BOLTING RESPONSE AND ROOT YIELD OF SUGAR BEET STRAINS AT TUCSON, ARIZONA

by

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ABSTRACT OF THESIS

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Twenty strains of sugar beets were evaluated for bolting tendency, root and sucrose yield in a field experiment at Tucson, Arizona. The seeds were planted in a sandy loam soil on October 20, 1963. A randomized complete block design was used with five replications.

Only a few bolters appeared among the strains tested. Strain 301H2 gave the highest percentage of bolting (twelve per cent). Twelve of the strains did not show any evidence of bolting.

Results did not indicate any significant difference in root weight among these strains at the five per cent level. Plants harvested on July 7 gave a slightly higher sucrose yield than in a later harvest on August 6.

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INTRODUCTION

Sugar beets and sugar cane are the chief sources of sugar in the world. The average annual world production of sugar from 1953 to 1955, was 41,877,000 tons. Forty per cent of that sugar was produced from sugar beets (69). For the same period, the average production of the United States was 2,490,000 tons of sugar, of which 75.6 per cent was from sugar beets. The United States' sugar consumption for the period 1936-1945 averaged 5,977,390 tons of refined sugar (46). Rather and Harrison (46) stated that the continental United States produced only about 25 per cent of its sugar requirement. In 1963, the estimated production of beet sugar in the United States was 3,100,000 tons of sugar from 1,236,000 acres (29).

Sugar cane is a perennial plant that is adapted to the tropics or subtropics where temperatures are high enough to allow the plant to grow rapidly for eight months or more. This plant is very susceptible to freezing; on the other hand, the sugar beet is a cool weather plant, the young or mature plants withstand light spring or fall frosts without injury (46). For sugar production, sugar beet plants make their best growth where there is a moderately long frost-free period with an average summer temperature of about 70°F.

Extremely high summer temperatures are detrimental to growth and the storage of sugar in the roots.

The cultivated sugar beet when used for seed production in northern latitudes is a biennal. It develops a large succulent root the first year and a seed stalk the second (10, 41). Until the early 1930's, the conventional European method for seed production was to seed in the spring, lift the roots in the fall, store them throughout the winter and replant the desired roots the next spring in an isolated field. The plants developing from the transplanted roots would flower and produce the seed crop. Because of a need to produce seed of new disease resistant sugar beet varieties which were developed during the 1930's by the U. S. Department of Agriculture, various methods were tested for growing sugar beet seed in the United States.

It was found that sugar beet seed could be produced under the mild winter conditions of the southwestern United States by over-wintering the plants in the field. In this method the seed is planted in the fall and mature seed is harvested the next summer. Thus, expensive harvest, storage and replanting of roots for seed production are avoided.

Bolting refers to sugar beet plants that develop seed stalks. The tendency to flower or bolt is dependent on both heredity and environmental conditions. Low temperatures followed by a period of long days are conducive to bolting, especially if the cool period occurs after the plant has attained an advanced stage of development (14, 15). For reproduction in a seed field and in breeding programs, bolting is necessary. On the other hand, this characteristic is highly undesirable in beet fields grown for sugar because it lowers root and sugar yield, and it causes difficulties in harvesting and processing the sugar beets. Varieties and strains of sugar beets that are highly resistant to bolting are desirable for better sugar production, especially in regions where the crop is grown as a winter annual and subjected to cool temperatures which might cause a high percentage of bolting.

The objective of this study was to evaluate twenty sugar beet strains for their bolting characteristics, root yield and sugar content under the climatic conditions at Tucson, Arizona.

LITERATURE REVIEW

The sugar beet, Beta vulgaris L., is a plant which normally grows best in temperate regions (55, 68). Sugar beets are generally grown as a summer crop in the northern latitudes. In the southern latitudes such as in the southwestern United States the crop is grown as a winter annual. Here the main vegetative growth of the sugar beet plant takes place during the winter and spring months (62).

Effect of Bolting on Root and Seed Production

Early spring sowing of sugar beets is favorable for root yield in some areas of the United States (5, 19, 20), but extremely early sowing may have a detrimental effect on sugar production by increasing the percentage of bolting (65, 67). Willey (65, 66) and Thompson (61) reported in England that early bolters, counted at the end of July, caused the greatest loss of sugar and interfered most with machine harvesting. Price, et al., (43) mentioned that if bolting occurred early in the growing period, the roots remained relatively small and became fibrous and woody. They also stated that if the plants produced seed stalks, a decrease in sugar content usually occurred. Nelson and Deming (35) showed that early bolting plants which formed true seed stalks produced only about one-half of the yield of roots of normal plants. They also showed that the root yield of leafy-type bolting plants which produced no seed and late-bolting plants which bloomed, but produced little or no seed, were comparable to yields from normal plants. In the same experiment, a lower sucrose percentage was obtained on the roots of bolting plants from which the seed stalks were removed.

In regions with mild winters, where sugar beet seed is sown in late summer, fall or early winter, heavy bolting may occur and decrease the yield (17, 32, 48, 63). Fife and Price (15) found that the roots of early bolting types of sugar beets did not continue to increase in weight after the reproductive phase began. On the other hand, seeding in the fall is very favorable for seed production by the field-overwintering method (21) especially if bolting occurred early (9).

Effect of Temperature and Light on Bolting

Conditions conducive to bolting in sugar beets are low temperatures followed by a period of long days (3, 4, 6, 13, 18). Natural or artificial conditions may be used to supply either or both of these requirements for seed production. Thompson (61) observed in England that the extent of bolting varied greatly between locations. Willey (65) found in spring-sown sugar beets that May frosts accelerated the development of bolters. Seed yields of sugar beets are usually poor in regions following a mild winter (27). In Italy, Ragazzi (46) stated that for seed production, the sugar beet is grown in regions having long, cold winters.

Artificial induction of bolters may be achieved by vernalizing sugar beet seed (27, 44), young seedlings (6) or by subjecting stecklings to low temperature before transplanting (14, 15, 54). Landau (27) induced bolting in some sugar beet varieties by subjecting the seed to low temperature (36.5°F.) for a period of 4.5 months, when the subsequent development took place under high temperature and a favorable photoperiod. Vernalization of germinating seed had been used to induce early fruiting in greenhouse tests and also afforded a reliable means of judging tendencies towards early bolting (6). Bell (2) found that photothermal induction of seedlings was effective in two different strains for isolating bolting-resistant types.

The effect of temperature on sugar beet reproduction was studied by Stout (54). He found that when beets were grown under a 17- to 18-hour photoperiod in the greenhouse, they bolted more rapidly and in larger numbers after root storage at 43° to 48°F. than after storage at cooler temperatures (near 32°F.) for a 52-day period. He also stated that storage of beets at temperatures near 32°F. induced little change in the rate and percentage of plants that bolted, indicating that the processes involved in thermal induction were nearly arrested during such storage.

Erdman (14) found that sugar beet plants should be at least four months old when cold-treated if they are to flower and set seed within one year. Fife and Price (15) stated that root size may be an important factor in the thermal induction process. They found that sugar beet roots did not increase in weight after the reproductive phase began. There was a significant negative correlation between the gain in root weight and the root weight at the time of transplanting. While vernalization occurs normally in young plants by direct sowing in the field during the fall and winter months, it may also be accomplished by subjecting the seed to cold temperature before sowing. The latter method was more effective for increasing seed yield in Czechoslovakia (44).

Concerning seed yield and quality, Snyder and Hogaboam (53) found that the yield of seed at a higher temperature (75°F.) during anthesis was reduced to about half of that produced at a lower temperature (65°F.). He also found that plants producing seed at the lower temperature had greater fresh weights of shoots and greater weight, size, and number of fruits. Usually a smaller percentage of fruits had shed seed at the lower temperature. On the other hand, the seeds in fruits that matured at the higher temperature germinated more rapidly than those in fruits matured at the lower temperature.

After vernalization, Margara (31) found that there was an opposite effect of long and short photoperiods. Under short days, the vernalized beets did not show any stem elongation and remained in a rosette stage. Sinjagin (50) found that when sugar beet plants had already passed the vernalizing stage, non-flowering stalks were actively formed under short-day conditions (four to eight hours).

Bolting was induced in "annual beets" by one-half hour supplemental illumination at midnight during long winter nights, but seed-stalk development through the use of an interrupted dark period, was somewhat slower than that induced by continuous illumination at night (49).

Reversal of bolting in the sugar beet can be effected by a short period of exposure to warm greenhouse temperatures before transplanting or by longer exposure to medium range outdoor temperatures (37). Gaskill (26) stated that the tendency of young, photothermally induced sugar beet seedlings to revert to the vegetative stage in a natural, long day, post-induction environment without supplement light, varied with variety. He also stated that the tendency could be reduced substantially in some bolting-resistant strains by an increase of several weeks in the length of the pre-induction growth period. Reversal of thermal induction was found by Stout (54) to occur in sugar beets that had been thermally induced previously when those beets were stored at relatively warm temperatures (52° to 79°F.).

Photothermal induction is now used by plant breeders to reduce the life cycle of sugar beets (3, 7, 23, 24). In one of the techniques (24), seed is planted in the greenhouse in the fall and photothermal induction of the young seedlings is accomplished by means of continuous illumination and cool temperature (approximately 2½-3 months at an average temperature of about 50°F.). Within six or seven months from date of planting the new seed crop may be harvested. Munerati, cited by Coons (7), developed sugar beet strains that passed from a vegetative to reproductive phase of growth in only a few weeks after germination. With continuous light exposure, as many as five generations could be obtained from these strains in a single year.

Effect of Chemicals on Bolting

Many workers report that seed stalk initiation and development are accelerated by applying gibberellic acid (11, 25, 40, 52, 56, 57, 64). Gibberellic acid is also used in breeding programs to reduce the time required for the life cycle of sugar beet (11, 25). Stout (56) pointed out that gibberellic acid, applied to the foliage as a spray or to the growing points of sugar beet plants, usually initiated bolting in most varieties. He also stated that gibberellic acid applied to the growing points of field-grown sugar beets reduced the sugar percentage and respiration rate of root tissue with an increase in the root weight. Snyder and

Wittwer (52) reported that considerable stem elongation in sugar beets resulted from different gibberellin treatments, irrespective of photoperiod and temperature. They also stated that flowering in sugar beets might be accelerated and even induced by repeated spraying of the growing tips with gibberellic acid (1,000 p.p.m.) if these treatments were accompanied by exposure of the plants to a long (18 hour) photoperiod. At an 18-hour photoperiod and a night temperature of 55°F., gibberellin promoted earlier flowering of both annual and biennial sugar beets. Their results also showed that gibberellic acid could substitute for the temperature requirement but not the light requirement. No normal flowering occurred at 9-hour photoperiod, while an appreciable amount of flowering was induced with gibberellin under a non-inducive temperature (65°F.) and a long (18-hour) photoperiod.

Similar results to those of Snyder and Wittwer were obtained by Wheatley and Johnson (64). They found that where the thermal induction of beets appeared to be borderline or barely insufficient to induce the beets to develop seed stalks, gibberellic acid might be of some use in providing the additional stimulus for seed production. No advantage was demonstrated in their experiment from the use of gibberellic acid on sugar beets overwintered for seed production if the plants had had sufficient thermal induction to stimulate seed-stalk development.

In annual beets, gibberellic acid treatment was found to have a decided effect on photoinduction when considered separately from thermal induction (57). In a greenhouse experiment, Stout and Owen (57) found that gibberellic acid treatment accelerated the rate of seed-stalk initiation and the rate of seed development under high temperatures with continuous illumination. Margara (31) found after vernalization and under long days, gibberellic acid increased stem elongation and accelerated flowering when the treatment was applied at the rosette stage. Early growth of sugar beet plants has been accelerated by treating the seed with gibberellic acid (28). It was found by Doxtator (13) that high rates of gibberellic acid (1000 p.p.m.) gave greater stem elongation than light treatments, and that varieties react differently.

Price, et al., (42) mentioned that flowering appeared to be a hormone-influenced process. They found that a foliage spray containing a low concentration of 2,4-D applied in September to plants seeded in July delayed bolting and also lowered the sucrose percentage and sucrose per root of plants of two sugar beet strains.

Ririe, et al., (47) found an increased percentage of sucrose without affecting root yield when they applied foliar sprays containing 0.3 per cent maleic hydrazide and 0.025 per cent of 2,4-D. Simular results were obtained by Ririe, *et al.*, (48). They found that maleic hydrazide applied before any visible evidence of bolting on sugar beet plants, delayed and reduced bolting and increased sucrose percentages.

Plant Density and Bolting

Low plant density within a range from three to 25 plants per eleven square feet was found by Flamini in Italy (16) to favor bolting in the types N and Z sugar beets. However, for seed production, close planting was favorable since one seed stalk developed per plant (22). Thinning or spacing sugar beets is undesirable in seed-growing areas where winter days are often warm. Carsner and Owen (4) mentioned that in such regions, leaving the plants thick, favoring large growth of sugar beet leaves in the fall to shade the soil and each other, helped to reduce the temperature and increase bolting and seed production. In Oregon (39), highest average seed yields were obtained with row-spacing of 16 inches and an unthinned stand. The best range of plant population for seed production in Oregon was found to be from 30,000 to 100,000 plants per acre in irrigated fields (38). In Europe, Heinisch (21, 22) mentioned that close planting of 16 inches between rows at a seeding rate of 11 pounds per acre was the most practical for seed production. High plant density tends to protect sugar beet plants from a severe winter. In Germany (58), barley drilled in alternate rows with sugar beet seed was used to protect sugar beet plants from frost during the winter by leaving a tall barley stubble.

Heredity and Bolting

The different amounts of thermal induction required to induce bolting in sugar beet varieties and the different percentage of bolters between varieties under the same condition indicate that bolting is influenced by heredity (4, 18). Owen and Mc Farlane (36) found that the annual characteristic is attributed to a single gene derived from Munerati's annual beet, which essentially replaced the necessity of thermal induction or prolonged low temperature treatment necessary for reproductive development in biennal beets. They also stated that the rate of bolting is attributed to the effect of accessory genes in association with the major gene for annual growth habit. Johnson (17) studied the effects of non-bolting characteristics of successive seed generations. Most of the evidence indicated a deterioration in the non-bolting quality of the varieties. He believes that the non-bolting quality of a variety is a characteristic which would lend itself much more to natural selection than would root yield. It appeared to Marcum (30) after crossing a bolting-resistant variety to a bolting one, that bolting resistance is a dominant characteristic. Munerati (1942) [cited by Coons, _et al._, (7)] established an annual sugar beet strain, and found that the annual characteristic was transmitted as a dominant character in crosses with sugar beets of normal biennial cycle of growth. The same result was achieved by Abegg (1). He also found that annuals in both F_1 and F_2 progenies were slower in average seedstalk development than the plants from the annual parental strain. This indicated that dominance (BB), although shifting strongly toward the annual side, might not be complete. The difference between BB and Bb plants in rate of seedstalk development did not appear to be very great. He concluded that other factors might exist which partly inhibited seedstalk growth of F1 and F_2 annuals. Swink and Doxtator (59) observed an unusual type of bolter in Colorado which produced a stalk directly after emergence of the seedling and which under field conditions produced a large stalk and no flowers.

Skuderna (51) found in 1945 that variety U. S. No. 15 was free from bolters when the seed was planted on February 12 in California and variety O-419 was next most free. Later on, in 1948, U. S. 56 was reported by Price, et al., (42) to be slightly better than U. S. 15 in resistance to bolting, and it was the suggested variety for fall and winter planting in interior areas of California. The same two varieties were recommended in 1950 by Coons and others (8) depending upon the prevailing diseases. In 1952, Mc Farlane and Price (33) reported that a new, non-bolting, curly-top resistant sugar beet variety designated U. S. 75 had been developed by selection from the

U. S. 22/3 variety. In 1961 Mc Farlane, et al., (34) reported that five new sugar beet hybrid varieties had been developed in California. U. S. H2, U. S. H3 and U. S. H4 had moderately good bolting resistance. U. S. H5A and U. S. H5B had good bolting resistance.

In England, Thompson (60) found that the varieties Battle's E, Bush N, and Bush E ranked first, second, and third in bolting resistance among the fourteen varieties recommended for commercial sugar production in 1958. The variety Cambro was reported by Willey (65) to give the lowest number of bolters. In 1963, the best non-bolting varieties in England were Camkill, Sharps Klein E, and Johnson's E, respectively (66). Camkill was again reported by Willey in 1964 (67) to have an excellent resistance to bolting.

MATERIALS AND METHODS

Twenty strains of sugar beets supplied by the Spreckles Sugar Company were seeded in an irrigated field on October 7, 1963. Table 1 gives a brief description of each strain. The strains varied in tendency to bolt as well as in disease resistance, seed type and their genetic characters.

The planting plan was a randomized complete block design with five replications. Planting was repeated in different plots on October 20 because of severe seedling damage by grasshoppers. One hundred and fifty selected seeds or seedballs of each strain were planted in rows 38 inches apart and 24 feet in length and running in an east-west direction. The planting was on the University of Arizona Casa Grande Highway Farm. The seed was drilled in a moist sandy loam soil at a depth of one inch after knocking off the dry tops of the beds.

After emergence, the seedlings of the second planting were dusted with malathion as a protection against the grasshoppers. Dusting was repeated after two weeks to assure further protection.

At the 4-to 6-leaf stage of growth, thinning and transplanting were done at the same time to secure a stand

TABLE 1. Description of twenty sugar beet strains studied.

Strain	Description of seed	Bolting tendency	Reaction to curly-top
A5218	Commercial; open-pollinated; multi-germ; diploid	very non-bolting	susceptible
A5305	Commercial; open-pollinated; multi-germ; diploid	intermediate bolting	resistant
A5401	Commercial; open-pollinated; multi-germ; diploid	very non-bolting	resistant
101H1	Commercial hybred; monogerm; diploid	non-bolting	susceptible
102H2	Commercial hybrid; multigerm; diploid	non-bolting	susceptible
102H4	Commercial; hybrid; multigerm; diploid	non-bolting	intermediate resistance
201H3	Commercial hybrid; monogerm; diploid	easy bolting	intermediate resistance
202H2	Commercial hybrid; multigerm; diploid	fairly easy bolting	intermediate resistance
202H4	Commercial hybrid; multigerm diploid	fairly easy bolting	intermediate resistance
301H1	Commercial hybrid; monogerm, diploid	non-bolting	resistant
301H2	Commercial hybrid; monogerm; diploid	intermediate bolting	resistant
301H3	Commercial hybrid; monogerm; diploid	non-bolting	resistant
302H1	Commercial hybrid; multigerm; diploid	non-bolting	resistant
302H2	Commercial hybrid; multigerm; diploid	non-bolting	resistant

TABLE 1--Continued

Strain	Description of seed	Bolting tendency	Reaction to curly-top
A61168	experimental hybrid; monogerm triploid	non-bolting	resistant
A62162	experimental hybrid; monogerm; diploid	non-bolting	resistant
A62168	experimental hybrid; monogerm; diploid	very non-bolting	resistant
A62183	experimental hybrid; monogerm; diploid	non-bolting	resistant
A63123	experimental hybrid; monogerm; diploid	non-bolting	intermediate resistance
A63180	experimental hybrid; monogerm; diploid	non-bolting	resistant

of 50 plants in each 24-foot row. Transplanting was repeated three more times because many plants were damaged by rabbits. This gave an average spacing of six inches between plants. The plants were irrigated regularly, and the weeds were removed by hoeing.

The preceeding crop on the land used for this experiment was safflower. The plants were fertilized on October 10 with ammonium phosphate at a rate of 50 pounds of $P_2 O_5$ and 40 pounds of N per acre. An additional 50 pounds of N per acre were added at the first of June, 1964.

Observations on seed germination, the vegetative growth of plants, the appearance of the first seed stalk, the total number of bolters and diseases were noted twice a week during the growing season.

On July 7, 1964 the plants in an 8-foot length of each row, which had been selected randomly, were harvested by hand. The beets were topped and data were taken on number of roots and root weight. On August 6, an additional 8-foot sample was harvested from each row by the same method and the same data were taken. The number of decayed roots was also recorded at the second harvest.

Root samples were taken immediately after harvest for sugar analysis. Each of the twenty sugar analysis samples at each harvest was a composite of roots representing the five replications of each strain. The roots were taken to

The University of Arizona Agricultural Experiment Station at Mesa immediately after harvest. The best roots were ground and a sample taken for sugar and purity analysis. The sample was held at approximately 10°F. until analysis. The sugar analysis was made by the Spreckles Sugar Company at their Mendota, California Sugar Laboratory.

Seed of the same strains was planted in a dry loam soil at the Safford Experiment Station on October 14, 1963 by Dr. Fred Turner, Superintendent of the Experimental Farm. The beds were 40 inches between centers with two rows 12 inches apart on each bed. Data about the percentage of bolting were recorded.

RESULTS AND DISCUSSION

Favorable conditions of temperature, moisture and soil type resulted in rapid emergence of the sugar beet seedlings in both plantings. The average weekly maximum and minimum temperatures during the growing season, measured in an adjacent field, are shown in Figure 1. Seedling emergence was nearly complete by the end of the second week after planting. The temperature during these two weeks fluctuated between 91° and 52°F.

By the time of the first frost on December 14, 1963 most of the plants were still in the 6 to 8 leaf stage because of rabbit damage and repeated transplanting. Retardation of early growth occurred mainly in the eastern-most plots where rabbit damage was concentrated. Generally, the rabbits ate the young leaves and left the outer-most two leaves which barely kept the plant alive. There was a pronounced border effect on plants growing in the first row on the south side of the experimental plots. Plants in this row had attained a size of 10 to 12 leaves by the time of the first frost. This border effect might be attributed to better exposure of the plants to sunlight, a better moisture supply, higher soil fertility and a larger area for root and foilage expansion of the plants. It was also noticed that those plants emerging first were not damaged by rabbits because they apparently preferred the younger plants.

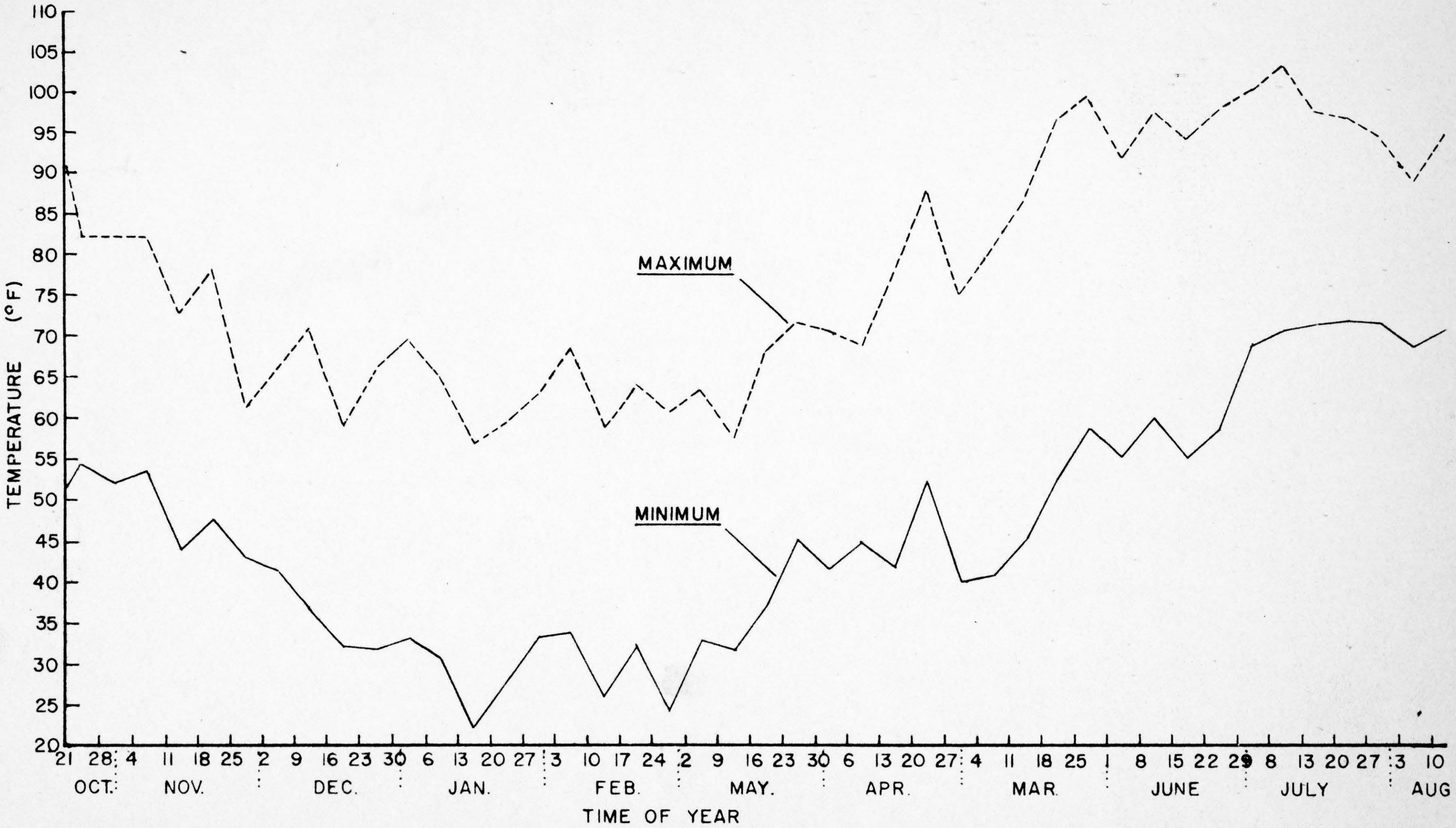

FIGURE I. AVERAGE WEEKLY MAXIMUM AND MINIMUM TEMPERATURES AT U OF A CASA GRANDE HIGHWAY FARM.
OCTOBER 21, 1963 TO AUGUST 10, 1964

During the cold period of winter, between December 14 and March 11, only slight growth was observed due to the frequent occurrence of freezing temperatures. During that period, the temperature fluctuated between 78° and 16°F. However, no frost damage was observed on the plants.

After the last frost on March 11, vegetative growth rapidly resumed, especially the small plants that were previously damaged by rabbits. Figure 2 shows a general view of the field plots. This photograph was taken on June third when the plants were about seven months old. By that time, the plants appeared vigorous and healthy although aphids, curly-top disease, and weeds were observed, but none of these was serious enough to affect growth.

Bolting Response

The plants had attained a fairly large size when the first bolter was observed on April 29. The rest of the bolters appeared gradually until June third after which no more bolters were observed. Figure 3 shows a view of a bolting plant of strain A61168 located on a south row. By June third, the root size of the earliest bolting strain was about two pounds and the larger plants had about 52 leaves of large size.

Data in Table 2 show the percentage of bolting plants counted on July 7. In general, the percentage of bolting was low although a temperature as low as 16° F. was recorded on

Figure 2. A general view of the field plots at Tucson, Arizona.

Figure 3. A view of a bolting plant of strain A61168.

TABLE 2. Bolting percentage in twenty sugar beet strains grown at Tucson and Safford, Arizona.

Strain No.	Bolting Percentage (Tucson)	Bolting Percentage (Safford)
A5218	0	5
A5305	2	25
A5401	0	3
101H1	4	4
102H2	4	6
102H4	0	7
201H3	6	22
202H2	8	29
202H4	4	64
301H1	0	6
301H2	12	59
301H3	0	3
302H1	0	13
302H2	0	7
A61168	10	31
A62162	0	0
A62168	0	0
A62183	0	0
A63123	0	3
A63180	0	0

January 18. The period between the first and the last frost was 13 weeks. Strain A61168 which was classified by the sugar beet breeders of the Spreckles Sugar Company as non-bolting, ranked first in earliness to bolt and second in the percentage of bolting. It should be mentioned that all bolters of that strain were concentrated in one plot on a southern border row. The second strain in earliness was 202H2 which was replicated twice on a southern border and bolted on May 10 and May 21st, respectively.

Fifty six per cent of the bolters occurred in the row located at the south edge of the planting. This row occupied only one-tenth of the experimental area. Strains A5218, A5401 and A62168, which had been classified as very non-bolting, did not show any evidence of bolting.

At Safford, germination was slow in the clay loam soil and at the prevailing temperature. The average temperatures for October, November and December were 67.9°, 54.4° and 43.9°F. respectively. By the time of the first frost on November 17, the beets were only at the 4-leaf stage. Temperatures as low as 9°F. occurred in January and February and killed plants to such an extent that no hand thinning was needed. The above-ground growth stopped until late February and then resumed. Bolting started about the middle of May and came to an end by the middle of June. The bolting percentages at that location counted on August 30 are also presented in Table 2.

Although a higher percentage of bolting occurred at Safford than that at Tucson, it was still a low percentage compared with the amount of flowering expected in a commercial seed field in Arizona. The percentage of bolting fluctuated between zero and twelve at Tucson, whereas this range was between zero and sixty-four at Safford. Strains 202H4, 301H2 and A61168 ranked first, second, and third in bolting response at Safford. These strains were classified by the plant breeders at the Spreckels Sugar Company to be fairly easy bolting, intermediate bolting, and non-bolting, respectively.

It is interesting to note that strain A61168 which was classified as a non-bolting one, gave a relatively high percentage of bolting in both locations. At Safford, strains A5218, A5401 and A62168 gave a bolting percentage of five, three, and zero, respectively. These strains had been classified as very non-bolting. On the other hand, strains A62162, A62183 and A63180 whose classification was non-bolting did not show any bolters.

The low percentage of bolting that occurred at Tucson might be attributed to one or more of the following reasons:

(a) Delaying the planting date appeared to be a prime factor since the first planting was destroyed by grasshoppers. Seedlings from the second planting were delayed in growth because of rabbit damage in the experimental area and repeated transplanting. The plants might have been too small by the time the cold vernalizing temperatures occurred. According to the results obtained by Erdman (14), sugar beet plants should be at least four months old when cold treated if they are to flower and set seed within one year. To achieve this amount of growth under Tucson climatic conditions, seed should be planted in early September.

(b) Thinning the plants to about six inches in the row and planting a single row on wide beds 38 inches apart kept them from shading each other and shading the soil during the vernalizing period. The plants and the soil were exposed to incoming radiation which probably raised the plant and soil temperatures. A heavy, unthinned stand of 30,000 to 100,000 plants per acre was recommended by Pendleton (38) for seed production of irrigated sugar beets in Oregon. In the spacing practiced at Tucson, the stand consisted of about 26,000 plants per acre. The higher percentage of bolting obtained at Safford, might be partly attributed to the heavier stand by planting two rows on a bed and leaving the plants unthinned. The soil of the experimental field at Tucson was of a sandy type that warms rapidly. High soil temperature is unfavorable for bolting. The finer soil texture at Safford was accompanied by a higher percentage of bolting than that at Tucson.

(c) Reversal of bolting might have occurred in the planting at Tucson because of warm temperatures that were recorded after the middle of May. A temperature as high as 101°F. occurred on May 23. According to Stout (54), reversal of thermal induction may occur if the thermally induced beets were stored at a relatively warm temperature (52° to 79°F.). The results obtained by Pendleton (37) showed that long exposure to medium range outdoor temperature could effect reversal of bolting.

<u>Root Yield</u>

First Harvest: By the time of the first harvest at Tucson on July 7, 1964 the plants had attained a fairly large size and were free of weeds and diseases with the exception of minor symptoms of curly-top on a few strains. The mature leaves had started to yellow and die. Figure 4 shows a view of topped roots of some plants during the first harvest.

Data in Table 3 show the root and sucrose yields obtained and calculated. Actual root yields per plot of a row eight feet long ranged between 9.9 and 29.3 pounds. This range, calculated on acre basis lies between 8.1 and 23.9 tons. Although root weight of plots fluctuated widely, the analysis of variance shown below did not indicate any significant difference between strains at the five per cent level. This result might be attributed to the wide variation among replications due to border effect, rabbit damage, and variations in soil fertility.

Figure 4. A view of topped roots of some plants during the first harvest.

TABLE 3. Root and sucrose yields of twenty sugar beet strains grown at Tucson, Arizona and harvested July 7, 1964.

Strain Number	Root Yield Per plot (lbs.)	Root Yield Per Acre (Tons)	Sucrose Content (Per cent)	Sucrose Yield Per Acre (Tons)
A5218	18.4	15.0	12.9	1.94
A5305	19.6	16.1	13.0	2.09
A5401	17.6	14.4	13.7	1.97
101H1	19.6	16.0	13.8	2.21
102H2	18.5	15.2	13.8	2.09
102H4	19.1	15.6	13.6	2.13
201H3	18.6	15.2	13.1	1.98
202H2	20.7	16.9	13.5	2.28
202H4	18.6	15.2	14.3	2.18
301H1	18.9	15.4	13.7	2.11
301H2	19.6	16.0	14.0	2.24
301H3	18.3	15.0	13.5	2.02
302H1	20.5	16.7	14.0	2.34
302H2	19.5	15.9	13.4	2.13
A61168	21.7	17.7	12.8	2.27
A62162	16.8	13.7	15.4	2.11
A62168	20.4	16.7	13.0	2.16
A62183	16.0	12.9	13.7	1.77
A63123	16.8	13.7	13.9	1.90
A63180	14.9	12.2	14.6	1.78

* Average of five, 8-foot rows.

Analysis of Variance (root weight)

Source	d.f.	SS	MS	Calc. F
Replication	4	302.41	75.60	
Strains	19	265.58	13.97	1.49
Error	76	709.24	9.33	
Total	99	1277.23		

$F_{0.05} = 1.72$

The average root weight per plot of the southern border was 24.3 pounds. This average exceeded the overall average by 30 per cent. It should be mentioned that strain A61168 which gave the highest yield, not only was a hybrid but also was the only triploid strain used.

Data in Table 3 also show that sucrose content for the first harvest ranged between 12.8, and 15.4 per cent. The average sucrose content for all twenty strains was 13.7 per cent. The low percentage of sucrose in these roots compared to a normal sucrose content of 17 per cent, might be attributed to one or more of the following reasons: (1) the relatively large root size resulting from spacing and thinning practiced, (2) to the nitrogen fertilizer added in June and (3) to delaying the planting date that shortened the length of the growing season. Data in Table 3 indicate further that strains A62162 and A63180 were highest in sucrose percentage, but these strains were low in root yield. On the other extreme, strains A61168 and A62168 which gave a relatively high root yield were low in sucrose percentages. These data suggest that sucrose percentage was adversely associated with high root yield. The correlation coefficient between root weight and sucrose percentage was r=-0.58 which is highly significant.

The relationship between bolting and sucrose content does not appear to be clear. The highest bolting strains, 301H2, A61168 and 202H2, had a sucrose percentage of 14.0, 12.8 and 13.5, respectively. It would appear that the reduction in sucrose percentage has a higher negative correlation with the increase in root yield than the percentage of bolters.

Second Harvest: After the first harvest at Tucson, the plants showed a continuous decline in vigor; the outer leaves yellowed and died. Curly-top disease appeared in a higher percentage on plants of some strains while some other plants were killed by root rot. Data in Table 4 represent the percentage of rotted roots found at the second harvest (August 6).

The average root yield of one hundred rows eight feet in length increased 120.6 pounds or 6.4 per cent from the first harvest to the second, indicating that the plants were still growing during that period. This increase in root weight was equivalent to 985 pounds per acre.

Data in Table 5 show the root and sucrose yields obtained and calculated per acre. Actual root yields per

TABLE 4. The total number of roots harvested in the second period for each strain of sugar beets and the percentage of decayed roots when grown at Tucson, Arizona.

Strain No.	Total number of roots	% diseased roots
A5218	87	1.1
A5305	86	2.3
A5401	85	2.3
101H1	80	1.2
102H2	84	1.2
102H4	73	2.7
201H3	68	10.3
202H2	90	0.0
202H4	84	1.2
301H1	82	0.0
301H2	93	2.1
301H1	89	3.4
302H1	79	1.3
302H2	93	0.0
A61168	90	0.0
A62162	86	1.2
A62168	93	1.1
A62183	87	1.1
A63123	76	6.6
A63180	86	1.1

* Average of five 8-foot rows.

TABLE 5. Root and sucrose yields of twenty sugar beet strains grown at Tucson, Arizona and harvested August 6, 1964.

Strain Number	Root Yield Per plot (lbs.)	Root Yield Per Acre (Tons)	Sucrose Content (Per cent)	Sucrose Yield Per Acre (Tons)
A5218	20.6	16.9	11.8	1.99
A5305	15.8	12.9	----**	----
A5401	19.5	15.9	11.5	1.83
101H1	18.8	15.4	11.8	1.81
102H2	18.6	15.2	11.3	1.71
102H4	18.6	15.2	11.0	1.68
201H3	20.7	16.9	11.8	1.99
202H2	23.1	18.9	11.8	2.23
202H4	19.9	16.3	12.6	2.05
301H1	21.8	17.9	11.1	1.99
301H2	23.7	19.4	12.3	2.38
301H3	20.2	16.5	11.6	1.92
302H1	20.1	16.5	12.6	2.08
302H2	23.6	19.3	11.6	2.24
A61168	24.0	19.6	11.7	2.30
A62162	17.4	14.2	12.8	1.82
A62168	19.1	15.6	11.6	1.81
A62183	16.6	13.6	12.7	1.72
A63123	19.7	16.1	11.8	1.90
A63180	19.7	16.1	12.6	2.02

* Average of five, 8-foot rows

** Sample lost

plot of a row eight feet long ranged between 9.9 and 29.9 pounds. On an acre basis, the root yield fluctuated between 8.1 and 24.4 tons. No significant difference in root yield was found among strains at the five per cent level. The border effect was also present in the second harvest. Strain A61168 was also the highest in root weight.

The sucrose percentage for the second harvest dropped to an average of 11.9, ranging between 11 and 12.8 per cent. The same negative correlation that occurred between root weight and sucrose percentage in the first harvest prevailed in the second harvest. The correlation coefficient between root weight and sucrose percentage was $r=-0.43$ which is not significant. The decrease in sucrose percentage in the second harvest might be attributed to high temperatures which reached a maximum of 103^{o}F. on July 10 and to the increased percentage of plants infected with diseases. Although root weight increased after the first harvest, the total sucrose production decreased six per cent due to the decrease in sucrose percentage. Statistical analysis of the sucrose values was not possible because of bulking of samples of each strain from the five replications for sugar analysis.

The average purity of the root juice of the sugar beets from the second harvest was 80.3 per cent. No purity analysis was made for the sugar beets harvested on July 7.

Suggestions for another experimental design to determine bolting response of these strains are:

(a) Planning the experimental area in a more squared shape by having 20 rows of 125 feet in length instead of 10 rows of 250 feet in length. This arrangement would tend to minimize the border effect and soil variation.

(b) Planting several border rows all around the experimental area with a non-bolting strain to further minimize the border effect and protect the experimental plots from unexpected mechanical injury and pests would be an advantage.

(c) The time of planting is a major factor that determines the percentage of bolting. The planting should be made in early September as the commercial sugar beet seed growers do in Maricopa County, Arizona. Another advantage of earlier planting might be the assurance of more protection against pests. It was noticed that grasshoppers and rabbits preferred to feed on sugar beet seedlings more than on mature cotton plants. No other crops were available to these pests in November and December.

(d) Planting two rows in a bed and leaving a heavy stand unthinned or thinning to three to four inches within the row is recommended.

SUMMARY

A field experiment was conducted at Tucson, Arizona from October 20, 1963 until August 6, 1964 to evaluate the bolting tendency and root yields of twenty commercial and experimental sugar beet strains. The seed was supplied by the Spreckles Sugar Company. Plantings were made in a sandy loam soil at the University of Arizona, Casa Grande Highway Farm.

A low percentage of bolting occurred in all strains ranging between zero and twelve. It appeared that a late planting date, wide spacing, soil type, and high temperatures were the main factors that kept the plants in the vegetative stage. Strain 301H2 was the highest bolting one, followed by strain A61168, and 202H2, respectively. No bolters were observed in twelve of the strains tested.

Seed of the same strains was also planted in a clay loam soil on October 14 at the University of Arizona Safford Experiment Farm at Safford, Arizona. At that location, the percentage of bolting ranged between zero and 64.

Root weight and sucrose percentage were determined for all strains grown at Tucson on July 7 and August 6, 1964. No significant difference in root weight was found among the strains at the five per cent level.

In the July harvest, strain 302H1 gave the highest sucrose yield, followed by strains 202H2 and A61168. In the August harvest, strains 301H2, A61168, and 302H2 gave the highest sucrose yield, respectively. During the period of the two harvests, root yield increased but sucrose percentage decreased. The total sucrose production dropped from an average of 2.09 tons per acre for the first harvest to an average of 1.97 tons per acre for the second harvest.

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