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Title: SEED DEVELOPMENT AND GERMINATION OF MONOGERM SUGAR BEETS (BETA VULGARIS L.) AS AFFECTED BY MATURITY

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Maturation rates of monogerm sugar beet seed grown in Western Oregon were measured quantitatively to determine attainment of maximum seed development and germination. Seed was collected at various intervals after anthesis from two hybrid varieties representing the extremes in resistance (hard bolting) and susceptibility (easy bolting) to seedstalk development. The effects of harvesting procedures on seed development and germination were compared at the various stages of maturity using simulated direct and windrow methods.

Maturity as determined by maximum germination and dry seed weight occurred at 40, 43 and 45 days after anthesis for the three years studied. Heat units accumulated from anthesis to maturity remained constant for all three years, even though 1965 was much warmer. It was concluded that the seed on sugar beet plants should

be mature after 900 heat units are attained or 45 days after peak anthesis.

The primary factor lowering the germination potential of mature seed was the occurrence of underdeveloped seeds. Chemical inhibitors in the sugar beet fruits as measured by firm ungerminated seeds may also reduce the germination for seed collected prior to maturity.

Some seeds were capable of germination 20 days after anthesis.

Plants and seeds of the hard bolting variety remained green throughout the maturation period, whereas easy bolting plants reached senesence and shattered. Plant appearance and percent moisture content were not found to be reliable indicators of sugar beet seed maturity.

Maximum germination and dry seed weight were attained at nearly the same levels regardless of harvesting method used. Sugar beets cut prematurely continued seed development while drying on the windrowed plant, but also contained more substances inhibitory to germination.

It was determined that germination, dry seed weight, heat unit accumulation and days from anthesis to maturity could all be used to estimate the optimum stage to harvest sugar beets for seed.

Seed Development and Germination of Monogerm Sugar Beets (*Beta vulgaris* L.) as Affected by Maturity

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INTRODUCTION

Western Oregon produces approximately 60 percent of the monogerm sugar beet (Beta vulgaris L.) 'seed'[1] planted in the United States. This 'seed' was developed for a wide range of environmental conditions where the beets are grown for sugar.

Sugar beet varieties possess varying degrees of resistance to floral initiation and seedstalk development (bolting). Hard bolting varieties are bred for resistance to seedstalk development when used in southern sugar production areas. Easy bolting varieties bolt too readily in these areas but are very adequate in northern sugar production areas (81). When these two genetically diverse types are grown for 'seed' production under identical cultural practices in Oregon, the plants respond quite differently. Hard bolting varieties remain green throughout the growing season and fail to reach senescence and shatter as do the easy bolting varieties. This creates harvesting problems for seed producers as it is difficult to determine

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[1]The following definitions are used in this paper in reference to sugar beet seed and fruit:

1. Fruit - ripened ovary(s), enclosing the seed(s).
2. Seed - ripened ovule, true botanical seed within fruit.
3. 'Seed' - general agricultural term referring to the botanical fruit (9)

the precise time of seed maturation.

Ninety percent of the sugar beet 'seed' presently produced in Oregon is of the monogerm type. Low germination problems in these monogerm varieties have caused constant concern for the sugar beet industry in the United States ever since their introduction in the late 1950's. Low germination has been attributed primarily to three factors: underdeveloped seeds, chemical inhibitors, and physical restrictions of the fruit. It was recently concluded (104, 105) that the major cause of low germination in monogerm sugar beet 'seed' produced in Oregon was the occurrence of underdeveloped seeds. Many researchers (24, 72, 97, 106) have isolated inhibitory substances in sugar beet fruits which have been shown to restrict germination of sugar beet and other seeds. The maternal tissue of the fruit has also been shown to cause a physical restriction which delays or prevents germination (94).

Even though many studies have been conducted on sugar beet 'seed' germination, little is known of the effects of maturity on the germination and development of this seed. No investigations were noted on the maturation of sugar beets measured by quantitative and physiological methods. Likewise, few observations have been made which would indicate that the hard bolting lines mature at the same rate as the easy bolting lines, even though the hard bolting plants remain green.

The objectives of this research were to determine maturation rates of monogerm sugar beet seed using quantitative and objective measurements of seed development and germination. The effects of varieties and harvesting methods on maturity were also evaluated.

LITERATURE REVIEW

Many factors influence the germination potential of sugar beet 'seed', including underdeveloped seeds, chemical inhibitors, physical restrictions by the fruit, and environmental influences. Any factor individually or in combination with others, may seriously impede or restrict 'seed' germination. Seed maturation and timely harvesting is known to affect seed development and germination in other crop plants. Several studies have been conducted on the problems of sugar beet 'seed' germination, but none have directly related these germination differences to 'seed' maturity. Likewise, little information is available on the effects of harvesting procedures on sugar beet 'seed' maturation or on quantitative measures that can be used on a field basis for predicting harvest dates.

Reproductive Development of Sugar Beets

Sugar beets (*Beta vulgaris* L.) are biennial plants which, under natural conditions, produce a large taproot the first year, as is common for sugar production, and the reproductive seedstalk the second year. 'Seed' production can be accomplished on a seasonal basis, however, using the winter annual method (76). To employ this method, 'seed' production areas must have mild winters, yet cool temperatures of 45° - 55°F for at least 100 days to satisfy the thermal induction requirement (82).

When following the winter annual method, sugar beet 'seed' is planted in early fall and develops into plants possessing large rosettes of leaves which are carried throughout the winter. In the spring, new leaves are formed which become progressively smaller and finally the apical portion begins to elongate, thi s initiating reproductive development. The main floral axis elongates very rapidly but the leaves that develop on this shoot are much smaller than the rosette leaves and more widely spaced. In axils of the leaves of this main stem, primary lateral branches arise which also elongate rapidly and give rise to secondary and eventually tertiary lateral branches. The terminal portion of the main stem and lateral branches produce paniculate inflorescences (7).

Perfect flowers are born sessile and occur singly (monogerm) at the axil of a large median bract. The flower consists of five narrow sepals, five stamens, and a tricarpellate pistil. The plants are inherently self-sterile and naturally cross-pollinated. The ovary of the mature pistil forms a truit which is embedded in the base of the perianth of the flower. The fruits are formed by cohesion of the receptacle to the perianth and ovary of the flower. The true seeds are small, dark, kidney-shaped structures. The mature fruit has a thick, corky maternal tissue (pericarp and perianth) which surrounds the true seed (7, 47).

There are two important practical considerations regarding induction of flowering in sugar beets. On the one hand, development of seedstalks (bolting) is objectionable when the crop is grown for sugar production due to reductions in yield. On the other hand seed-stalk production is essential when the crop is grown for 'seed'. As new varieties of sugar beets have been developed through the years, each had varying degrees of bolting resistance or susceptibility, depending on the genetic constitution. Easy bolting varieties produced a great abundance of 'seed' in all seed production areas, but had the tendency to bolt in the sugar production areas of California and Arizona (17). This forced plant breeders to develop hard bolting varieties that would resist reproductive development in southern sugar production areas (81). However, these hard bolting lines also resisted bolting in the southern seed production areas. Therefore, the Willamette Valley of Oregon became a major sugar beet production area, especially for the hard bolting lines. This area has temperatures mild enough for over-wintering and yet cold enough to induce the hard bolting lines into reproductive development (81). Sugar beets produced for 'seed' in Oregon initiate seedstalk development in late spring (May) and begin flowering in early summer (June). Due to the indeterminate flowering habit of this species, flowering continues for approximately 30 days after initial anthesis. However, 75 percent of the flowers open during the first seven to 14 days of anthesis, which is designated as the "peak" flowering period.

Maturity

Publications on seed development and maturity date back to 1893 (58), but an excellent review of the early literature was made by Arny and Sun (6) in 1927. Many of the early attempts to estimate maturity were based on the external appearance of the ear, spike, or panicle, as well as the browning of the plant (2). In later years, it became evident that the stage of seed development was also important, as seeds may reach maturity before the parent plants appear, by senescence of leaves and stems, to be ready for harvest.

Since Arny and Sun's (6) early review, many estimates of maturity have been based on internal measurements, such as moisture content, dry seed weight, viability, vigor, and overall rate of seed development. Recently, it also has become apparent that objective measures of seed maturity are necessary to determine the best stage to cut a crop to obtain both maximum yield and quality of seed. Many methods of estimating maturity have been utilized; however, most scientists have compared the relationship of maturity to: (1) dry seed weight, (2) moisture content, and (3) germination.

(The scientific names of all crops or plants referred to by common name in this thesis are presented in Appendix Table 1.)

Estimates of Maturity Based on Dry Seed Weight, Moisture Content, and Germination

Aldrich (3) defined maturity as the point at which maximum grain development was first attained. He also coined the term "relative maturity" as the point at which grain reached maximum dry weight. This point has been termed "physiological maturity" by Shaw and Loomis (92) and "morphological maturity" by Anderson (4). These were the only attempts to define maturity in the literature, although moisture content, germination, and days after anthesis have also been used as maturity criteria.

Aldrich (3) reviewed some of the moisture levels which have been reported for corn and cereals when grain development was considered complete. A current review of the seed moisture levels and days after anthesis required for seed maturation of several crops is presented in Table 1.

Corn and Sorghum Maturity

Many investigations have been conducted and contributions made to the total knowledge of maturity of corn. However, because of the lack of uniformity in describing maturity, it is often difficult to compare the results of one worker with another.

Several workers have concluded that the date of silking was the most significant time for establishing a base point of corn maturity

Table 1. Survey of crops indicating the percent moisture content or days after anthesis that maturity occurs.

Crop	Percent moisture content	Days after anthesis	Year reported	Investigator
Barley	42	26	1920	Harlan (41)
Barley	Below 40		1930	Burnett & Bakke (15)
Bromegrass, Smooth	47	17-18	1956	Grabe (36)
Clover, Red		24	1959	Hyde _et al._ (55)
Corn	31-44	61-68	1948	Dessureaux _et al._ (25)
Corn	30-42	50	1951	Shaw & Thom (93)
Corn	29-40	60-63	1962	Hallauer _et al._ (39)
Corn, Sweet	40		1950	Brimhall & Haber (14)
Oats	Below 40		1930	Burnett & Bakke (15)
Oats	45	20-28	1958	Frey _et al._ (32)
Ryegrass, Italian	38	28	1959	Hyde _et al._ (55)
Ryegrass, Perennial	44	28	1959	Hyde _et al._ (55)
Safflower	22-25	28	1964	Leininger & Urie (64)
Sorghum	23-30	33-45	1963	Collier (21)
Sorghum	27	36	1968	Clark _et al._ (19)
Timothy		35-40	1959	Stoddart (99)
Wheat	40		1923	Olsen (75)
Wheat	Below 40		1930	Burnett & Bakke (15)
Wheat		24-26	1941	Bartel (10)
Wheatgrass, Crested		30	1939	Hermann & Hermann (48)

(2, 93). Shaw and Thom (93) concluded that on the basis of their results and the examination of 25 years data from the Iowa Department of Agriculture, the interval from silking to maturity appears to be little affected by weather. This interval was 51 days and very constant. Hallauer (39) agreed that the interval from silking to maturity was relatively constant within years but was longer (63 days) than previously reported. However, Dessureaux et al. (25) reported that the interval from silking to maturity may not be constant and can range up to 64 days. Aldrich (3) reported that differences of 9.5 days existed among corn varieties for the number of days from silking to maturity.

Many researchers have used the criterion that maturity in corn occurred at that point when maximum dry weight was first attained (3, 25, 93). Moisture percentage as a basis for prediction of maturity has been shown to be unreliable (39, 93). This unreliability was attributed to large differences in moisture content (26 to 48 percent) at the time of maximum dry seed weight, which existed among hybrids in any one year or for any one hybrid in different years (93).

The conclusions that have been drawn from maturity studies on corn are:

1. Plant appearance is not a good criterion for estimating maximum dry matter of the seed (2, 3)

2. Grain moisture content alone cannot be considered a true

indication of maturity (25, 39, 93)

3. Days after silking and tasseling alone is not a dependable criterion since different lines or hybrids mature at different rates (25)

4. The time at which maximum dry weight is first obtained is a reliable estimate of grain maturity. This maximum dry weight is most often expressed as the number of days after silking, since this interval appears to be relatively constant for a given climatic region or group of hybrids (3, 39, 93).

It has been shown that harvesting corn seed before the moisture content dropped to approximately 25 percent reduced seed germination and seedling vigor, even though maximum dry weight was achieved at a higher moisture level (2, 98).

Sorghum researchers (19, 59) have reported that the point at which the seed reaches maximum dry weight provides a good indication of maturity and seedling vigor. However, they have had difficulty measuring this by seed moisture content due to wide variations between varieties and years. Kersting et al. (59) found that maximum dry weight accumulation in male sterile combine Kafir-60 sorghum occurred 45 days after pollination with 23 percent moisture in 1958 and at 33 days after pollination with 30 percent moisture in 1959.

Collier (21) compared several varieties of grain sorghum over a two-year period and found that maximum dry weight accumulation ranged from 24 to 35 days after anthesis for the varieties compared. Clark et al. (19) attempted to use both moisture percent and days after anthesis as estimates of maximum dry weight and maturity for five sorghum varieties. It was concluded that maturity varies, depending on the variety, but that maximum germination could not be obtained until the seed had reached maximum dry seed weight. This occurred at moisture contents ranging from 27 to 30 percent and at not earlier than 36 days after anthesis.

Maturity in Cereals

Unlike corn and sorghum, many researchers have shown a close interrelationship between seed moisture content and the point at which maximum dry seed weight occurred in barley, wheat and oats. Because of this close relationship, the measurement of seed moisture content has commonly been used as a criterion for estimating maturity in cereals.

In an early study on kernel development of Hannchen barley, Harlan (41) reported that translocation of plant material into the kernels stopped when seed moisture content was reduced to 42 percent. He concluded that maturation occurred at this moisture level, which was 26 days after flowering for the three years studied. Bartel (10) has shown that maximum dry seed weight in wheat was obtained at 24 to 26 days after anthesis.

More recently, others (13, 26, 29) have verified Harlan's work and agreed that maximum dry seed weight occurred at approximately 40 percent moisture content in barley. Brewer and Poehlmen (13) also reported that barley yield and test weight showed no additional increase after moisture content reached 40 percent.

Olson (75) reported that for three varieties of wheat studied, the kernels showed little increase in dry seed weight after the moisture content had declined to 40 percent. In maturity studies of oats seed development, Frey _et al._ (32) found that near maximum seed weight was reached when the moisture content of the grain was approximately 45 percent, with only a slight increase thereafter. A close interrelationship was found between oat germination, moisture content, seedling weight and dry seed weight. Germination increased with maturity up to 20 to 28 days after anthesis for seven oat varieties even though maximum dry seed weight occurred up to 10 days earlier.

These studies indicate that maturity of barley, wheat and oats occurred at a point when the seed moisture content was approximately 40 percent. However, research in Iowa (15) indicated that yield increases occurred after moisture content had reached 40 percent. Therefore, it was concluded that maximum dry seed weight in oats, wheat and barley may occur at values somewhat lower than 40 percent (15).

Maturity in Forage Crops

For many grass and legume species commonly used in forages and turfs, the optimum stage for cutting the seed crop is unknown. Few quantitative measures have been used and plant color changes and seed shattering are still utilized to estimate seed maturity (109). Harvest dates are based on an arbitrary classification system which can fail. One of the common reasons for failure in harvesting forage seed crops is that many species within this group have a very exacting time requirement for maximum seed yield and quality. If the crop is harvested too early, the seed might be in a state of dormancy. On the other hand, if harvesting is delayed too long the seed may completely shatter.

In an early study of range and pasture grasses, McAlister (68) compared the viability and vigor of eight grass species collected at four stages of maturity. His studies indicated that the Gramineae species will normally germinate when harvested in the milk stage, but field plantings showed that only mature seeds for seven of the eight species studied gave good emergence. Similar results were reported for crested wheatgrass (48) where high germination was obtained by harvesting in the early dough stage, but maximum field emergence could not be expected before the hard dough stage. Maximum dry seed weight and the most vigorous crested wheatgrass seedlings also occurred at the hard dough stage which was 30 days after pollination. Seed harvested 21 days after pollination reached maximum germinations comparable to mature seed if stored for 14 days prior to conducting the germination test.

Griffeth and Harrison (37) found with Reed canarygrass that seed harvested at 66 percent moisture showed no germination, but seed harvested two days later at 48 percent moisture gave 30 percent germination. They noted that as the moisture content dropped below 40 percent, the yield and germination were the highest; however, considerable shattering was noted when the moisture content went below 35 percent. British scientists (99) report that for three varieties of timothy, maximum dry seed weight was reached at 35 to 45 days and maximum germination at 40 to 45 days after anthesis. It was pointed out that one of the three varieties had started to shatter badly by 45 days after anthesis.

In a study comparing various quantitative methods of measuring maturity in bromegrass, Grabe (36) reported a close interrelationship between seed moisture content, dry seed weight, germination, and seedling vigor. He reported that maximum germination, dry seed weight, and seedling vigor were obtained 17 and 18 days after anthesis for the two years compared. Moisture content decreased slowly and uniformly from over 60 percent in the young seed to 47 percent at the time of maximum dry seed weight. A similar study was conducted in

New Zealand (55) on the seed development of ryegrass and red and white clover. For both perennial and Italian ryegrass, maximum dry seed weight was obtained at 28 days after anthesis, with a moisture content of 44 and 38 percent, respectively. However, full germination capacity was reached 14 days after anthesis when the moisture content was over 60 percent. Similar germination responses were noted for red clover and white clover with maximum dry seed weight occurring at approximately 25 days after anthesis for both species.

In studies of birdsfoot trefoil, Anderson (4) found that seeds reached maximum dry seed weight within 27 days after full bloom, at which time the pod color was light brown. He termed this "morphological maturity." Seeds of high quality could be harvested at this stage without the risk of shattering which occurred when the seed pods became brown or black, as had previously been thought to indicate seed maturity.

Maturity in Other Species

Gill (33) cut several weed species at various stages of maturity from bud to "dead ripe" and studied the viability of immature seeds. The results were extremely variable between species but interesting in that four species within the *Compositae* family produced viable seeds from open flowers, providing the stigmas were visible. However, other species within the same family produced viable seeds only from mature "dead ripe" plants. Of the Gramineae, Gill found that the wild grasses, Hordeum nodosum L. and Bromus mollis L., when cut in the pre-milk stage (after flowering but from green plants), produced seeds which were as viable as mature seeds. Safflower, a Compositae crop species, was found to accumulate maximum dry seed weight 28 days after flowering at a moisture content of 22 to 25 percent (49, 64).

In studies of horticultural species, Harrington (44) found that germination increased up to 42 days after anthesis for muskmelon seed; however, maximum dry seed weight occurred at 37 days after anthesis which was concluded to be maturity. In a detailed study of carrot seed (46), maximum dry seed weight increased until 60 days after flowering. Maximum germination occurred much earlier (35 days after flowering); however, maximum speed of germination nearly coincided with maximum dry seed weight occurring at 55 days after flowering. In a study of fruit maturity in pimiento seed (20), it was concluded that the seed was mature when the fruit was bright red, 60 days after anthesis. However, fruits cut at 30 or 40 days after anthesis had germinations equal to mature seed, if they were allowed to dry intact in the fruit for an additional 30 days.

Other Measures of Maturity

Heat Unit Concept

Temperature, as it influences the plant throughout the growing season, has been the object of intensive study. The major generality which can be drawn from these studies is that the effects of temperature are strongly interrelated with the other factors of environment (69). Regardless of how favorable light and moisture conditions may be, however, a certain minimum temperature is required before any growth can take place (60). Minimum temperatures for growth vary for different species. In 1959, Holmes and Robertson (53) completely reviewed the suggested minimum (base) temperatures for many agronomic and horticultural crops.

Although specific minimum temperatures have not been established for sugar beets, germination studies indicated that growth will not occur at a temperature of 40°F (1, 84). In field studies of growth and yield for three years in Montana (85) it was found that as the air temperature dropped below 50°F there was little or no weekly growth. It was estimated that 45°F was close to the minimum for growth in sugar beets and a recommended base temperature for studying heat unit accumulation (35).

An interesting application of the temperature effect on plants which has received considerable attention is the "heat unit theory."

This theory integrates phenology, physiology, and climatology as a tool for predicting plant growth, development, maturity, and yield (69). That plants have a "temperature requirement" was first suggested in the 18th century. However, it was not until 1916 that any practical use was made of this idea. At that time, Livingston (65) reported on the use of "physiological temperature indices" for the study of plant growth in relation to climatic conditions.

Many subsequent workers (56, 69, 90) have applied the "remainder index method" to numerous cultivated crops. This method has also been expressed in "degree days," "heat units," and "direct summation index." It is based upon the accumulation of daily mean temperatures above a base temperature for a certain period of the plant's growth. If a plant has a base temperature of 40°F and the mean temperature on a given day is 55°F, the difference in degrees for that day is termed heat units, and for this example would be 15 heat units. If 120 heat units are required for maturity, the plant should reach maturity by the time 120 heat units have accumulated.

One assumption when using the remainder index method is that rate of plant growth is directly proportional to increase in temperature. Other assumptions are; that there is only one base temperature throughout the life of the plant, that the day and night temperatures are of equal importance to growth, and that plant response to temperature is linear over the entire temperature range (53). Some investigators have sought to overcome this weakness by using other methods. An "exponential index" was based on the supposition that plant growth rates follow the rule of van't Hoff, doubling with each increase of temperature of 18°F (56).

Gillmore and Rogers (34) also proposed a modification of the remainder index by correcting for temperatures below the minimum for growth (50°F) and above the optimum for growth (86°F) in corn. The new classification was termed "effective days." This method was found adequate to classify maturity of genetic material; however, it was pointed out that because of its simplicity, the remainder index method was still preferred.

The heat unit concept for estimating seed maturity has been used widely in horticultural crops (53, 56, 90) and to some extent in agronomic crops, especially corn (5, 34, 110). Andrew et al. (5) compared maturation and yield of several corn hybrids grown at two climatically diverse areas: Wisconsin (80 days growing season) and in The Netherlands (155 days growing season). It was reported that maturity in corn measured by moisture content and dry seed weight required up to nine more weeks growing season in The Netherlands and occurred as much as six weeks later. However, accumulative heat units above a base temperature of 50°F were nearly equal in effectiveness at the two locations.

Wiggans (110) attempted to use the heat unit theory to predict maturity in several varieties of oats. Results indicated that there were varietal differences in the number of heat units required for maturity but little difference for a specific variety from year to year. It was felt that some variation may be caused by incidence of disease, rainfall, soil type, fertility, and plant population. This points out that environmental factors may cause fluctuation in the summation constant used for a specific crop. Holmes and Robertson (53) indicate that soil fertility level, plant population, soil type, soil temperature and moisture are all factors that should be considered when using the heat unit theory. Wang (108) has conducted a critical critique of the heat unit approach to plant growth responses. He pointed out six procedures that he felt were necessary to improve the heat unit system, recognizing that this would lessen its value for use on a practical basis.

Morphological Measures

In 1933, a Russian scientist (62) described an index for corn which could be used to characterize the length of the growing season (maturity), instead of number of days from silking to maturity. This index was the number of leaves on the main stem of the maize plant. The index means that the earlier the variety, the fewer the leaves on the main stem, whereas the latest maturing varieties have the maximum number of leaves. More recently, Chase and Nanda (18) tested the constancy and predictive value of a similar type of classification. A highly significant positive correlation was obtained between the number of leaves developed on the main stalk of maize and the days to anthesis after each planting date. However, the studies were not continued until seed maturity. Several morphological measures of vegetative plant parts have also been studied as they relate to maturity of bolls in cotton (86). It was reported that a positive association was found between boll maturity and (1) node of the first fruiting branch, (2) number of vegetative branches, and (3) percentage of bolls on vegetative branches.

Seed and Tissue Analysis

Studies have been conducted to compare plant and seed maturity to carbohydrate, fat, and mineral element accumulation in plants, especially in the canning and oil seed crop industries. Some efforts include: correlating nitrogen content in grain of cereals to yield and maturation (71), and comparing amylose accumulation in sweet corn to moisture content of developing kernels (57). In a unique study, Salunkhe and Pollard (87) examined microscopically the starch grains of two strains of lima beans in different stages of maturity. The results indicated that the hylum of the starch grain becomes larger and more ramified as maturity advances. When the hylum began to thicken along these ramifications, the beans had reached maturity.

Seed Development at Various Stages of Maturity

In 1922, Harlan and Pope (43) conducted a detailed experiment to determine the earliest date after pollination at which seeds were sufficiently developed to germinate. Working with seven barley varieties, it was discovered that 100 percent germination occurred in greenhouse flats if spikes were removed from the plant six days after fertilization. Ninety percent germination occurred for spikes removed from the plant five days after fertilization. Earlier removal led to death of the ovary. The average kernel at six days after anthesis weighed only 5 mg., whereas the kernel at maturity (25 days after anthesis) weighed 35 mg. In a subsequent paper, the same researchers (42) studied the development of immature barley kernels in order to determine the possible source of nutritive materials. They reported that immature barley kernels collected three days after anthesis, which remain in the culm or lemma and palea, continued to grow in both embryo and endosperm at least eight days after collection. Those kernels kept moist in the culm or lemma and palea will also be approximately 40 percent larger in length than those exposed and air dried. There was no evidence that immature kernels would grow if removed from the culm or lemma and palea, regardless if they were kept moist or air dried. It was concluded that immature barley kernels most certainly abstract food materials from the culm after harvest.

After this early research, many subsequent studies were conducted to determine the earliest date after anthesis at which seeds are sufficiently developed to germinate. A survey of literature indicating the time required after anthesis for germination of the first viable seed in several crops is shown in Table 2. It can be observed that initial germination in all of the cereals occurred at four to eight days after anthesis.

Studies on barley (41), wheat (12), oats (32), and rye (74) indicate that seed of all cereals develop similarly, although each has its unique characteristics. These studies show that dry matter was accumulated both rapidly and uniformly the first 12 to 14 days after pollination. Moisture was highest (nearly 80 percent) immediately after fertilization and decreased uniformly until maximum dry matter had been accumulated in the seed, after which seed moisture was lost rapidly. It was not clear whether dry matter always increased in a seed after the stem was severed from the roots. However, nitrogen definitely appeared to be translocated to the seed during the drying period. Similar seed development responses have been reported by Grabe (36) in smooth bromegrass and Hyde et al. (55) in ryegrass and clover.

Harlan and Polk (43) reported that immature barley seeds

Table 2. Survey of several crops which indicates the earliest date after anthesis at which seeds are sufficiently developed for germination.

Crop	Days after anthesis necessary for first viable seed	Year reported	Researcher
Barley	5	1922	Harlan & Pope (43)
Barley	5	1945	Hatcher & Purvis (45)
Bromegrass, Smooth	5	1956	Grabe (36)
Clover, Red	12	1959	Hyde et al. (55)
Clover, White	12	1959	Hyde et al. (55)
Corn	10	1936	Sprague (98)
Oats	4	1958	Frey et al. (32)
Pea, Rough	18	1966	Bennett & Marchbanks (11)
Pimiento	20	1943	Cochran (20)
Rye	5	1941	Nutman (74)
Rye	5	1945	Hatcher & Purvis (45)
Ryegrass, Italian	10	1959	Hyde et al. (55)
Ryegrass, Perennial	10	1959	Hyde et al. (55)
Safflower	4	1964	Leininger & Urie (64)
Sorghum	12	1961	Kersting et al. (59)
Wheat	8	1941	Bartel (10)
Wheat	5	1945	Hatcher & Purvis (45)
Wheatgrass, Crested	12	1939	Hermann & Hermann (48)

collected six days after anthesis were very small, but eventually developed into normal plants which set seed. Hatcher and Purvis (45) reported similar plant development from premature harvesting of rye seed as early as five days after anthesis.

A thorough investigation was carried out by Nutman (74) on the formation and subsequent growth of immature rye seeds. He reported that seeds removed as early as five days after fertilization produced viable seedlings, even though they were 1/16 the weight of the normal seed development. The anatomy and morphology of the immature and normal rye embryos were similar, but the immature embryos differed from normal in that they had only two leaf primordia instead of three. It was found that during most of the experiment, the plants grown from immature seed exceeded those grown from normal seeds in (1) relative growth rate on a fresh weight basis, (2) rate of tiller production, and (3) rate of leaf formation. As a result, all plants, whatever their original seed weight, reached approximately the same size at the termination of growth.

Effect of Harvest Methods on Maturity

Since direct combining and swath-combining both are commonly practiced in cereals, there have been several studies relating the effects of both to wheat, barley, and oat maturity. In an early experiment, Wilson and Raleigh (111) harvested Victory oats and Marquis wheat at various stages of maturity using several methods. The methods were: (1) drying plants in the oven immediately after harvest, (2) allowing the plants to dry in the shock as they normally do, and (3) drying the plants in the shock with a culm base in water. No differences in 1000-kernel weight were noted for any of the methods compared, as apparently the transfer of material was too small from the plant to seed to affect kernel weight. It was felt that life action probably continued for some time after harvest, however, as evidenced by the wheat caryopsis changing from green to red when left in the glumes but remaining green when dried immediately in the oven. In a similar study in barley, Harlan and Polk (42) concluded that the immature kernel most certainly abstracts food materials from the culm after harvest. It was also pointed out that barley kernels left intact in the lemma and palea continued to grow after collection, regardless if they were kept in a moist condition or allowed to air dry.

Swathing is a common method of harvesting in the northern areas of spring cereal production; however, it is seldom used in the winter growing areas. The effect of swathing at different stages of maturity on yield, bushel weight, and quality in spring barley was reported by Dodds and Dew (29) and Dew and Bendelow (26) and in wheat by Dodds (28). In all cases, results indicated that these cereals may be swathed at a moisture content of 35 to 40 percent without loss of yield or quality. It was pointed out that harvest operations may be advanced by as much as five to seven days by swathing compared to direct combining. Brewer and Poehlmen (13) confirmed these results and indicated that swathing of winter barley may be safely done when the average kernel moisture content reached 40 percent without loss to grain yield, dry seed weight, or test weight.

In an early study of corn, data were reported which indicated that grain development continued for a time after corn was prematurely cut and shocked (3). Kernel weight increased up to 20 percent in the three varieties of corn compared, especially when cut at very immature stages prior to maximum accumulation of dry seed weight.

In 1923, McAlister (68) studied maturity and harvesting methods for several range and pasture grasses. Preliminary tests were conducted to determine if food was translocated from a swathed plant to the seed, during the curing process. Crested wheatgrass and smooth bromegrass plants were cut in the dough stage of development and the seed compared with seed stripped from the plant at the same stage but dried immediately. There was little increase in weight of seeds dried on the plant compared to those air dried off the plant.

In a recent detailed study of seed maturation in smooth bromegrass (54), there was evidence that seed maturation or "after ripening" occurred in immature grass seed which remained attached to the harvested culm. In this study, smooth bromegrass seed was harvested at varying stages of maturity from 65 to 12.5 percent moisture using two methods: the simulated windrow method and the simulated combine method. The simulated windrow method gave maximum seed weight and vigor index at 45.2 percent moisture and maximum laboratory germination at 60.8 percent moisture. However, seed harvested by the simulated combine method gave maximum seed weight at 34.1 percent moisture and maximum laboratory germination and vigor index at 24.1 percent moisture. It was concluded that physiological maturity was reached at 45.2 percent moisture for the simulated windrow method and 24.1 percent moisture for the simulated combine method. Highest quality in combine harvested seed was not obtained until after shattering had begun.

In a study of Russian wild rye grass seed, Lawrence (63) showed that removal of the seeds from the culms at an immature stage and drying the seed immediately, had a detrimental effect on germination. On the other hand, if the seed was left attached to the harvested culms until dry and then threshed, the loss of germination was considerably less. Dewitt _et al._ (27) found that smooth bromegrass seed harvested by a simulated windrow method was consistently higher in germination than seed combined directly. They reported no significant differences in germination of seed harvested over a range of moisture levels from 11 to 54 percent by the simulated windrow method. However, seed harvested by direct combining at 11 percent moisture, germinated significantly better than that harvested above 21 percent moisture.

It is a general conclusion of these studies (27, 37, 54, 63) that considerable maturation occurs in grasses while drying on the plant in a windrow or swath, especially if cut in premature stages. Horning and Canode (54) point out that this maturation in the windrow allows commercial grass seed producers to cut before seed shattering and adverse weather conditions.

Factors Affecting Sugar Beet Seed Germination

Most of the research on sugar beet 'seed' germination is based on studies conducted with multigerm 'seed', since the monogerm varieties have been available for commercial use for only a decade. Conflicting results have evolved from the multigerm 'seed' studies as to the possible cause of poor germination. The most common factors reported to cause low germination in multigerm varieties are chemical inhibitors, physical restrictions of the fruit, and environmental conditions. Recent research by Snyder *et al.* (97) has shown that chemical inhibitors are also present in monogerm 'seed'. The general assumption has been that the factors which reduce germination in multigerm 'seed' are also responsible for the germination problem of monogerm 'seed'. Research in Oregon in the past few years (104, 105) has revealed an important fourth factor, underdeveloped seeds, which are reported as the primary factor contributing to low germination of monogerm sugar beet 'seed' produced in that area.

Chemical Inhibitors

One of the more popular explanations for the germination problem is the presence of chemical germination inhibitors in the fruit of sugar beets. Germination tests using sugar beet 'seed' in the presence of other kinds of seed have shown that the beet 'seeds' have inhibiting action on germination and growth (24, 106). As early as 1940, Tolman and Stout (106) found that water soluble substances in the fruit of sugar beet produced a toxic effect on germination by retarding germination and killing the radicles. A year later, they identified this toxic substance to be largely due to the action of ammonia (100). Other workers later isolated and identified a number of compounds from the water extract of sugar beet fruits that may be inhibitory to seed germination. These include an unsaturated yellow oil (24), water soluble oxalates (72, 97), and several acids including caffeic, ferulic, vanillic, p-coumaric, and p-oxybenzoic (61, 67).

In 1965, Snyder *et al.* (97) reported that one of the chemical inhibitors, oxalic acid, was found in the maternal tissue or pericarp of the sugar beet fruit. It was also found that a large percentage of these soluble oxalates could be removed from the sugar beet fruit by a 'seed' decortication process.

The inhibitory action of these soluble inhibitors on germination is routinely counteracted in seed testing laboratories by thoroughly washing the 'seeds' prior to testing. TeKrony and Hardin (102, 103) report that the hydrogen peroxide method provides an accurate estimate of laboratory germination potential provided the ungerminated 'seeds' are cut and examined for internal seed development at the final germination count. This cutting test provides the percent of firm ungerminated and underdeveloped seeds present in a lot. It was reported that for 12 varieties of sugar beets examined in 1968 (102) the mean of firm ungerminated seeds was three percent.

It has been proposed (101, 102) that the percent firm ungerminated seeds was a good indication of the level of chemical inhibitors in a variety. Recently (40) the percent firm ungerminated seeds occurring in a lot was compared to the germination and growth of sugar beet and radish seeds on water extracts of sugar beet seed from that same lot. Results showed a close correlation between percent firm ungerminated seeds and the degree of inhibition imposed by the extracts.

Physical Restrictions of the Fruit

Another factor that may influence sugar beet 'seed' germination is the tightness of the seedcap attachment which may impose a physical restriction on seedling emergence and a restriction of the flow of water and oxygen into the seed (95). Snyder (94) concluded that the maternal tissues of the fruit usually hinder germination since fruits notched to expose a portion of the true seed germinated more rapidly than natural unnotched fruits of the same variety. Sedlmayr (91) confirmed that the speed of germination was controlled mainly by the maternal part of the fruit and that this was a heritable trait. Peto (83) reported that monogerm sugar beet 'seed' produced in Southern British Columbia, possessed a thicker, tighter seedcap than multigerm 'seed' from the same area. He also reported that germination of sugarbeet fruits having tight seedcaps can be improved greatly by 'seed' treatment with dilute hydrochloric or sulfuric acid.

Effects of Environment

Another factor which some researchers feel may influence the germination performance of sugar beet 'seed' is maturation of the seed under adverse environmental conditions. Snyder and Hogabom (96) found that seedcaps of sugar beet 'seed' maturing at higher temperatures (76°F) are looser and may be shed more rapidly than seedcaps from 'seed' produced at lower temperatures (66°F). 'Seeds' produced at the higher temperature usually germinated more rapidly than those produced at the lower temperature. However, the higher temperatures depressed yields and were detrimental to seed development.

In recent studies of seed development of monogerm sugar beet 'seed' (104), it was reported that there was little difference in the number of underdeveloped seeds occurring in the Oregon-production area compared to the Arizona-production area. These underdeveloped seeds were the primary cause for lowering germination in both 'seed' production areas for the two years compared.

In an extensive study of fertility, Schweitzer (89) studied the effects of lime, nitrogen, phosphorus, and potassium on monogerm seed development at two locations having different soil types in the Willamette Valley of Oregon. High nitrogen fertilization negatively influenced seed development, causing an increase in the occurrence of underdeveloped seed. However, lime, phosphorus, and potassium applications had no apparent influence on seed development. A large difference in seed development was noted between the two experimental locations which was attributed to factors other than the fertility level of the fields.

Underdeveloped Seeds

From studies in the Oregon 'seed' production area (103, 104, 105), it was concluded that the primary factor responsible for low germination in monogerm sugar beet 'seed' was the presence of underdeveloped seeds. Underdeveloped seeds were defined as those sugar beet fruits having either completely empty (seedless) ovarian cavities or partially developed shrunken seeds (104). The partially developed shrunken seeds occurring in this classification exhibit three types of seed development: (1) a fully developed perisperm but no embryo, (2) a fully developed embryo but no perisperm, and (3) underdeveloped, shriveled embryo and perisperm. Fruits with underdeveloped seeds were reported to have a direct effect on the germination potential of a 'seed' lot, even though they cannot be visibly detected from completely filled fruits.

Several investigators (38, 51, 105) have shown that internal seed development can readily be determined by X-ray examination. It has also been reported that the underdeveloped seeds can be determined by a cutting test which is accomplished at the final count of a germination test or on dry 'seed' prior to planting (104, 105).

In a study of 60 'seed' lots in 1967 (105), it was found that the percentage of underdeveloped seeds occurring in these lots ranged from 4.5 percent to 55.5 percent. In a subsequent paper (104), a survey was conducted to determine the percentage of underdeveloped seeds occurring in Oregon-produced lots over a three-year period. Results showed that the mean percentage of underdeveloped seeds for over 100 lots compared for each year, was 19 percent in 1965, 18 percent in 1966, and 21 percent in 1967.

Even though underdeveloped seeds are presently considered to be a serious problem, little information had previously been reported on their occurrence in either monogerm or multigerm sugar beet 'seed' lots. In 1957, Goiko (35) reported that the development of seedless fruits of the red beet variety, Long Erfurt, were the primary factor to lowering yields and germination of 'seed' produced in the southern Ukraine of Russia. It was concluded that the reasons for these seedless fruits were drought, high temperature of the air and dry winds during the flowering period. The seedless fruits developed only pericarps from the walls of the ovaries of the unpollinated pistils.

Hogaboam (51) observed from 2 to 35 percent seedless fruits in a study of one monogerm sugar beet variety and also noted variation in the development of perisperm and embryos within the fruits. In a subsequent paper, Hogaboam and Snyder (52) found 10 percent seedless ovarian cavities in fruits examined in sizing experiments. They reported that fruit size, whether it be diameter or thickness, was a poor indicator of the contents of the ovarian cavity. TeKrony and Hardin (104) verified this conclusion and reported that location on a plant or branch had little influence on the internal seed development.

The occurrence of these underdeveloped seeds may be attributed to several factors: insect damage, parthenocarpy, or incompatability due to selfing.

Hills (50) found that lygus bugs, Lygus elisus Van Duzee, which feed on the soft developing fruits can cause the embryos to collapse and the resulting fruit cavity to be empty, thus reducing germination potential. He reports that the lygus nymphs do the most damage and that maximum damage is caused during the late bloom to early 'seed' stages of sugar beet seed development. He has shown that lygus bugs can be controlled by insecticides but states that rarely can satisfactory results be obtained in one application. Preliminary research at Oregon State University (40) gave additional evidence that lygus bugs can increase the occurrence of underdeveloped seeds.

Lygus bugs are known to feed on other cultivated crops, causing reductions in crop yields due to flower and bud blasting, as well as the formation of embryoless seeds. The occurrence of embryoless seeds and immature embryos was reported for several species within the Umbelliferae family (31). Subsequent studies indicated that lygus bugs are primarily responsible for the natural occurrence of the high frequency of embryoless seed in this family. Reduction of seed yields and the occurrence of shriveled and deteriorated ovules has also been attributed to lygus bug damage in alfalfa (16) and in cotton (70).

Namazie and Kohls (73), while attempting to induce parthenogenesis in sugar beets by treating flowers with several hormones, obtained a number of parthenocarpic fruits containing neither embryo nor perisperm development. Further evidence of parthenocarpic fruit development in sugar beets was obtained by Oregon State University researchers (40) when they observed that some male sterile plants grown in complete absence of pollen, produced fruits which were normal in exterior appearance but empty (seedless).

Sugar beet is naturally a cross pollinated crop which exhibits a high degree of inherent self sterility, althoug highly self-fertile strains also exist (79). Both cytoplasmic and Mendelian inherited male sterility have been identified and are used in developing hybrid sugar beet varieties (77, 78, 80). Cytoplasmic male sterility is introduced into an inbred line by back crossing (77). However, not all inbred lines currently used are successful pollinators and as a result, varying degrees of male sterile progeny are produced. This ranges from completely male sterile progeny to male sterile progeny having up to 25 percent normal fertility.

While developing inbred lines of sugar beets by selfing, plant breeders have noted irregular or abnormal seed and fruit development on several occasions (8, 79). As early as 1930, Down and Lavis (30) reported in selfing studies on isolated beet plants that a comparatively large number of fruits developed normally from every external appearance, but did not germinate. Internal examination of these fruits showed that for some unknown reason, the fruit developed without the production of seed. They theorized that pollination had stimulated the fruit to develop while fertilization did not take place to form an embryo.

In subsequent studies of self-sterility and self-fertility, Owen (79) reported that the intermediate or partly self-fertile plant types should be avoided in inbreeding programs, since these types commonly produced either parthenocarpic fruit development or a fruit containing an aborted embryo.

In a detailed study of self-fertility and self-sterility, Savitsky (88) reported the mechanisms which aid to insure self-sterility in sugar beets. However, she also discussed two types of seed and fruit development that may occur in selfed lines. In case one, it was reported that the sugar beet pollen grains germinate after selfing but growth becomes slower and stops in the tissues of the pistil. As a result, for eight or nine days after fertilization, the pollen tubes are unable to reach the embryo sac and the ovules remain unfertilized. In 10 to 12 days only a dark clump remains of the egg cell and synergids. The ovules become shriveled and the embryo sac is tightened by the nucellus. These non-fertilized ovules appear as small dark lumps at the bottom of the expanded fruit cavity. In case two, the pollen tubes of the selfed plants grow faster and fertilization may take place, in which case the embryo sac may either degenerate immediately or start to develop. However, at a certain stage of development, growth ceases and degeneration occurs. Simultaneously with the degeneration of the embryo sac, the ovule also degenerates. It becomes wrinkled and contracted and the seedcoat is pressed inward. Due to the death of the embryo and the absence of normal seeds in completely developed fruits, the germination of the seed is very low. A similar type of ovule and seed abortion after selfing has been reported in alfalfa (22, 23) and may also result in the development of non-functional seed-like structures in the pod.

In 1968, Schweitzer (89) reported that pollen concentration over a distance of 80 feet had little influence on the occurrence of underdeveloped seeds. These pollination studies were conducted using a pollinator with a red marker gene and two highly male-sterile female lines. When comparing the progeny collected at varying distances from the pollinator, it was found that approximately three percent were not carrying the marker gene. It was concluded that some of the plants in the two male-sterile lines used were producing viable pollen. Since these two lines are among the most highly male-sterile lines currently used in Oregon, it was concluded that they must possess some of the intermediate types of male sterility previously described by Owen (79).

MATERIALS AND METHODS

The influence of stage of maturity and harvesting methods on subsequent sugar beet seed development and germination was studied for three years: 1964, 1965, and 1966. The field experiments were conducted on the East Experimental Farm, Farm Crops Department, Oregon State University (1964 and 1965) and in two commercial seed fields (1964 and 1966). The laboratory evaluations and quantitative measures of maturity were conducted at the Seed Laboratory, Farm Crops Department, Oregon State University.

Two single cross monogerm lines were selected to represent the extremes of bolting (seed stalk development) resistance used by the sugar beet industry. The easy bolting (EB) male sterile line was SL(126×128)ms, whereas the hard bolting (HB) line was F62-569H3(ms). Both male sterile single crosses were crossed to a common pollinator (A5702) to complete the three-way cross which is commonly used in sugar beet 'seed' production. The two lines selected represented commercially important monogerm varieties.

Field Procedures

Both varieties were grown on the East Experimental Farm in 1964 and 1965. A comparison study of the easy bolting variety was also conducted in a commercial seed field located three miles north of Corvallis, Oregon in 1964. Only the hard bolting variety was evaluated for maturity in 1966 in a commercial seed field 10 miles east of Salem, Oregon.

For the studies in 1964 and 1965 on the East Experimental Farm, the male sterile plants were spaced 18 inches apart and in 24-inch rows on a Chehalis sandy loam soil. Pollinator plants were at similar spacings and in rows adjacent to the female plants. Soil fertility levels and control of insects and weeds were maintained at levels similar to seed production practices commonly followed in Oregon. Additional precautions were taken to prevent injury by lygus bugs. This included dusting all plants with DDT at weekly intervals throughout anthesis. This flowering period for an individual panicle covered approximately 30 days, beginning at the lowermost flower on the branch and progressing upward to the tip of the branch. When approximately 75 percent of the flowers on a plant were opened, it was termed "peak" anthesis.

The following quantitative measures were made on all 'seed' collections for both varieties:

1. Germination test
    a. Underdeveloped seeds
    b. Firm ungerminated seeds
2. Speed of germination

3. Heat unit accumulation

4. Dry 'seed' weight

5. Percent moisture content

All of the determinations were made each year, except for 1964 when only the first three were conducted.

1964

Maturation and seed development were studied on an individual seed basis. Primary emphasis was directed toward determining how long it takes sugar beet seed collected at various intervals after first anthesis to reach maximum germination and development. Observations were also made to determine the number of days after anthesis that a seed was sufficiently developed to germinate.

Because of the indeterminate flowering habit of sugar beet plants, it was necessary to identify anthesis on an individual flower basis and to mark the first flowers to open on each primary lateral branch. Following this procedure, over 1,000 branches on 79 plants were tagged in the easy bolting variety and over 1,200 branches on 108 plants were tagged in the hard bolting variety from June 13 to June 22. On the dates tagged, these branches had from one to three of the lowermost flowers open. It was observed that the first 10 flowers on the branch opened within a five-day period.

To be certain that the first collection was made prior to first viability, the groups of 10 'seeds' were observed on a daily basis. At each collection, the first 10 'seeds' were removed from 50 randomly selected lateral branches, representing more than 30 plants of each variety. The first collection of 500 'seeds' was made on July 6 which was 22 days after first anthesis for the hard bolting variety and 25 days after first anthesis for the easy bolting variety. Collections of 500 'seeds' were continued at two-day intervals until 61 days after first anthesis for both varieties, which was August 15 for the easy bolting variety and August 19 for the hard bolting variety. All 'seed' was removed from the plant between 8:00 and 10:00 a.m. for each collection. Enough branches had been tagged initially so that collections could continue well into September. However, due to a disease problem, several plants having tagged branches died and were removed throughout the course of the study.

After each collection, the 500 'seeds' were air dried on wire mesh trays at room temperature. This drying continued until 'seeds' had reached a moisture content of lower than 12 percent. This drying period normally continued for about one week after collection. The 'seeds' from all collections were blown in a South Dakota Model B pnuematic air separator at a setting of 20 to remove chaff and dust. They were then packaged and stored at room temperature until tests for viability and seed development were conducted approximately five months later.

The comparison study of the easy bolting variety at a commercial field was run in conjunction with the studies conducted on the East Experimental Farm in 1964. This commercial field was of a Chehalis sandy loam soil type and received fertility, irrigation, and insect control as is common for sugar beet seed production in Oregon. The plants were in 24-inch rows and a solid stand (one plant per inch). The field reached "peak" anthesis on approximately June 15 and initial anthesis for the first flower on each branch was estimated to be June 11. As for the other two varieties, 500 'seeds' were collected at two-day intervals starting on July 6 (25 days after anthesis). The collections were taken from four rows centrally located in a group of male sterile plants. At each collection, 50 lateral branches were randomly selected from plants within these four rows, recognizing that the date of initial anthesis was not as well defined as for the plots on the experimental farm. Collections continued in this commercial field until August 11, which was 61 days after anthesis and five days after the field was swathed. The drying, blowing, and storage procedures were similar to that discussed earlier for the two varieties grown on the experimental farm.

1965

As in 1964, maturation and seed development were studied on an individual 'seed' basis. The first ten seeds on a branch were collected at various intervals after first anthesis and evaluated for maximum germination, dry 'seed' weight and seed development. Additional studies of maturation and seed development were conducted on an entire plant basis, whereby 'seed' was collected from all plant locations at various intervals after peak anthesis. The effects of two simulated harvesting procedures on subsequent post-harvest measures of maturity were also studied.

Seventy plants of each variety were located and tagged at first anthesis. The first flowers to open on individual lateral branches of these 70 plants were also located and tagged. 'Seeds' on these branches were used in maturation studies on an individual 'seed' basis. From 20 to 30 lateral branches with initial anthesis dates ranging from June 18 to June 26 were tagged on each plant. The first 10 'seeds' on these branches were observed to have opened within a seven-day period. The initial collection of the first 10 'seeds' on lateral branches was made 29 days after first anthesis for the hard bolting variety (July 24) and 28 days after first anthesis for the easy bolting variety (July 21). Collections from 50 lateral branches (500 'seeds') continued at three-day intervals until 65 days after anthesis, which was the end of August for both varieties.

"Peak" plant anthesis occurred about July 1 for the group of 70 plants tagged for each variety. For 'seed' maturation studies on an entire plant basis, five randomly selected lateral branches, including secondary and tertiary side branches, were removed from five plants at each collection. These collections were made in conjunction with the 500 'seed' samples made from 50 lateral branches for the individual 'seed' studies outlined in the preceding paragraph. The first 'seed' collection from entire plants was made 20 days after peak anthesis for the easy bolting variety and 22 days after peak anthesis for the hard bolting variety. The final collections were made at 55 days after peak anthesis.

Two simulated harvesting methods were utilized at each collection for the 1965 maturation studies on an individual 'seed' and plant basis. These methods will be described in a later section entitled "Harvesting Methods."

1966

Only the hard bolting variety was studied in 1966. Primary emphasis was directed toward determining how long it takes 'seed' collected at various intervals after anthesis to reach maximum viability and development. Plants utilized in this study were located in a commercial sugar beet field approximately 10 miles east of Salem, Oregon. This field was on a Woodburn clay loam soil and received fertility, irrigation, and insect control, as are commonly practiced for sugar beet seed production. However, additional treatments of DDT were dusted on the plots at one-week intervals throughout the flowering period. The male sterile plants were planted in

24-inch rows and a solid stand. The pollinators were mixed at a five percent level throughout the solid stand.

Initial anthesis for the plot occurred from June 17 to June 22. At this time, 16 plants which had the same initial flowering date, were tagged for utilization in later maturity collections. These collections started approximately 39 days after anthesis and continued at four-day intervals until after the field was swathed, 63 days after anthesis. At each collection, the first 20 'seeds' were removed on 30 lateral branches selected at random from the 16 plants. These 500 'seeds' were then dried, blown, and stored, as has been indicated for the 1964 collections.

Methods of Evaluating and Estimating Maturity

It was recognized for these studies that weather varies from year to year, and the time taken for seed to ripen varies accordingly. Likewise, the proportion of time required for the various stages of seed development, and consequently seed maturity, are influenced by environment. For this reason, calendar dates are not referred to in this paper, but instead a time scale is used which is based on the number of days from first anthesis or "peak" anthesis, as observed for each variety in each year. Therefore, the parameter to which all data are referrable is the number of days after anthesis.

Germination

The laboratory germination tests were conducted using the hydrogen peroxide procedure (102) on eight 50 'seed' replicates for each variety. Following this procedure, each 50-'seed' replicate was soaked in 200 milliliters of a 0.1 percent hydrogen peroxide solution for 16 hours. After the soak period, the solution was drained off and the 'seeds' were rinsed in warm running water for five seconds. They were then placed on paper towels and allowed to dry for two hours at room temperature. The 'seeds' were carefully rinsed and dried to prevent any injury to protruding radicles which are often present at the end of the soak period.

After drying, 'seeds' were hand planted in blotter boxes prepared from standard germination blotter medium (102). The planted 'seeds' were placed in a water jacket type germinator which maintained a temperature of 20°C for 16 hours and 30°C for eight hours. No watering of medium was necessary during the test period. Normal seedlings were counted at 3, 4, 5, 7, and 14 days after planting. Abnormal diseased seedlings were removed at the interim counts to prevent contamination of other seedlings. Other abnormal seedlings were evaluated at completion of the test (14 days). Normal and abnormal seedling evaluation was in accordance with AOSA rules (9).

<u>Underdeveloped and Firm Ungerminated Seeds</u>

It has previously been reported (104, 105) that an accurate estimate of the internal seed development within a sugar beet fruit can be determined by the germination-cutting method. The procedure is classified as the germination-cutting method since it is commonly conducted at the final count (14 days) of a germination test. In using this method, the percentage of sugar beet 'seeds' that do not have adequate seed development for germination are classified as underdeveloped seeds.

It has been proposed (101, 102) that the number of firm ungerminated seeds remaining at the end of the germination test was a good indication of chemical inhibitors present in a sugar beet 'seed' lot. The germination-cutting method was also used to determine these firm ungerminated seeds.

The procedure followed for the germination-cutting method was to initially germinate eight 50-'seed' replicates using the hydrogen peroxide method, as was previously described. At the final count, all ungerminated 'seeds' in each replicate were placed with the 'seed-cap' down and each one was cut in half with a razor blade. The halves were examined internally for seed development and separated into two classes: firm ungerminated and underdeveloped. The firm ungerminated class included seeds which filled more than half the fruit cavity and had white chalky perisperm and a firm white embryo.

The underdeveloped class included fruits having completely empty cavities or those having partly developed, shrunken seeds. The seeds classified as underdeveloped (shrunken) were either discolored and watery or filled less than half of the fruit cavity.

Speed of Germination

The procedure followed for conducting the speed of germination test was developed by Maguire (66) as a tool for evaluation of seedling vigor. The speed of germination rating was determined from the normal seedlings that germinated at the 4-, 7-, and 14-day counts of the hydrogen peroxide germination test outlined above. This rating was calculated by dividing the number of normal seedlings per 100 'seeds' obtained at the 4-, 7-, and 14-day germination counts by the day counted, i.e. 4, 7, and 14. The values obtained for each of the counts mentioned are then summed to obtain the speed of germination rating as follows:

$$SG = \frac{\text{No. normal seedlings (4 days)}}{4} + \frac{\text{No. normal seedlings (5-7 days)}}{7} + \frac{\text{No. normal seedlings (8-14 days)}}{14}$$

Dry Seed Weight

The 'seed' utilized to determine dry seed weight for each collection was obtained after a storage period of not less than three months, during which all samples were stored under the same conditions. Two 100-'seed' samples were counted from the composite samples for each collection and each 100 'seeds' was weighed in milligrams for determination of dry seed weight.

Percent Moisture Content

At each collection in 1965 and 1966, approximately 500 'seeds' were stripped from branches for use in determining the percent moisture content of the 'seed'. These 'seeds' without bracts were placed immediately in moisture bottles, after which they were dried at 105°C for 24 hours. The moisture content was then calculated on a wet-weight basis using the following formula:

$$\text{Percent moisture content} = \frac{\text{weight of moisture}}{\text{initial weight of 'seed'}}$$

Heat Unit Accumulation

The number of heat units accumulated from the time of first anthesis until the last collection was determined each year using the summation or remainder index method (53, 90). Temperature records for 1964 and 1965 were obtained from summarized data of the

Oregon State University Vegetable Research Farm[2] located approximately one-fourth mile west of the sugar beet plot location on the East Experimental Farm and two miles south of the commercial field studied in 1964. These data were recorded on a 4-pen Gotham continuous recording thermograph, located inside an official instrument shelter at a height of approximately three feet above ground level. Temperature records for 1966 were obtained from the U. S. Weather Bureau station located at Salem, Oregon (107). This station was located approximately 10 miles west of the commercial field in which the hard bolting variety was grown that year.

The procedure followed for determining accumulative heat units by the summation index system was to add the minimum and maximum temperatures for a day and divide by 2 to obtain the daily mean. The base temperature was then subtracted from this daily mean temperature, which equals the number of heat units for that day. The heat units were accumulated by starting at the day of first anthesis for each variety and adding each daily heat unit rating throughout the maturation period.

For each species of plants, there is a minimum temperature at which growth takes place, which is called the base temperature

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[2] Air and Soil Temperature Data for 1964 and 1965. Vegetable Research Farm, Horticulture Department, Oregon State University.

used in the direct summation index system. The base temperature used for this study was 45°F. This temperature was selected on the basis of existing literature (1, 84, 85) and a supplemented laboratory experiment. The formula followed for determining heat units on a daily basis using the summation index method was:

$$\text{Heat units} = \frac{\text{Max. temp. (°F) - min. temp. (°F)}}{2} - 45°\text{F}$$

Harvesting Methods

In 1965 the effects of harvesting procedures on 'seed' and plant maturity were compared using two simulated methods of direct and windrow harvesting at each collection. Five plants from each variety having the same initial date of anthesis were randomly selected at each collection and the main stalk was cut at six inches above ground level.

Simulated Direct Harvesting

Immediately after cutting, the first 10 'seeds' occurring on 10 previously tagged lateral branches of each plant were removed, leaving the branches intact. This provided 500 'seeds' for each variety for use in estimating maturity on an individual 'seed' basis.

Similarly, immediately after cutting, five lateral branches including secondary and tertiary branches, were removed at five different locations on each plant. This provided a composite sample of 'seed' which was used to estimate maturity on a plant basis.

The 500 individual 'seeds', as well as the lateral branches, were dried on wire mesh trays at room temperatures until they reached a moisture content below 12 percent. The lateral branches were then threshed. All 'seed' was then blown, packaged and stored as in 1964.

Simulated Windrow Harvesting

On the date of each collection, 10 primary lateral branches, immediately opposite those harvested in the simulated direct method, were tagged for later collections. Likewise, five lateral branches, including secondary and tertiary branches opposite those collected in a direct harvesting method, were tagged for later collections. The plants were then hung, base end up, in a greenhouse for drying. This structure eliminated many of the climatic variables which may occur during field drying.

After the plants had dried 14 days, the 'seeds' had a moisture content of less than 14 percent and collections similar to the simulated direct method were made. These included collections of the first 10 'seeds' from the 10 primary lateral branches directly opposite those previously sampled for the individual seed maturity study. Five lateral branches directly opposite those previously sampled were also collected from five plants in each variety for the plant maturity study. All 'seed' was then handled as described for the simulated windrow method.

RESULTS

Means of all maturity indicators evaluated at each collection of both varieties in 1964 and 1965 are shown in Appendix Tables 2, 6, and 11. Similar means for the hard bolting variety in 1966 are shown in Appendix Table 14. Mean squares comparing varieties, methods and collections are shown for 1964 and 1965 for all variables measured (Appendix Tables 3 and 7). Simple correlation coefficients for all combinations of variables are presented in Appendix Tables 5, 9, 10, 13, and 15. Similar coefficients between varieties and methods for each variable are shown in Appendix Tables 4, 8, and 12.

Maturation of Sugar Beet Seed

The days after first anthesis (DAFA) that maximum levels of germination, dry 'seed' weight and speed of germination occurred for two sugar beet varieties are presented in Table 3. 'Seed' was declared as "mature" at the point where either maximum germination, dry seed weight or both occurred. The days after first anthesis that maturity occurred for the three years studied are also shown in Table 3.

Varietal Comparisons

In 1964, the hard bolting variety reached maturity at 43 DAFA

Table 3. Number of days after anthesis before attainment of maturity for both varieties over a three year period.[a]

Maturity indicators	Level attained	Days after first anthesis							
		1964			1965				1966
		HB	EB	EB-C	HB-D	EB-D	HB-W	EB-W	HB-C
Percent germination	Maximum	43	45	45	38	40	38	40	43
Speed of germination	Maximum	45	45	47	35	40	38	40	43
Dry 'seed' weight	Maximum	--	--	--	38	40	38	40	47
Percent underdeveloped seed	Minimum	39	43	45	41	40	38	40	43
Percent firm ungerminated seed	Minimum	43	45	45	35	37	35	37	43
MATURITY		43	45	45	38	40	38	40	43

[a]The two varieties compared in this paper will be referred to as:

HB = Hard bolting on experimental farm (1964 and 1965)
EB = Easy bolting on experimental farm (1964 and 1965)
HB-C = Hard bolting in commercial field (1966)
EB-C = Easy bolting in commercial field (1964)

The two simulated harvesting methods used in 1965 are referred to as:

W = Windrow method
D = Direct method

compared to 45 DAFA for the easy bolting variety grown at two locations (Table 3). These levels were similar to those observed for a maximum speed of germination rating. Total seed development, which was measured by minimum underdeveloped seeds, occurred for the hard bolters at 39 DAFA which was four and six days earlier than the easy bolters. Minimum levels of firm ungerminated seeds were reached at 43 DAFA for the hard bolting variety and 45 DAFA for the easy bolting variety. Simple correlation coefficients between the two varieties for each of the four variables showed a highly significant association in each comparison except firm ungerminated seed.

Maturity occurred approximately five days earlier in 1965 than in 1964 (Table 3). The hard bolting variety reached peak germination, speed of germination, and dry 'seed' weight at 35 to 38 DAFA, regardless of the method used. This compared to 40 DAFA for the easy bolting variety for the same three variables. Minimum underdeveloped seeds and firm ungerminated seeds occurred at approximately 40 DAFA and 36 DAFA, respectively, for both varieties. Simple correlation coefficients comparing all collections made in 1965 indicated that germination and dry 'seed' weight were highly associated for the two varieties. Significant associations were also reported for speed of germination between the two varieties.

An F test comparing treatment means in 1964 indicated that for all variables tested, significant differences were noted between the two varieties at the one percent level. All variables tested in 1965 also showed significant differences at the one percent level except firm ungerminated seed. When the means of each collection were compared, it was determined that the variation between varieties exceeded the least significant difference at the five percent level only for those collections made prior to seed maturation. There was little or no difference between the two varieties for those collections made after maturity occurred. It was concluded that yearly seed maturation occurred at essentially the same time for both varieties, thus only the means of the two varieties are presented in the succeeding results.

Maturity Indicators

Data for several of the maturity indicators evaluated at each collection are presented graphically on Figures 1 through 6. The vertical lines dissecting the yearly curve for each method indicate the point at which mean maturity for the two varieties occurred that year. The mean values used for 1965 were calculated from data obtained by the similated direct harvesting method on an individual 'seed' basis.

Germination

The time required for monogerm sugar beet 'seed' to reach sufficient development for germination ranged from 20 to 29 days after first anthesis (Table 4). There was little difference in time required for initial germination between the two varieties. This germination occurred approximately seven days earlier in 1965 than in 1964. The 'seeds' were dark green in color and about one-fourth their normal size when initial germination occurred.

Table 4. Days after first anthesis that 'seeds' of two sugar beet varieties had reached sufficient development to germinate in 1964 and 1965.

Year and variety	Days after first anthesis to initial germination
1964	
Hard bolting	27
Easy bolting	29
1965	
Hard bolting	22
Easy bolting	20

In 1964, the germination gradually increased to over 80 percent at maturity which was 45 DAFA (Figure 1). A similar germination trend was noted in 1965, with increases from 32 percent at 31 DAFA to over 80 percent at 40 DAFA (maturity). For both years, rapid germination increases of up to 25 percent occurred within a three-day period prior to maturity. After maturity was reached, the percentage of germination did not differ significantly throughout the remaining collections for all three years. The 'seed' color was changing to brown at maturity for the easy bolting variety, but was

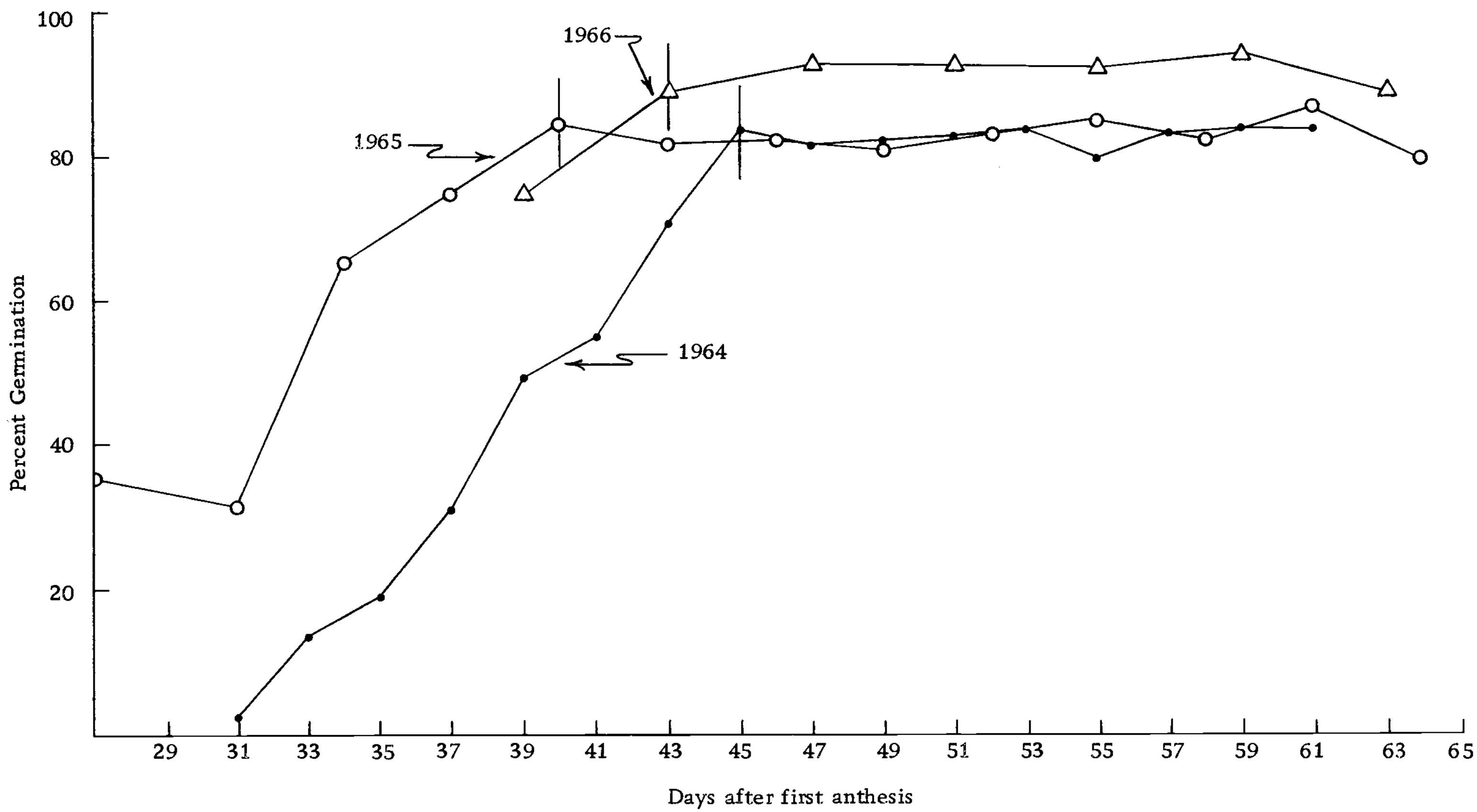

Figure 1. Percent germination of sugar beet 'seed' collected at various stages of maturity for three years.

still green at a similar stage for the hard bolting line. The plants and 'seed' of the easy bolters became straw colored by 55 DAFA, whereas the hard bolters remained green throughout all collections.

Factors Affecting Germination: Underdeveloped and Firm Ungerminated Seeds

In 1964, underdeveloped seeds decreased from 81.8 percent at 31 DAFA to 5.7 percent at 43 DAFA, after which they leveled off and remained constant (approximately 6 percent) for the remaining collections (Figure 2). Similar results were noted in 1965 where underdeveloped seeds decreased from 47 percent at 28 DAFA to approximately 10 percent at maturity (40 DAFA) after which they did not differ significantly for the remaining collections. Rapid decreases of up to 20 percent in underdeveloped seeds occurred within a three-day period in both 1964 and 1965 prior to maturity. In 1966, underdeveloped seeds decreased to approximately five percent at 43 DAFA and remained constant for the remaining collections. Highly significant negative associations were noted between underdeveloped seeds and germination in 1964 and 1965 when compared by simple correlation coefficients.

The percentage of firm ungerminated seeds was approximately 12 percent at 31 DAFA in 1964 (Figure 3). This percentage increased gradually to 42 percent at 37 DAFA and then gradually decreased to

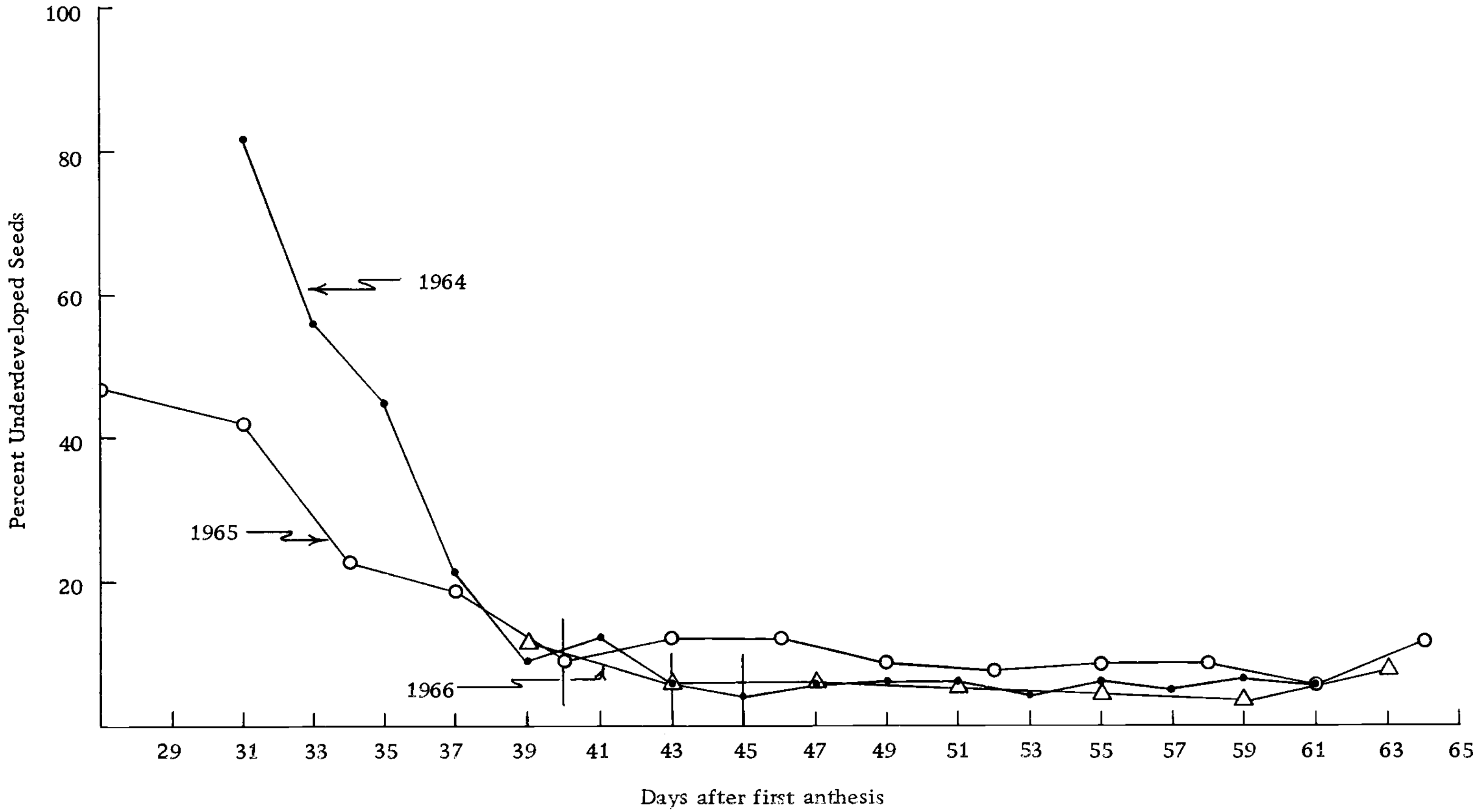

Figure 2. Percent underdeveloped sugar beet seeds occurring at various stages of maturity for three years.

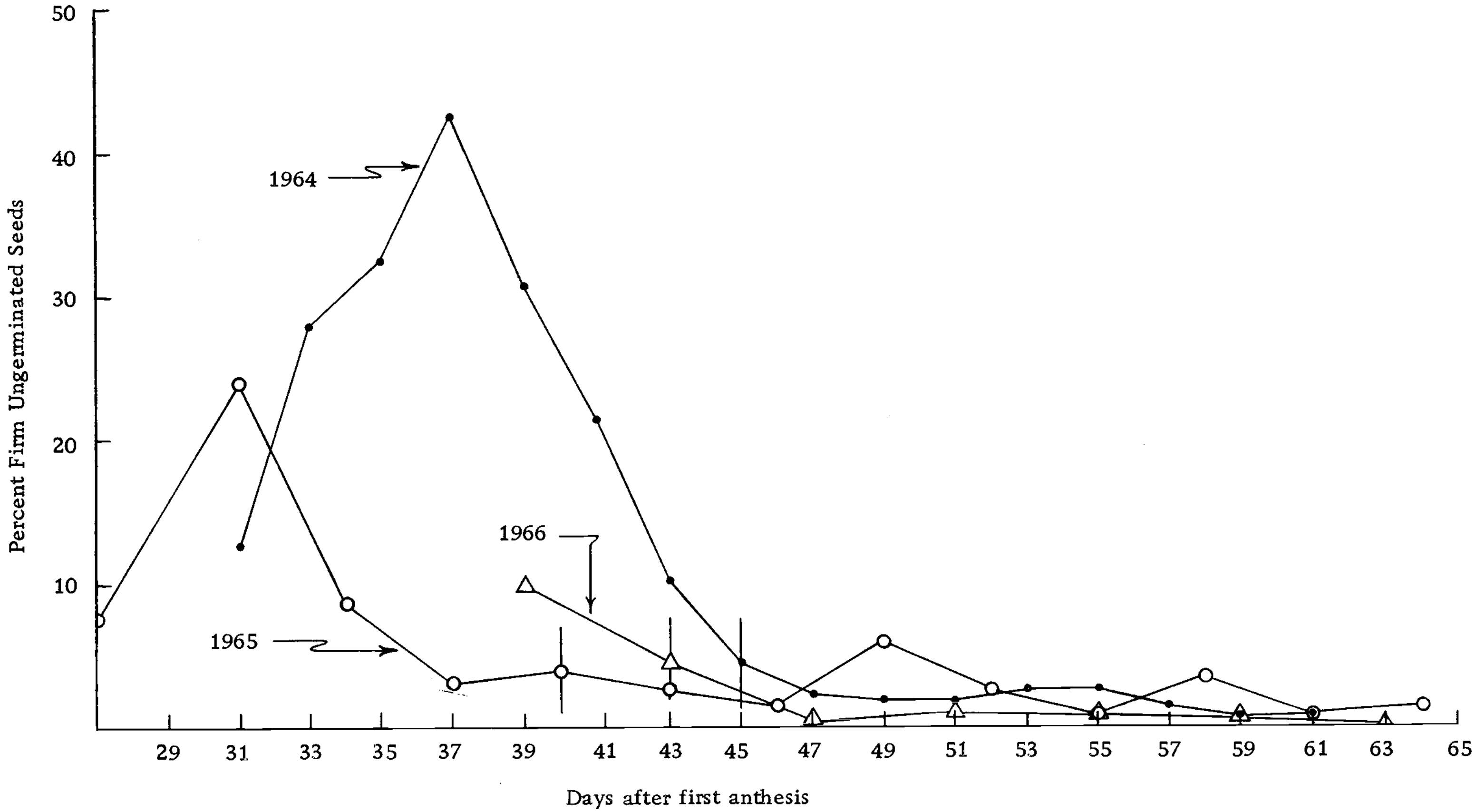

Figure 3. Percent firm ungerminated sugar beet seeds occurring at various stages of maturity for three years.

four percent at maturity (45 DAFA), after which it remained constant. A similar trend of increasing and decreasing prior to maturity was noted in 1965 where the minimum number of firm ungerminated seeds (3 percent) occurred at 37 DAFA. In 1966, firm ungerminated seeds decreased from 10 percent at 39 DAFA to two percent at 47 DAFA, after which they did not differ significantly for the remaining collections. Simple correlation coefficients revealed that percent firm ungerminated seeds and underdeveloped seeds were not closely associated for any of the three years compared. The firm ungerminated seeds were negatively associated to germination when correlated over all collections for the three years studied.

Speed of Germination

The speed of germination followed trends similar to percent germination for the three years studied (Figure 4). In 1964, this rating increased uniformly until maturity was reached, after which no significant difference was noted throughout the remaining collections. Considerably more fluctuation was noted in speed of germination rating in 1965. This rating increased very rapidly after the second collection (31 DAFA) until the 'seed' reached maturity at 40 DAFA. It then decreased significantly from a rating of 15 at 46 DAFA to 11 at 49 DAFA, after which it gradually increased for the remaining maturity collections. In 1966, the speed of germination

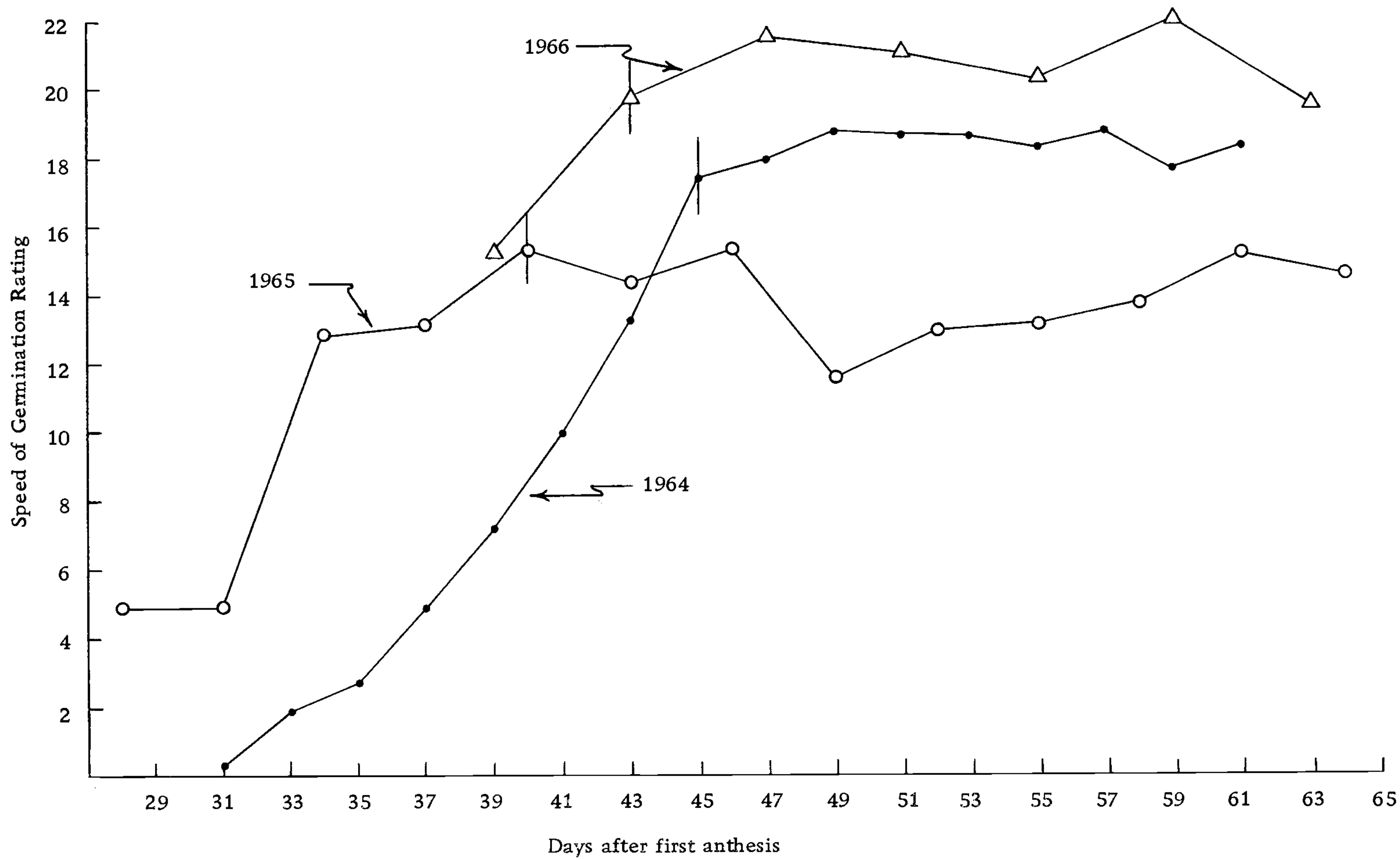

Figure 4. Speed of germination for sugar beet 'seed' collected at various stages of maturity for three years.

rating increased until maturity (43 DAFA) and did not differ significantly for the remaining collections. Simple correlation coefficients comparing the speed of germination to percent germination show highly significant associations between the two variables for all three years.

Dry 'Seed' Weight

The mean results of both harvesting methods for dry 'seed' weight accumulation in 1965 are shown in Figure 5. These results indicate that dry 'seed' weight followed the same general trend as 'seed' germination over all 'seed' collections. This weight increased from 81 mg. at 28 DAFA to 140 mg. at maturity (40 DAFA). It then remained constant for several collections after which it fluctuated from a low of 132 mg. at 52 DAFA to a high of 160 mg. at 61 DAFA. Dry 'seed' weight accumulation followed a similar trend in 1966.

Simple correlation coefficients indicate that dry 'seed' weight was significantly associated to germination and speed of germination for both 1965 and 1966.

Moisture Content

In 1965, the moisture content of sugar beet 'seed' at each collection decreased uniformly and gradually from 81.9 percent at 28 DAFA to 58.8 percent at the final collection (Figure 5). The

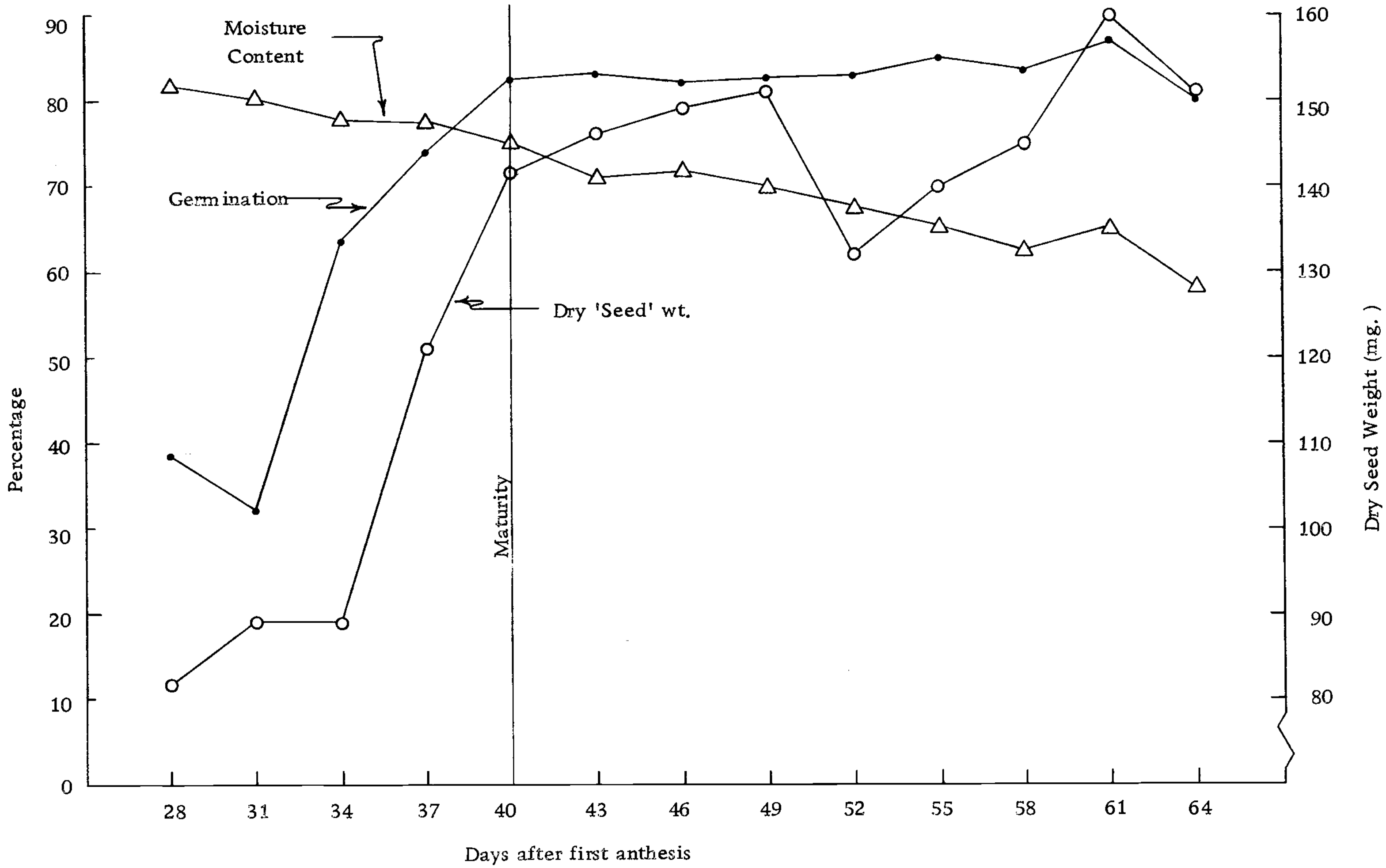

Figure 5. Percent germination, moisture content and dry 'seed' weight for sugar beet 'seed' collected at various stages of maturity in 1965.

moisture content at maturity (40 DAFA) was 75 percent. It dropped to approximately 70 percent three days later (43 DAFA) and remained at or below this level for the remaining collections. In 1966, the moisture content was approximately 70 percent at maturity (43 DAFA) and gradually decreased to 58 percent at the final collection before windrowing the field (55 DAFA). The moisture content was 10 percent after three days drying in the windrow.

The percent moisture content was negatively associated to dry 'seed' weight, germination, and speed of germination, over all collections in 1965. However, it was not associated to the same three variables in 1966.

Heat Unit Accumulation

The heat units accumulated at intervals after first anthesis for the three years studied are shown in Figure 6. These accumulations show that the weather conditions in 1965 were much warmer than the other two years. At 40 days after first anthesis in 1965, there was an accumulation of 862 heat units, which compared to 766 for the same period in 1964 and 762 in 1966.

To get an estimate of sugar beet maturity on a yearly basis, the maturation dates of the two varieties were averaged. This resulted in a maturation time of 44 DAFA in 1964 and 39 DAFA in 1965. The hard bolting variety matured at 43 DAFA in 1966. These

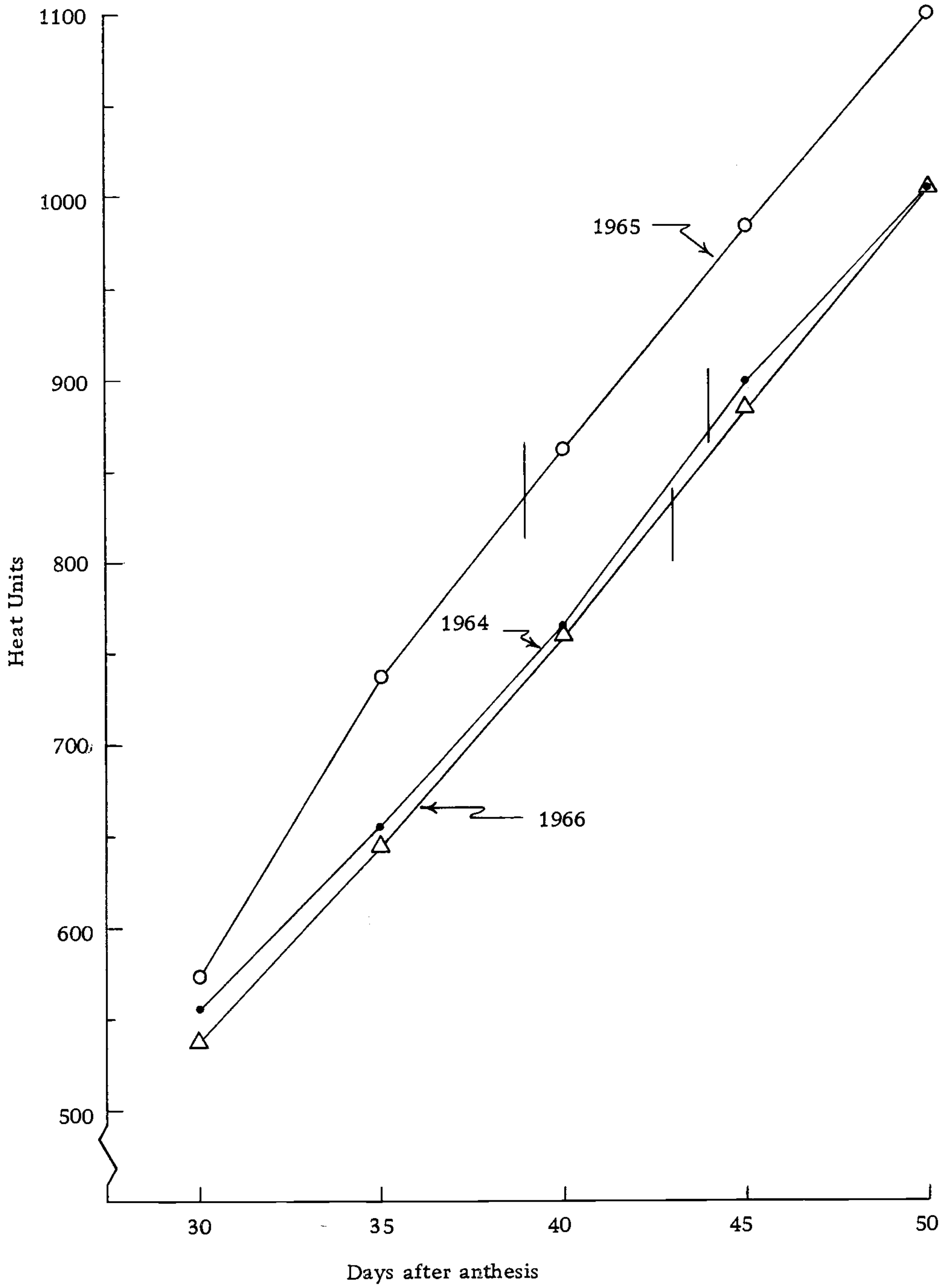

Figure 6. Heat units accumulated by developing sugar beet 'seeds' at various intervals after first anthesis for the three years studied.

yearly averages are plotted in Figure 6 (vertical line dissecting heat accumulation curve) for each year. This showed that the number of heat units accumulated at maturity was 870 in 1964, 840 in 1965 and 835 in 1966. Even though 'seed' maturation occurred five days earlier in 1965 than in 1964, the heat unit accumulation at maturity for the two years was very similar.

Results of simple correlation coefficients indicate that heat units were significantly associated with germination and speed of germination in 1964 and 1965. Heat units were not associated with the two germinability variables in 1966. Heat units and dry 'seed' weight were also significantly associated in 1965 but not associated in 1966. Significant negative associations were shown between moisture content and heat units for 1965 and 1966.

Effects of Harvesting Methods on Seed Maturity

The results in 1965 of the simulated windrow and direct harvesting methods are shown graphically as they affected sugar beet seed maturity on: (1) an individual 'seed' basis (Figures 7 and 8) and (2) an entire plant basis (Figures 9 and 10).

Maturation of Individual 'Seeds'

The maturity of 'seed' collected from individual branches at various intervals after first anthesis occurred at approximately 40

DAFA for both harvesting methods (Table 3).

Germination results obtained after harvesting by both methods followed a similar trend throughout all collections with no significant differences between methods after maturity was reached at 40 DAFA (Figure 7). Simple correlation coefficients indicated a highly significant association between the two methods for percent germination. The two harvesting methods had a similar speed of germination rating (approximately 4) at the initial two collections (Figure 7). However, from 31 to 49 DAFA, the windrow method had a significantly lower speed of germination rating than the direct method. There was no significant difference between the two methods for the collections occurring between 49 and 64 DAFA. Even though the speed of germination rating for the windrow method was lower than the direct method for approximately 20 days, the two methods were highly associated when compared by simple correlation coefficients.

The percentage of underdeveloped seeds occurring at 28 and 31 DAFA was significantly higher for the direct method than for the windrow method (Figure 8). This difference exceeded 20 percent for both of these initial collections. There was little difference between the two methods, however, as the percent underdeveloped seeds gradually decreased from 34 DAFA to maturity (40 DAFA). The direct method had significantly more underdeveloped seeds at 43 and 46 DAFA. The mean of underdeveloped seeds was

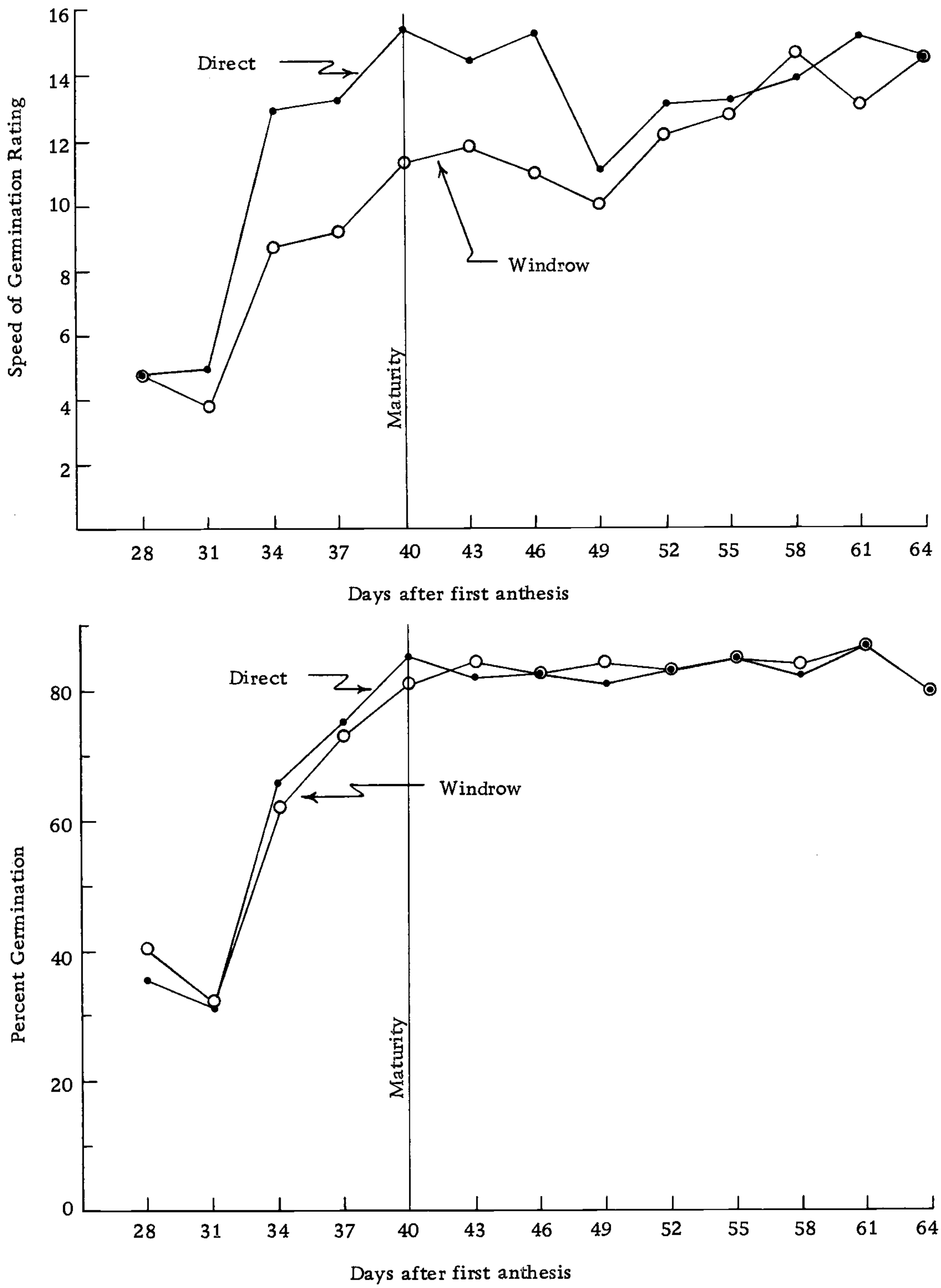

Figure 7. Percent germination and speed of germination for sugar beet 'seed' collected in 1965 at various stages of maturity using two simulated harvesting methods.

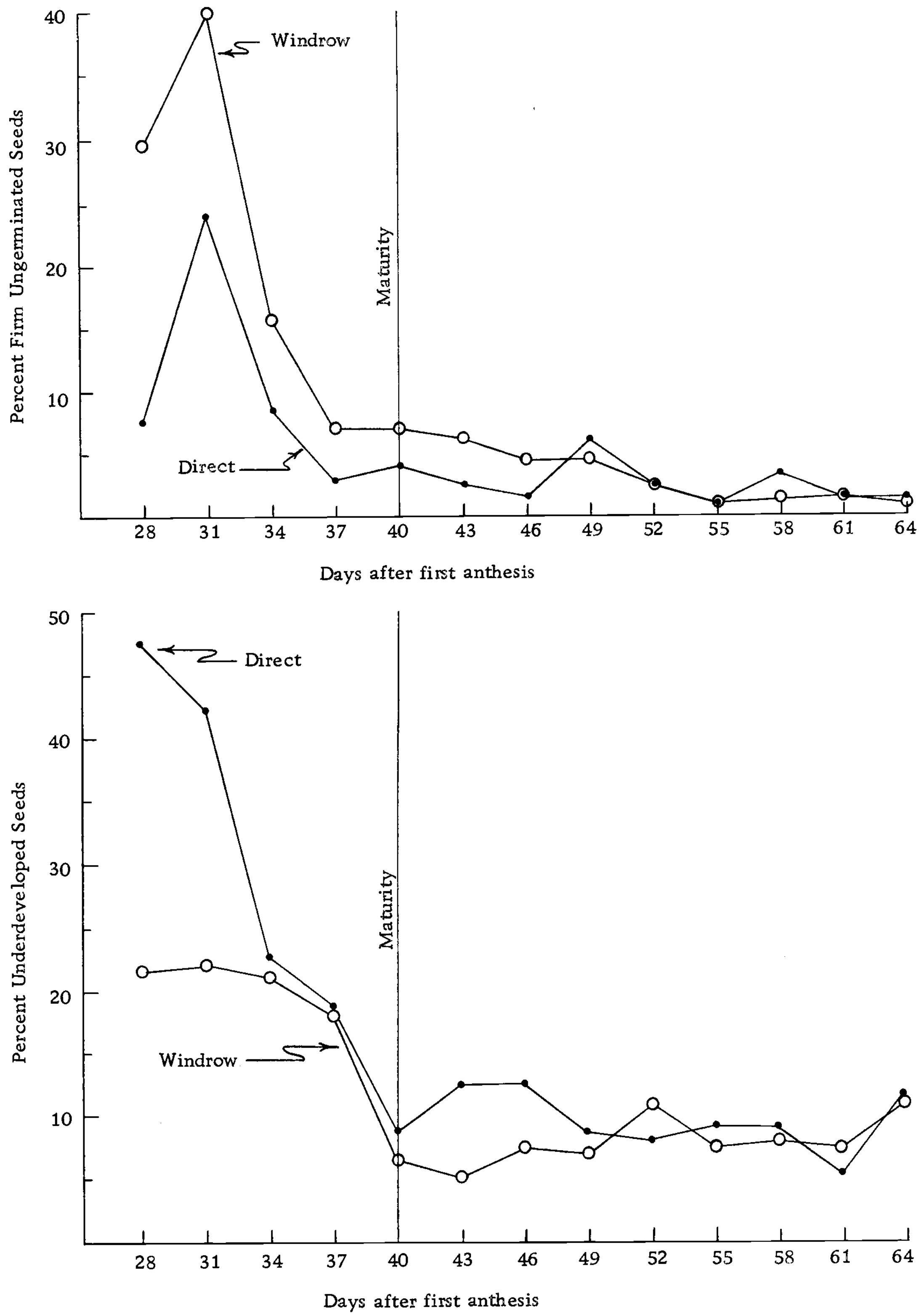

Figure 8. Percent underdeveloped and firm ungerminated sugar beet seeds occurring at various stages of maturity in 1965 after simulated direct and windrow harvesting.

approximately 8 percent from 49 DAFA to 61 DAFA, with an increase to 11 percent at the final collection. Simple correlation coefficients between the two methods for underdeveloped seeds showed a highly significant association over all 13 collections, but little association for the collections prior to maturity.

The percentage of firm ungerminated seeds occurring after windrow harvesting was significantly higher than that occurring after direct harvesting for the initial three collections (Figure 8). This difference exceeded 10 percent for the first two collections. The percent firm ungerminated seeds, when harvested by the direct method, remained consistently lower than the windrow method from 37 to 46 DAFA, although this difference was not significant. Firm ungerminated seeds gradually decreased from approximately five percent at maturity to approximately two percent at the final collection. Simple correlation coefficients indicated that the two harvesting methods were highly associated when correlated over all collections for firm ungerminated seeds, but were not closely associated when compared for the collections prior to maturity.

The dry 'seed' weight increased much the same for both methods and followed trends similar to germination. The point at which minimum dry 'seed' weight occurred for both methods coincided exactly with a similar level for percent germination.

'Seed' Maturation of Entire Plants

Results in Figures 9 and 10 show that entire plants harvested at intervals after "peak" anthesis (DAPA) followed trends similar to those observed for individual 'seeds' harvested at intervals following first anthesis. The percent germination and speed of germination rating both increased uniformly until maturity was reached 43 days after peak anthesis (Figure 9). As for 'seeds' harvested from individual branches, the speed of germination rating for 'seed' collected from entire plants was consistently lower by the windrow method than by the direct method (Figure 9).

The percent underdeveloped seeds was consistently lower when harvested by the windrow method for all collections made prior to maturity (Figure 10). Underdeveloped seeds declined to a low of approximately 18 percent at 46 DAPA, after which they increased to 30 percent at the final collection.

Firm ungerminated seeds were consistently lower in the initial collections (22 to 43 DAPA) when harvested by the direct method. This difference exceeded 10 percent at 37 DAPA just prior to maturity (43 DAPA).

Significant associations between methods were shown for all variables except firm ungerminated seeds.

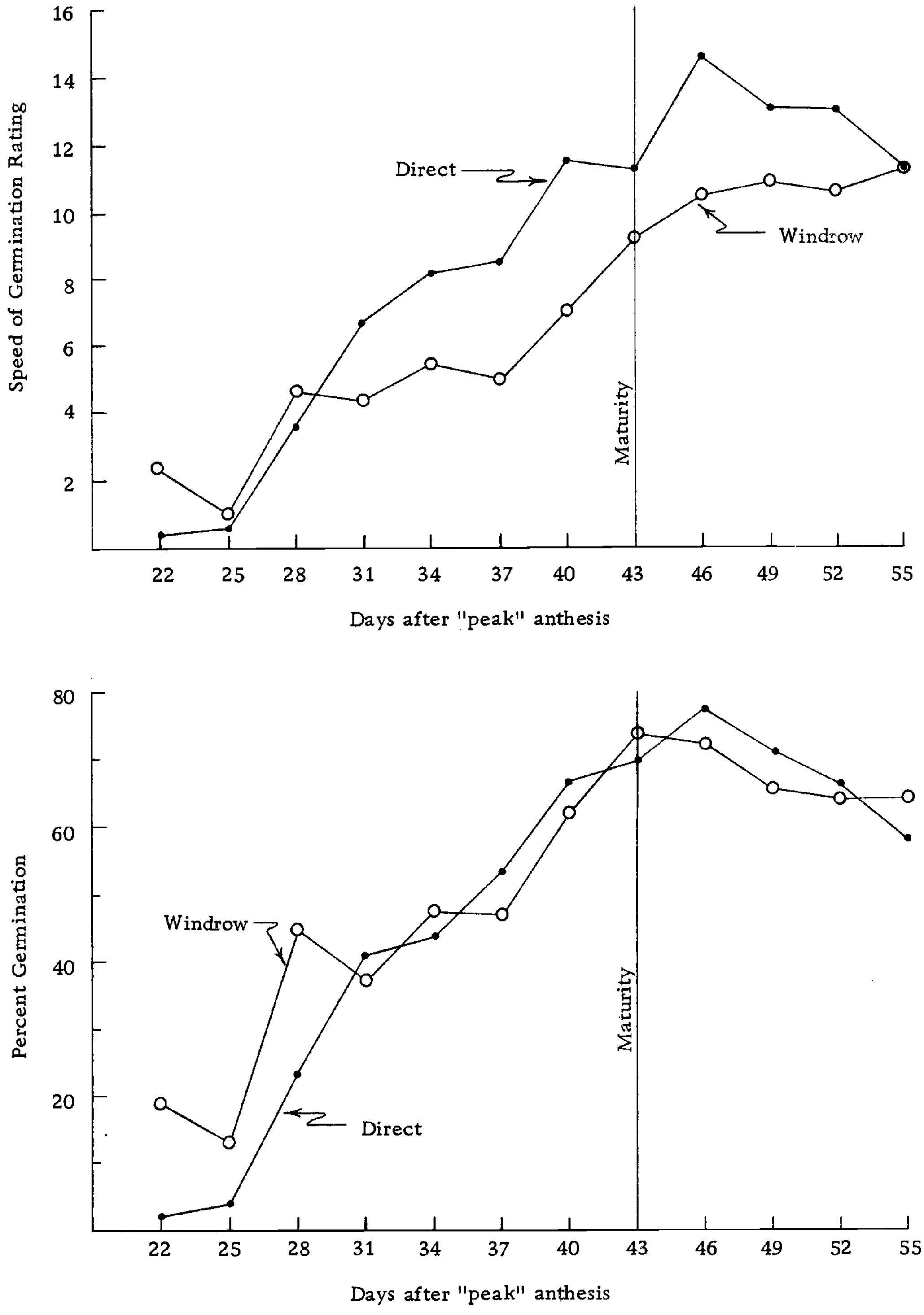

Figure 9. Percent germination and speed of germination for sugar beet 'seed' collected in 1965 from entire plants at various stages of maturity using two simulated harvesting methods.

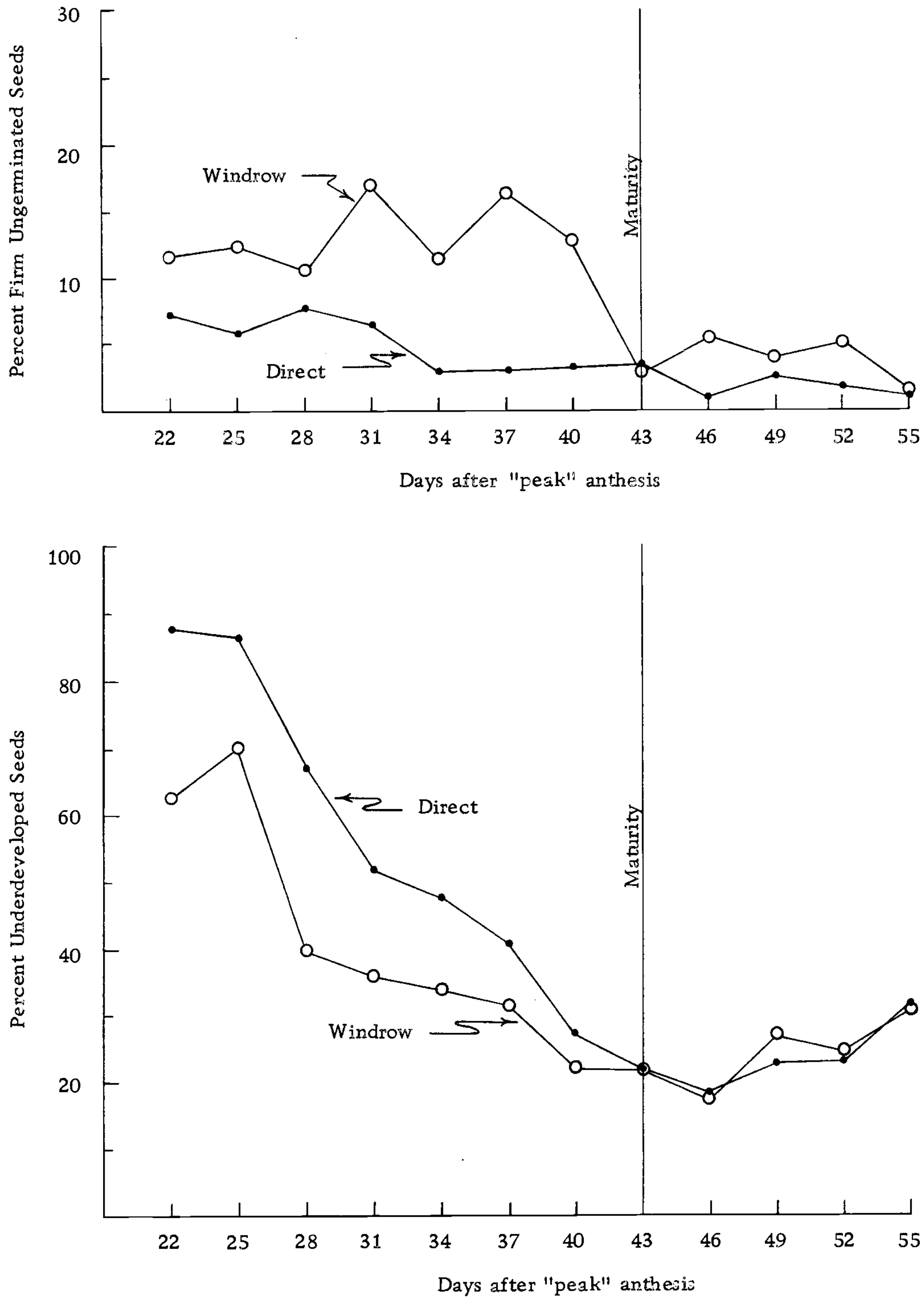

Figure 10. Percent underdeveloped and firm ungerminated sugar beet seeds collected from entire plants at various stages of maturity using two simulated harvesting methods in 1965.

DISCUSSION

The criterion presently used by fieldmen and seed growers when estimating sugar beet seed maturity is to randomly select several 'seeds' from different plant and field locations and cut them with a knife to determine the stage of seed development. The plants in a field are swathed when the majority of the seeds have reached the "hard dough" stage. Even though this qualitative measure of seed maturity is widely used, it is rather vague and is subject to individual variation in interpretation.

It was the intention of these research studies to develop quantitative measures which would accurately estimate the maturity for sugar beet 'seeds' and yet be of practical value to the seed grower. Results indicate that measurements of percent germination, dry 'seed' weight and heat unit accumulation may all be used as reliable indices of stage of maturation. This maturation is defined as that point at which either maximum germination, maximum dry 'seed' weight or both occur. It was concluded that sugar beet seed should have attained maturity by 45 days after peak anthesis or after an accumulation of at least 900 heat units. Either of these two methods can be utilized to estimate the proper time to harvest seed fields for maximum seed development and quality.

Maturity Indicators

The days after anthesis at which sugar beet 'seed' reached maximum gernimation and dry 'seed' weight were very similar for the two years compared (Table 3). The viability measures (germination and speed at germination) followed similar trends for all three years (Figures 1 and 4) and were closely associated to the dry 'seed' weight. Even though, maximim germination and dry 'seed' weight were both found to be effective estimates of stage of maturity, care should be taken when using either individually as a maturity indicator in sugar beets. Due to the previously reviewed germination problems with this crop, it is essential that the testing procedure followed gives an accurate measure of the germination potential or the results are of little value to estimate maturity. Likewise, due to complex 'seed' structure of sugar beets, caution should be taken when using only dry 'seed' weight as a maturity indicator. In explanation, the 'seed' structure weighed for sugar beets is actually a combination of the fruit and seed. It was observed that there is considerable variation between plants within a variety and between varieties in the amount of maternal tissue deposited on this 'seed' unit. This variation was the primary reason for the large fluctuation in dry 'seed' weight, even after maturity was reached in 1965 (Figure 5).

Percent moisture content, which is a popular maturity index in cereal crops, appeared to be of little value in estimating the stage of maturity in sugar beets. For the two years studied, the moisture content at the initial collections (approximately 30 DAFA) was 80 percent, from which it gradually and uniformly decreased to near 70 percent at seed maturity. This decline continued after maturity was reached to a low of about 60 percent at the final collection (Figure 5). For the easy bolting variety, the 'seeds' were completely straw-colored and near shattering when the final collection was made, yet the moisture content still remained well above 50 percent. It was assumed that this moisture content remained higher than in other crops because of the thick, fleshy maternal tissue of the sugar beet fruit which surrounds the true seed. This tissue retains a high percent of moisture, even though the 'seeds' are becoming straw-colored. It was determined at the onset of this study that the only practical procedure for estimating moisture content would be to strip the 'seeds' from lateral branches and determine the moisture percentage. It was recognized that if the moisture content of the true seeds could have been determined, the results might be more beneficial in estimating maturation.

Due to the indeterminate flowering habit of the sugar beet plant, it was necessary to study maturation rates on an individual 'seed' basis. Since this would be impractical for estimating field maturity, the "peak" flowering dates of entire plants were estimated in 1965, after which 'seed' collections were made to estimate the plant maturity. The results indicated that maturation based on maximum germination occurred approximately 43 days after "peak" anthesis (Figure 9). This compared very favorably to the 40 days after first anthesis required for 'seeds' collected from individual branches to reach maturity for the same year (Figure 1). Therefore, it seems practical that "peak" anthesis can be used effectively on a field basis to estimate the time to cut sugar beet plants to obtain maximum seed development and germination.

Many methods of estimating heat unit accumulation have been utilized in other crops. The procedures followed vary from complex to rather simple estimates of the effects of temperature and other climatic factors on plant growth. Considering the practicality of using such a method on a field basis, a simplified procedure, the summation index system (53, 90), was utilized in these studies. Following this summation index method, a base temperature (45°F) was subtracted from the mean daily temperature in degrees Farenheit to determine the heat units accumulated for that day. These daily accumulations were merely added from the time of first anthesis throughout the various 'seed' collections.

The temperatures in 1965 were considerably higher than for the other two years examined in these maturity studies (Figure 6).

Because of these higher temperatures, the sugar beet seed matured approximately five days earlier in 1965 (Table 3). It was interesting to note, however, that when the heat unit accumulations at maturity were compared for the three years, they were very similar. The heat units accumulated ranged from lows of 835 for 1966 and 840 in 1965 to a high of 870 for 1964. This resulted in less variation in estimated maturity date based on heat unit accumulation, than was observed by counting the days after anthesis. It appears that for the two varieties studied seed should be mature after an accumulation of approximately 850 heat units. After considering the varietal and yearly variation observed, it was concluded that if the heat unit system is to be used to estimate sugar beet maturity at least 900 heat units should have accumulated before the plants are cut for seed production.

It should be pointed out that some of the criteria which have led to the failure of the heat unit system in other crops were controlled in these studies. These controls included similar soil fertility levels for each field and regular irrigation schedules followed for each year. However, other factors which may cause fluctuations were not controlled. These include: variation in plant populations and soil types, and the necessity of temperature recording equipment in close proximity of the field location.

Considering the pitfalls of the heat unit accumulation system which have previously been reviewed (108), it seems questionable that this system could be recommended as the only method to estimate sugar beet seed maturity based on this one study. It does seem appropriate, however, that it could be used in combination with other quantitative measures, such as days from anthesis to maturity, germination, and dry seed weight.

The "dough" content of the seed was examined at periodic intervals for the collections made in these studies. Using our interpretation, the 'seeds' were at or near the hard dough stage when maturation, as determined by quantitative methods, occurred for each year.

The age at which a sugar beet 'seed' has reached adequate development for germination (20 to 29 days after anthesis) was much later than that previously reported for other crops (Table 2). A partial explanation for this delay was that the thick, fleshy maternal tissue of the fruit may physically restrict germination of these immature seeds. It seems probable that if the true seeds could have been removed from the fruit at these early stages of development, the germination may have proceeded earlier than 20 days. There appeared to be little difference in initial germination between the two varieties tested; however, the 'seeds' germinated approximately seven days earlier in 1965 than in 1964. This coincides with the warmer temperatures in 1965 and increased heat unit accumulation. At initial germination, the fruits were dark green in color and about one-fourth their normal size. The seeds had soft, milky embryo and perisperm which became shriveled upon drying.

Contrary to visual appearance, the hard bolting variety reached maximum germination, seed development, and dry 'seed' weight at essentially the same time as the easy bolting variety (Table 3). It actually matured two days earlier than the easy bolting variety for the two years in which the two varieties were compared. It should be emphasized that the two varieties selected for this study represented the extremes in bolting resistance and senescence. The easy bolting type easily reached senescence of plants and seeds whereas, the hard bolters remained green throughout the summer.

As expected, the two varieties demonstrated considerable variation in visual ripeness for the first 10 'seeds' that were removed from 50 lateral branches at each collection. 'Seeds' of both varieties were dark green and considerably smaller than normal in initial collections. 'Seed' of the hard bolting variety was still green at maturity and remained green throughout most collections. It was observed, however, that for some hard bolting plants a gradual color change from green to light brown was noted for the first 10 seeds on each branch by the last collection. The 'seeds' of the easy bolting variety were brownish-colored at maturity (40 DAFA) and extremely straw-colored 10 days later. The first 10 'seeds' on each lateral branch were close to shattering by the final collections, at which time the entire plant was straw-colored.

It can be concluded that visual appearances of the 'seeds' or plants are poor indicators of maturity for the hard bolting variety. . The color changes of the easy bolting variety favorably compared with the previously discussed quantitative measures of maturity. Therefore, if quantitative measures were not available, coloration could be used as a guide to stage of maturity in the easy bolting varieties. It also seems possible that a few of these easy bolters could be planted as indicators in hard bolting fields for guides to harvesting procedures.

Germination Factors as Affected by Stage of Maturity

In previous studies of sugar beet 'seed', chemical inhibitors (24, 72, 97) and physical restrictions of the fruit (94) were reported as the principle causes of low germination. Recent studies of Oregon produced seed (104, 105), show that these two factors are of minor importance and that the presence of underdeveloped seeds is the primary factor reducing germination. It was also reported (101, 102) that the percent firm ungerminated seeds remaining at the final count of a germination test is a good indication of the percent inhibition in the seed lot tested.

Because of the complexities of sugar beet 'seed' germination, the percent of both underdeveloped and firm ungerminated seeds was determined for each maturity collection in these studies. The results indicate that both factors may act individually or in combination to lower the percent germination in premature 'seed' collections. It was also found that this effect may be quite different from one year to the next.

In 1964, the minimum percent underdeveloped seeds occurred 39 days after anthesis (Figure 2). However, the germination was only 50 percent at this level and did not reach peak germination (maturity) until approximately six days later (Figure 1). The primary factor lowering the germination percent for this period was the occurrence of firm ungerminated seed. There were 31 percent firm ungerminated seeds (Figure 3) at 39 days after anthesis, and this gradually dropped to five percent at maximum germination (45 DAFA).

In 1965, the influence of these two factors on germination prior to maturity was reversed compared to 1964. The firm ungerminated seeds reached a minimum level at 37 days after anthesis, which was approximately four days prior to maturity (Figure 3). However, the underdeveloped seeds gradually decreased throughout the initial collections and did not reach a minimum until maturity, which was 40 days after anthesis (Figure 2). This gradual decrease in underdeveloped seeds was caused by the continued development of immature seeds previously classified as shrunken. The underdeveloped seeds occurring after maturity were primarily empty (seedless fruits) with few partially developed seeds present in these later collections.

It was concluded that if sugar beets are harvested prior to maturity, either seed development or inhibitory action of the fruit may be responsible for lowering germination. It was observed that neither germination nor speed of germination were closely associated with underdeveloped or firm ungerminated seeds when compared by simple correlation coefficients. However, when these underdeveloped and firm ungerminated seeds were added together and the total correlated to germination, a highly significant negative association resulted.

It appears that the level of germination inhibiting substances in sugar beet fruits increases throughout the premature stages of seed development to a maximum level approximately one week before maturity (Figures 3 and 8). This level then decreases rapidly until it reaches a minimum at or before maturity. Miyamoto (72) found similar results when studying the percentage of water soluble and insoluble oxalates in sugar beet fruits at three stages of maturity. He reported that the fresher fruits (14 to 28 days after fertilization) contained nearly twice as much soluble oxalates compared to collections at 70 days after fertilization. The decrease in these water soluble oxalates in later stages of development was thought to be the action of rainwater on the sugar beet fruits. Snyder (95) has also observed that rain leaches soluble organic substances, as well as inorganic electrolytes from ripe sugar beet fruits.

It should be emphasized that even though these inhibitory substances may be detrimental to germination prior to maturity, they were of little consequence after maturity for all three years studied (Figure 3). This confirms previous conclusions (101) that the washing process used in germination testing was apparently effective in removing the soluble inhibitors prior to germination.

The maximum germination for the two varieties was approximately 85 percent in 1964 and 1965 and 90 percent in 1966. The percent germination remained relatively constant at these levels from maturity until the final collection for all three years (Figure 1). The principle factor which prevented germination from reaching its theoretical maximum of 100 percent was the occurrence of underdeveloped seeds. These underdeveloped seeds maintained a level of from five to 10 percent throughout all collections after maturity for the three years studied. Even though this was lower than previously reported (104, 105), it was rather high considering that the seeds removed at each collection were the first flowers to open on the plant and had adequate time for seed development. When seed was collected at various stages of maturity from an entire plant, as in 1965 (Figure 10), the percentage of underdeveloped seeds was much higher after maturation was reached (approximately 25 percent).

It was observed in 1965 and in 1966 that the percentage of underdeveloped seeds tended to increase slightly at the final maturity collections (Figures 2, 8, 10). Due to indeterminate flowering, it seemed possible that seed samples taken from all locations on an entire plant (1965, Figure 10) included more late flowering 'seeds' in the final collections. These 'seeds' may have developed after final application of insecticides or after adequate pollen sources were depleted. This could cause increased underdeveloped seeds due to Lygus bug injury or increased selfing from partially fertile female plants.

Effects of Harvesting Methods

Results of the simulated harvesting methods studied in 1965 leave little doubt that there was considerable development of seeds while drying on plants cut prior to maturity. The underdeveloped seeds were 20 percent higher for collections made directly from the plant at harvest compared to those taken from the windrow after two weeks of drying (Figure 8). It appeared that food materials from the windrowed plant must have been deposited in the sugar beet seeds during the drying process. Similar results have been reported by other investigators, especially on crops within the Gramineae family (27, 54, 63). It was also reported for these crops, however, that with increased seed development, a corresponding increase in seed germination occurred. The results of this study do not confirm this assumption for sugar beets, however, as there was little difference in sugar beet 'seed' germination between the two harvesting methods at all stages of development (Figure 7). The primary factor preventing a corresponding increase in sugar beet 'seed' germination with a decrease in underdeveloped seeds was the counteraction of inhibiting substances within the fruit as measured by firm ungerminated seeds. As the underdeveloped seeds were decreasing in the windrow, firm ungerminated seeds were increasing by the same method (Figure 8). Firm ungerminated seeds were consistently higher throughout the initial collections when harvested by the windrow method.

The speed of germination was much slower for the windrow method, even though percent germination was very similar to the direct method (Figure 7). One explanation for this may be that additional cementing substances from plant reserves were deposited between the tissues of fruit while drying in the windrow, creating a physical barrier to rapid germination. It also seems probable that additional inhibitory substances may be deposited from the plant while the 'seeds' are drying in the windrow. These substances, although not restricting germination, may act in delaying germination. The speed of germination rating has previously been utilized as a vigor index for crop seeds. The apparent dormancy encountered in the sugar beet seeds of this study demonstrates a fallacy which may occur when using this method as a vigor index. Unless care is taken seeds may be classified as less vigorous when they are actually dormant.

SUMMARY AND CONCLUSIONS

Maturation of monogerm sugar beet 'seed' was studied at three locations in the Willamette Valley of Oregon for three years, 1964, 1965 and 1966. Two hybrid varieties representing the extremes in resistance (hard bolting) and susceptibility (easy bolting) to seed-stalk development were compared.

The effects of stage of maturity on subsequent post harvest seed development and germination were studied at various intervals after anthesis for each year. Several quantitative measures of maturity were evaluated to determine the optimum stage to cut and harvest sugar beet fields for seed. The effects of harvesting procedures on seed maturity were compared using simulated direct and windrow methods.

Maturity based on maximum germination, and dry 'seed' weight was attained 45 days after anthesis in 1964, 40 days after anthesis in 1965 and 43 days after anthesis in 1966. It was concluded that maturity in monogerm sugar beet seed could be estimated on a field basis by determining the "peak" anthesis and then allowing approximately 45 days before harvesting.

Two factors, underdeveloped seeds and firm ungerminated seeds, can seriously reduce germination if 'seed' is harvested at premature stages of development. Underdeveloped seeds remained as the primary factor which prevented maximum germination even after seeds were mature.

Due to the high level of moisture attained by the fleshy sugar beet fruits, percent moisture content changed very little at various stages of maturity and was not found to be a reliable index of maturity.

Heat units accumulated, using the summation index method (45°F base), were approximately the same for all three years at seed maturation. This accumulation ranged from 835 to 870, even though the 1965 maturing season was much warmer than the other two years. It was concluded that sugar beet seed should have reached maturity by the time 900 heat units have accumulated.

When sugar beets were harvested by the simulated windrow method prior to maturity the seeds continued to develop while drying on the plants. This development did not result in higher germination however, since the windrowed seeds possessed more inhibitory substances then 'seeds' harvested by the simulated direct method. The levels at which maximum germination and dry 'seed' weight (maturation) occurred was very similar for the two harvesting methods.

Some sugar beet 'seeds' were capable of germination 20 days after anthesis in 1965, although this germination did not occur until 27 days in 1964.

Even though the hard bolting variety remained green throughout the summer, the 'seed' reached maturity approximately two days earlier than the easy bolting variety. Plant appearance was not considered to be a reliable index for estimating maturity, especially for hard bolting varieties.

It was concluded that maximum dry 'seed' weight, germination and heat unit accumulation were all reliable indices of sugar beet seed maturity. These quantitative measures can be combined with the time required from anthesis to maturity (45 days) to estimate harvesting time for sugar beet seed production.

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APPENDIX

Appendix Table 1. Common and scientific names of plants referred to in this thesis.

Common name	Scientific name (Genus, species, authority)
Alfalfa	Medicago sativa L.
Barley	Hordeum vulgare L.
Bean, Lima	Phaseolus limensis Macf.
Bromegrass, Smooth	Bromus inermis Leyss.
Carrot	Daucus carota L.
Clover, Red	Trifolium pratense L.
Clover, White	Trifolium repens L.
Corn	Zea mays L.
Cotton	Gossypium hirsutum L.
Muskmelon	Cucumis melo L.
Oats	Avena sativa L.
Pimiento (Pepper)	Capsicum annuum Irish
Radish	Raphanus sativus L.
Reed Canary Grass	Phalaris arundinacea L.
Roughpea	Lathyrus hirsutus L.
Rye	Secale cereale L.
Ryegrass, Italian	Lolium multiflorum Lam.
Ryegrass, Perennial	Lolium perenne L.
Safflower	Carthamus tinctorius L.
Sorghum	Sorghum vulgare Pers.
Timothy	Phleum pratense L.
Trefoil, Birdsfoot	Lotus corniculatus L.
Wheat	Triticum vulgare Vill. (aesitivum L.)
Wheatgrass, Crested	Agropyron desertorum (Fisch) Schult.
Wild Rye, Russian	Elymus junceus Fisch.

Appendix Table 2. Means of several maturity indicators for two varieties of sugar beets harvested at two-day intervals following first anthesis in 1964.[1]

Days after 1st anthesis	Percent germination			Percent underdeveloped seeds			Percent firm ungerminated seeds			Speed of germination			Heat unit accumulation (45°F base)	
	HB	EB	EB-C	HB	EB	EB-C	HB	EB	EB-C	HB	EB	EB-C	HB	EB & EB-C
31	4.0	0.8	2.2	78.5	85.2	61.0	15.0	10.5	34.0	0.6	0.1	0.3	580	576
33	16.5	10.5	11.2	48.5	64.0	45.0	33.0	23.0	42.5	2.5	1.3	1.7	612	624
35	23.0	15.2	24.2	41.0	49.5	32.0	30.5	34.0	37.5	3.4	2.1	3.7	656	656
37	43.5	19.0	30.5	15.2	28.0	21.0	36.5	49.0	37.0	6.9	2.9	5.0	696	696
39	52.5	47.0	57.0	7.2	11.7	16.0	34.0	27.7	24.7	7.7	6.7	10.8	743	738
41	62.2	48.2	57.2	8.7	16.0	15.2	21.5	21.7	21.7	11.7	8.4	10.6	806	779
43	78.7	62.7	54.2	5.5	6.0	13.5	7.5	12.7	26.2	14.5	12.1	10.7	853	836
45	84.5	83.5	77.7	5.2	3.0	7.5	5.7	3.5	5.7	18.7	16.3	16.7	910	888
47	83.5	79.7	85.2	6.7	5.2	7.2	2.5	2.0	4.0	18.7	17.2	18.8	952	945
49	84.5	80.0	81.0	5.7	6.7	7.2	1.2	3.0	8.0	19.2	18.4	18.0	989	987
51	86.0	80.0	83.5	7.5	5.7	6.5	2.2	1.7	3.2	20.3	17.2	20.3	1021	1024
53	88.2	79.2	82.0	4.5	5.0	8.2	2.2	3.0	3.2	20.7	16.7	19.6	1063	1056
55	85.5	74.5	84.5	6.0	7.2	4.7	2.0	3.5	4.0	20.0	16.6	20.9	1106	1098
57	90.0	77.2	81.0	6.2	4.5	8.0	1.0	1.7	3.2	19.7	18.0	19.2	1152	1145
59	89.2	80.0	(80.7)[2]	7.2	6.5	(6.0)	0.7	0.2	(2.2)	19.2	16.0	(18.8)	1203	1191
61	91.2	77.0	(83.5)	5.2	6.5	(7.2)	0.5	1.0	(1.2)	22.3	14.3	(20.2)	1249	1242
LSD_{05}	10.531			6.324			8.526			2.018				
LSD_{01}	13.922			8.359			11.269			2.666				

[1]HB = hard bolting variety (F62 $569H_3$) ms, EB = easy bolting variety (SL (126 x 128) ms) in east farm, EB-C = easy bolting variety but grown in commercial seed field.

[2]Brackets indicate that commercial easy bolting field was windrowed at 59 days after first anthesis (August 9, 1964).

Appendix Table 3. Mean squares of the four maturity variables measured for the easy bolting and hard bolting sugar beet varieties in 1964.

Source of variation	d. f.	Mean Squares			
		% Germination	% Under-developed seed	% Firm Un-germinated seed	Speed of germination
Varieties	2	1,404.48**	199.27**	282.42**	107.86**
Collections	15	10,093.49**	5,077.20**	2,394.26**	604.07**
V x C	30	75.03	107.21**	96.26	5.91**
Error	144	56.61	20.40	37.09	2.07
Total	191				

**Significant difference at 1% level.

Appendix Table 4. Simple correlation coefficients between two varieties of sugar beet for each of the variables measured for maturity in 1964.

Collections & Variables	Varieties Correlated[1]		
	HB to EB	HB to EB-C	EB to EB-C
First Eight Collections[2]			
Percent germination	.964**	.953**	.966**
Percent underdeveloped seed	.985**	.986**	.989**
Percent firm ungerminated seed	.868**	.667	.598
Speed of germination	.984**	.949**	.957**
All 13 Collections[3]			
Percent germination	.979**	.973**	.982**
Percent underdeveloped seed	.985**	.975**	.987**
Percent firm ungerminated seed	.941**	.886**	.837**
Speed of germination	.972**	.979**	.967**

[1] HB=hard bolting; EB=easy bolting in experimental farm; EB-C = easy bolting in commercial field.

[2] Values of r necessary for significance for first eight collections are: 0.666 at 5% level (*) and 0.798 at 1% level (**).

[3] Values of r necessary for significance for all collections are: 0.497 at 5% level (*) and 0.623 at at 1% level (**).

Appendix 5. Simple correlation coefficients between all maturity indicators for two varieties of sugar beets in 1964. [1]

Varieties & Variables	Germ.	Under.	Firm	U + F	S.G.	H.U.
Hard bolting						
% germination		-.899**	-.792**	-.998**	.979**	.901**
% underdeveloped	-.912**		.450	.911**	-.813**	-.705**
% firm	-.510	.115		.778**	-.864**	-.829**
% under + % firm	-.999**	.918**	.499		-.971**	-.878**
Speed of germination	.978**	-.826**	-.625	-.970**		.933**
Heat units	.989**	-.860**	-.592	-.986**	.993**	
Easy bolting						
% germination		-.913**	-.762**	-.995**	.983**	.879**
% underdeveloped	-.898**		.446	.927**	-.861**	-.767**
% firm	-.477	.603		.749**	-.799**	-.742**
% under + % firm	-.993**	.912**	.464		-.972**	-.880**
Speed of germination	.990**	-.852**	-.538	-.977**		.876**
Heat units	.981**	-.921**	-.392	-.979**	.980**	
Easy bolting comm.						
% germination		-.943**	-.951**	-.995**	.988**	.892**
% underdeveloped	-.934**		.809**	.954**	-.898**	-.804**
% firm	-.886**	.683*		.948**	-.975**	-.921**
% under + % firm	-.993**	.951**	.875**		-.923**	-.906**
Speed of germination	.993**	-.897**	-.923**	-.985**		.929**
Heat units	.959**	-.899**	-.868**	-.963**	.965**	

[1] r values above diagonal for all collections. r values below diagonal for first eight collections after initial anthesis. Values of r necessary for significance above diagonal are: 0.497 at 5% level (*) and 0.623 at 1% level (**). Values of r necessary for significance below diagonal are: 0.666 at 5% level (*) and 0.798 at 1% level (**).

Appendix Table 6. Means of several maturity indicators for two varieties of sugar beets harvested by two methods at three-day intervals following first anthesis in 1965.

Days after 1st anthesis	Percent germination		Percent underdeveloped seeds		Percent firm ungerm. seeds		Speed of germination		Seed weight (mg)		Heat unit accumulation (45°F Base)	Percent moisture content
	Direct	Windrow	Direct	Windrow	Direct	Windrow	Direct	Windrow	Direct	Windrow		
Hard bolting												
29	33.0	41.5	47.0	20.5	7.5	30.5	4.2	5.6	80	83	613	82.1
32	30.0	28.5	33.5	15.0	36.0	56.0	5.2	2.7	83	105	670	77.9
35	68.0	75.0	27.5	18.5	3.0	5.5	15.5	10.8	109	98	753	75.0
38	80.5	85.5	16.5	8.0	3.0	5.5	15.5	12.5	158	150	827	74.8
41	83.0	78.5	11.5	10.0	4.5	8.0	16.0	11.9	142	159	896	70.9
44	85.0	84.0	10.5	5.5	4.0	6.0	16.2	13.2	163	160	967	67.7
47	92.0	85.5	6.5	5.0	1.5	5.0	19.2	12.5	153	170	1044	71.6
50	82.0	86.0	7.0	4.5	5.5	6.0	11.4	11.0	159	162	1108	68.6
53	83.0	83.0	10.0	14.0	0.0	0.5	13.8	13.4	156	134	1183	65.1
56	89.0	83.5	9.5	8.5	0.5	0.5	14.8	14.7	144	143	1244	65.6
59	79.5	84.5	7.5	5.5	3.5	1.5	12.5	12.8	181	148	1315	66.0
62	84.5	88.5	7.0	6.5	0.0	1.0	13.6	12.7	160	176	1378	65.3
65	81.0	83.5	8.5	10.0	2.5	1.5	15.4	16.3	174	157	1428	55.7
LSD_{05}	8.454		7.414		5.944		2.374		18.370			
LSD_{01}	11.174		9.798		7.856		3.138		24.283			
Easy bolting												
28	38.0	39.0	48.0	22.5	7.5	28.5	5.6	4.1	80	84	562	81.8
31	32.5	37.0	51.0	29.0	12.5	26.0	4.7	4.9	81	88	641	82.5
34	63.0	49.0	18.0	23.5	14.0	21.0	10.3	6.7	75	76	698	80.9
37	69.0	61.0	21.0	28.5	3.0	8.5	10.9	5.9	97	81	781	80.3
40	87.0	83.0	6.0	3.0	3.5	6.0	14.8	10.7	123	140	855	79.2
43	79.0	85.0	14.5	5.0	1.5	6.5	12.6	10.4	126	139	924	74.0
46	73.0	79.0	19.0	10.0	2.0	4.0	11.7	9.0	144	133	995	71.8
49	80.0	83.0	10.5	9.5	6.5	3.0	11.6	9.0	139	143	1071	71.4
52	83.5	83.0	6.0	8.0	5.0	4.0	12.3	10.8	129	110	1135	70.2
55	81.5	87.5	8.0	6.5	1.5	1.5	11.4	10.7	131	142	1210	65.5
58	85.5	84.0	10.5	10.5	3.5	2.0	15.2	16.5	139	113	1271	58.5
61	90.5	85.5	3.5	8.5	2.5	2.5	16.7	13.3	162	143	1342	66.0
64	77.5	77.0	15.0	12.0	0.5	0.5	13.8	12.5	145	127	1405	62.0
LSD_{05}	8.454		7.414		5.944		2.374		18.370			
LSD_{01}	11.174		9.798		7.856		3.138		24.283			

Appendix Table 7. Mean squares of five maturity variables measured for both the hard bolting and easy bolting sugar beet varieties in 1965.

		Variables				
Source of variation	d. f.	Percent germination	Percent undeveloped seeds	Percent firm ungerminated seeds	Speed at germination	Dry seed weight
Varieties	1	140.58**	102.48**	8.89	171.01**	17,368.61**
Method	1	1.74	300.48**	222.24**	194.23**	8.65
Collections	12	1,329.84**	365.99**	324.28**	174.61**	6,490.82**
V x M	1	11.54	4.92	0.39	1.11	162.50
V x C	12	57.15*	42.65*	76.51**	31.47**	578.95**
M x C	12	6.58	74.44**	51.42**	13.62*	295.82**
V x M x C	12	23.68	12.53	2.18	4.54	128.75**
Error	156	9.12	7.01	4.50	2.88	86.11
Total	207					

*Significant difference at 5% level.

**Significant difference at 1% level.

Appendix Table 8. Simple correlation coefficients between the two varieties and two methods for each maturity indicator measured in 1965.

Collection & Variables	Variety & Method Correlated[1]			
	HB - Direct / EB - Direct	HB - Windrow / EB - Windrow	HB - Direct / HB - Windrow	EB - Direct / EB - Windrow
First five collections[2]				
% Germination	.965**	.764	.976**	.953*
% Underdeveloped seeds	.862	.207	.863	.633
% Firm ungerm. seeds	.473	.703	.932*	.729
Speed of germination	.913*	.645	.946*	.907*
Seed weight	.704	.643	.909*	.901*
% Moisture content	.837	.837	---	---
All 13 collections[3]				
% Germination	.927**	.848**	.970**	.945**
% Underdeveloped seeds	.873**	.556	.854**	.763**
% Firm ungerm. seeds	.592*	.808**	.937**	.804**
Speed of germination	.689*	.695*	.824**	.872**
Seed weight	.868**	.787**	.930**	.861**
% Moisture content	.843**	.843**	---	---

[1] HB = hard bolting variety and EB = easy bolting variety. Direct = simulated direct harvesting and Windrow = simulated windrow harvesting.

[2] Values of r necessary for significance for first five collections are: 0.878 at 5% level (*) and 0.959 at 1% level.(**).

[3] Values of r necessary for significance for all 13 collections are: 0.553 at 5% level (*) and 0.684 at 1% level.(**).

Appendix Table 9. Simple correlation coefficients between the maturity indicators evaluated for two sugar beet varieties and two harvesting methods for the first five collections after first anthesis in 1965.[1]

Varieties & Variables	Germ.	Under.	Firm	U + F	S. G.	Seed wt.	% M. C.	H. U.
Hard bolting								
% Germination		-.579	-.962**	-.993**	.997**	.688	-.749	.831
% Underdeveloped seeds	-.900**		.355	.535	-.558	-.949*	.706	-.829
% Firm ungerm. seeds	-.709	.342		.980**	-.972**	-.507	.610	-.687
% Under. + % firm ungerm.	-.982**	.819	.819		-.998**	-.662	.702	-.799
Speed of germ.	.974**	-.874	-.659	-.935*		.686	-.741	.829
Seed weight	.937*	-.907*	-.580	-.906*	.865		-.836	.939*
% Moisture content	-.868	.962**	.326	.787	-.880*	-.788		-.960**
Heat units	.932*	-.989**	-.444	-.875	.889*	.918*	-.960*	
Easy bolting								
% Germination		-.796	-.936*	-.987**	.926*	.800	-.969**	.936*
% Underdeveloped seeds	-.983**		.534	.881*	-.879*	-.927*	.735	-.571
% Firm ungerm. seeds	-.572	.420		.870	-.783	-.594	.920*	-.976**
% Under. + % firm ungerm.	-.998**	.979**	.597		-.950*	-.872	.943*	-.878*
Speed of germ.	.998**	-.984**	-.545	-.993**		.859	-.871	.859
Seed weight	.785	-.670	-.783	-.769	.789		-.660	.620
% Moisture content	-.988**	.948*	.670	.989**	-.985**	-.833		-.911*
Heat units	.941*	-.908*	-.573	-.932*	.935*	.824	-.911*	

[1] r values above diagonal for simulated windrow harvesting method. r values below diagonal for simulated direct harvesting method. Values of r necessary for significance are: 0.878 at 5% level (*) and 0.959 at 1% level (**).

Appendix Table 10. Simple correlation coefficients between the maturity indicators evaluated for two sugar beet varieties and two harvesting methods for all collections in 1965.[1]

	Germ.	Under.	Firm	U + F	S. G.	Seed wt.	% M. C.	H. U.
Hard bolting								
% Germination		-.698**	-.964**	-.991**	.922**	.748**	-.680*	.694*
% Underdeveloped seeds	-.925**		.519	.706**	-.567*	-.848**	.537	-.620*
% Firm ungerm. seeds	-.770**	.541		.972**	-.935**	-.611*	.662*	-.675*
% Under. + % firm ungerm.	-.976**	.913**	.837**		-.931**	-.740**	.696**	-.731**
Speed of germ.	.896**	-.755**	-.669*	-.816**		.690**	-.824**	.770**
Seed weight	.866**	-.893**	-.644*	-.892**	.679**		-.718**	.760**
% Moisture content	-.690**	.798**	.473	.748**	-.522	-.727**		-.930**
Heat units	.689**	-.812**	-.516	-.777**	.441	.788**	-.930**	
Easy bolting								
% Germination		-.902**	-.951**	-.991**	.816**	.859**	-.726**	.805**
% Underdeveloped seeds	-.982**		.753**	.931**	-.731**	-.897**	.592*	-.649*
% Firm ungerm. seeds	-.675*	.560*		.941**	-.802**	-.769**	.777**	-.869**
% Under. + % firm ungerm.	-.993**	.981**	.712**		-.820**	-.887**	.734**	-.815**
Speed of germ.	.949**	-.912**	-.649*	-.927**		.634*	-.896**	.880**
Seed weight	.817**	-.739**	-.770**	-.809**	.809**		-.571*	.668*
% Moisture content	-.671*	.607*	.618*	.661*	-.682*	-.816**		-.948**
Heat units	.779**	-.734**	-.670*	-.781**	.781**	.899**	-.948**	

[1] r values above the diagonal are for simulated windrow harvesting method. r values below the diagonal are for simulated direct harvesting method. Values of r necessary for significance are 0.553 at 5% level (*) and 0.684 at 1% level (**).

Appendix Table 11. Mean values of several maturity indicators for two sugar beet varieties when harvested by two methods from all locations on a plant at three-day intervals following "peak" anthesis in 1965.

Days after "peak" anthesis	Percent germination		Percent underdeveloped seeds		Percent firm ungerminated seeds		Speed of germination		Heat unit accumulation ($45^{o}F$ base)	Percent moisture content
	Direct	Windrow	Direct	Windrow	Direct	Windrow	Direct	Windrow		
Hard bolting										
22	0.5	23.7	97.0	61.1	2.5	13.1	0.1	2.9	410	82.1
25	5.0	14.7	88.5	70.5	2.5	11.0	0.7	1.2	491	77.9
28	23.0	49.0	64.0	35.2	12.3	11.2	3.6	5.5	552	75.0
31	46.0	46.2	47.5	37.0	4.0	7.0	8.7	5.7	643	74.8
34	51.2	50.5	41.7	30.2	2.7	12.5	9.8	5.8	707	70.9
37	69.5	57.2	24.0	24.2	2.5	16.2	12.1	7.4	780	67.7
40	72.2	66.0	22.2	20.5	2.2	12.2	14.1	7.9	851	71.6
43	72.7	77.0	21.0	20.5	3.2	1.7	12.6	9.9	922	68.6
46	83.5	75.7	13.5	12.0	0.2	8.5	17.2	12.4	990	65.1
49	76.5	79.5	19.7	17.2	3.2	2.2	16.9	15.7	1060	65.6
52	74.0	68.5	13.2	20.5	2.7	2.0	14.6	11.0	1123	66.0
55	69.0	60.7	21.5	34.5	0.7	1.0	13.6	10.9	1195	65.3
58	57.5	63.2	37.0	31.5	1.0	1.0	12.1	11.7	1256	55.7
Easy bolting										
20	7.0	14.2	86.5	66.0	4.0	9.5	1.0	1.4	416	81.8
23	4.3	17.7	79.5	64.0	12.0	10.0	0.7	1.9	495	82.5
26	3.2	11.2	86.5	69.5	9.0	13.5	0.6	0.7	552	80.9
29	23.2	40.5	70.3	44.5	3.0	10.0	3.6	4.0	635	80.3
32	35.7	28.5	53.0	35.0	9.2	27.0	4.7	2.8	709	79.2
35	36.7	44.5	55.5	38.0	3.5	9.2	6.7	5.2	778	74.0
38	37.5	36.7	58.0	41.0	3.5	17.0	4.9	2.6	849	71.8
41	61.7	58.2	32.0	24.0	4.5	13.2	9.2	6.4	926	71.4
44	66.7	71.0	22.7	24.7	4.0	3.5	10.0	8.8	990	70.2
47	71.0	68.7	24.2	23.0	1.0	2.5	12.0	8.6	1065	65.5
50	65.7	51.2	26.5	38.5	2.2	5.5	9.2	6.1	1126	58.8
53	58.5	60.7	33.5	29.2	1.2	8.2	11.5	10.3	1197	66.0
56	48.7	67.2	44.2	27.0	0.7	1.7	9.2	11.8	1260	62.0

Appendix Table 12. Simple correlation coefficients between two sugar beet varieties and two methods for the first eight collections after "peak" anthesis for each variable measured in 1965.[1]

	Variety and Method			
Variables	HB - Windrow / EB - Windrow	HB - Direct / EB - Direct	HB - Windrow / HB - Direct	EB - Windrow / EB - Direct
% Germination	.769*	.897**	.919**	.920**
% Underdeveloped seeds	.759*	.843**	.947**	.970**
% Firm ungerminated seeds	.593	.295	-.569	.297
Speed of germination	.715*	.869**	.989**	.925**
% Moisture content	.796*	.796*		

[1] Values of r necessary for significance are: 0.707 at 5% level (*) and 0.834 at 1% level (**).

Appendix Table 13. Simple correlation coefficients between several maturity indicators evaluated for two varieties and two harvesting methods for the first eight collections after "peak" anthesis in 1965.[1]

Varieties & Variables	Germ.	Under.	Firm	U + F	S. G.	% M.C.	H.U.
Hard bolting							
% Germination		-.969**	-.378	-.989**	.993**	-.847**	.933**
% Underdeveloped seeds	-.995**		.187	.976**	-.955**	.872**	-.894**
% Firm ungerminated seeds	-.243	.155		.395	-.387	.151	-.348
% Under. + % firm ungerm.	-.999**	.994**	.264		-.978**	.848**	-.912**
Speed of germination	.995**	-.986**	-.280	-.994**		-.842**	.932**
% Moisture content	-.926**	.943**	.107	.933**	-.896**		-.909**
Heat units	.973**	-.968**	-.242	-.973**	.962**	-.909**	
Easy bolting							
% Germination		-.923**	-.176	-.993**	.964**	-.813*	.873**
% Underdeveloped seeds	-.985**		-.369	.932**	-.871**	.789*	-.901**
% Firm ungerminated seeds	-.464	.316		-.799*	-.976**	-.129	.308
% Under. + % firm ungerm.	-.998**	.987**	.464		-.975**	.798*	-.849**
Speed of germination	.982**	-.968**	-.499	-.988**		-.706*	.763*
% Moisture content	-.876**	.829*	.548	.866**	-.875**		-.942**
Heat units	.936**	-.915**	-.433	-.928**	.920**	-.942**	

1 r values above diagonal for simulated windrow harvesting method. r values below diagonal for simulated direct harvesting method. Values of r necessary for significance are: 0.707 at the 5% level (*) and 0.834 at the 1% level (**).

Appendix Table 14. Mean values of several maturity indicators for a hard bolting sugar beet variety harvested at four-day intervals following first anthesis in 1966.

Days after first anthesis	Percent germination	Percent underdeveloped seed	Percent firm ungerminated seeds	Speed of germination	Seed weight (mg)	Heat unit accumulation (45°F base)	Percent moisture content
39	75.0	11.5	10.0	15.3	75	732	71.4
43	89.5	5.5	4.5	19.8	82	832	70.4
47	93.0	6.0	0.5	21.6	96	936	66.7
51	93.0	5.5	1.0	21.1	112	1032	61.9
55	92.5	4.5	0.8	20.3	105	1118	58.3
59	(94.5)[1]	(3.5)	(0.5)	(22.1)	(100)	(1212)	(10.5)
63	(88.5)	(8.0)	(0.0)	(19.6)	(97)	(1309)	(11.3)
LSD 05	8.17	6.14	4.25	2.70	11.04		
LSD 01	11.12	8.36	5.79	3.99	16.33		

[1] Brackets indicate that commercial field was windrowed at 57 days after first anthesis.

Appendix Table 15. Simple correlation coefficients between several maturity indicators for all collections of the hard bolting variety in 1966.[1]

Variable	Under.	Firm	U + F	S. G.	Seed wt.	M. C.	H. U.
% Germination	-.938**	-.917**	-.985**	.985**	.787*	-.315	.591
% Underdeveloped seeds		.759*	.913**	-.910**	-.666	.255	-.476
% Firm ungerminated seeds			.959**	-.901**	-.836*	.519	-.802*
% Under. + % firm ungerm.				-.962**	-.815*	.436	-.713
Speed of germination					.756*	-.353	.570
Seed weight						-.319	.681
% Moisture content							-.869*

[1] Values of r necessary for significance are: 0.754 at 5% level (*) and 0.874 at 1% level (**).