F. is very slow, and although they may have germinated they had not grown enough for the seedstalk to be visible. However, it appears one month will not induce consistant bolting in seedlings which later are grown at 60° F. or higher.

Sakr and Thompson (19), likewise obtained a low percentage of bolting with carrot seedlings subjected to one month at 40-50° F. starting 17 days after planting and they got more bolters at a subsequent growing temperature of 50-60° F. compared to any higher temperature. Even after 135 days at 40-50° F. they only got 54% bolting which seems to indicate seedlings are not very prone to bolting after cold induction, and probably have to reach a certain minimum size. This does not explain why in any commercial field there are always some and often 3-4% of the plants which will behave as annuals and flower the first Summer. It may be a genetic factor for annual form or a susceptibility in some plants to a very short period of cold.

With parsnips (which are of the same family as the carrot) Sakr (22) observed that no plants bolted when subjected to 40-50° F. for 15, 30 or 60 days beginning when the plants were 33 days old. However, 4-month old plants went to seed 100% after 35 days of cold induction. In contrast celery (also in the same family) can be induced to flower at any age (Pawar and Thompson 15). Older plants are more responsive than younger plants, but the shortest period from seed to seed is by treating 2-month old plants with cold. Cabbage (Boswell 3) needs to have a minimum of 6-7 mm stem diameter for cold to induce bolting.

It appears that further work is needed to determine if young carrot seedlings can be induced to bolt by a cold treatment or if they need to reach a certain minimum size before induction. And, whether those few which do behave as annuals do so regardless of cold and so are true annuals or just require a very short period of cold to induce seedstalk production has not been determined. When turnip seeds were placed on wet blotting paper at 37° F. for a month, 64 percent bolted if they had germinated in the cool room, but only 3 percent bolted if they had not germinated while in the cool room (Sakr 21). Likewise in carrots it may be that the sensitive age is in the germinating seed. In turnips this does not appear to be so since plants at any age from seed on, can be vernalized and subsequently produce seedstalks.

Photoperiod influences the type of growth; long days resulting in long upright growth while short days result in short spreading growth which would tend to make best use of the light. This agrees with Barnes (1) who observed no significant effects of day length on the color, chemical composition or size of carrot roots. He also observed that with 14 hours of light the leaves were longer and thinner than with shorter day lengths. He considered growth at 60-70° F. most normal while above 70° F. the root was shortened and below 60° F. it was lengthened.

However, the intensity of the light has a considerable effect on the rate of growth. During mid-winter plants grown under 8 hours of natural light which was almost normal day-length in Michigan grew very slowly. Garner and Allard (8) showed that the length of the leaf in carrots is greatly reduced by limiting the plants to 7½ hours of light compared to 14 hours and that only very small white roots grew. Thus, for growing carrot plants during the winter in the greenhouse for breeding purposes extra light is recommended to increase the day length to at least 12 hours and also to increase the intensity.

SUMMARY AND RECOMMENDATION

The effects of cold storage on seedstalk induction in mature carrot roots and on seedling carrots were studied. Mature roots were harvested from muck and loam soils, stored for periods of 1, 2, 4 and 8 weeks at temperatures from 32-50° F. The stored roots were subsequently grown in the greenhouse at temperatures of 55-60° F. and 65-70° F. Seedling carrots from 0-56 days old were subjected to 28 days at 40° F. and then grown at a night temperature of 60° F. and 65° F. in the greenhouse under day lengths of 8, 12, and 16 hours.

Mature carrot roots when stored for 4 or 8 weeks at temperatures between 32° F. and 50° F. and then grown in a greenhouse at 55-60° F. produced 90-100 percent seedstalks. Roots grown at 65-70° F. after eight weeks of cold storage also produced 90-100 percent seedstalks, but three months later than those grown in the greenhouse at 55-60° F. Those stored four weeks and then grown at 65-70° F. produced between 33 and 90 percent seedstalks and they were likewise later than those grown in the cool greenhouse after four weeks of storage at 32-50° F. There were no significant differences in bolting caused by differences in storage temperatures between 32° F. and 50° F. The best storage temperature for preserving sound roots can be utilized without affecting rate or percentage of seedstalk formation.

When roots were harvested on August 30, stored for eight weeks and then grown in the warm greenhouse fewer bolted and seedstalks were produced more slowly than those harvested October 3. This means that if roots are harvested early they should be stored longer than when harvested late in the fall.

The results of these experiments show that for the earliest and most reliable seed production, mature roots should receive 8-10 weeks of cold at 35-45° F., and then be grown at a greenhouse temperature of 55-60° F. until the seedstalks begin to elongate. When seedstalks become apparent the temperature should be raised to 70° F. to obtain rapid growth and flower development.

It was found that seedling carrots between 0 and 56 days old were not induced to bolt after being put in a cool room for 28 days at 40° F., and then grown at 60 or 70° F. For optimal growth in the greenhouse 12 or more hours of light are desired and extra light is needed in December and January under Michigan conditions.

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