COMPARISON OF SPRING AND SUMMER SOWING OF SUGAR BEET GENOTYPES AT DIFFERENT HARVEST DATES TO SHIFT FROM TRADITIONAL CROP TO CASH CROP IN CENTRAL IRAN

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ABSTRACT

This study was carried out in Karaj, Iran in 2017 and 2018 to assess the efficacy of summer sowing (June 22) versus spring sowing (April 20) of six sugar beet genotypes at three harvest times (October 13, November 2, and November 23) via the measurement of catalase (CAT), malondialdehyde (MDA), and agronomic traits. Results showed that in both sowing dates, higher growth and temperature were related to higher CAT activity and MDA content, and the maximum MDA and CAT activity were observed in 1700−1900 growth degree days (GDD). Genotypes responded to the shortening of the growth period differently. The best genotypes for summer sowing were found to be 'Paya', 'IR7', and 'Pars' when a combination of the least response to delayed sowing and the highest root yield in the summer sowing conditions was considered. Compared to the spring sowing, the summer sowing decreased white sugar yield (WSY) of all cultivars by 28.3−50.5% in the first year and 5.3−32.4% in the second year. 'Paya' and 'IR7' were the most capable cultivars in preserving WSY so that they maintained 70% of their yields. In addition, the genotypes exhibited their highest WSY at the November 23 harvest date so that root, raw sugar and white sugar yields were 41.21, 6.35 and 5.02 t ha^{-1} higher at the November 23 harvest date than at the October 13 harvest date, respectively. Based on the results, if summer-sown sugar beets are considered as a cash crop in rotation with grains and there is no limitation on water supply, it can then be recommended to farmers as it can make good profits for them.

Key words: CAT, MDA, root yield, sugar yield, WUE.

مقارنة بين الزراعة الربيعية والصيفية ومواعيد الحصاد لتراكيب وراثية من البنجر السكري للتحول من المحصول التقليدي الى الى المحصول النقدي

هداية فاهدي بهرام ميرشكاوي سعيد صادق زاده أزهر رجبي مهرداد يارنيا
باحث استاذ استاذ مشارك استاذ مشارك استاذ

المستخلص

نفذت هذه الدراسة في كراجي ايران في الموسميين 2017 و 2018 لتقييم الزراعة الصيفية في 22 حزيران والزراعة الربيعية 20 نيسان لستة تراكيب وراثية من البنجر السكري و ثلاثة مواعيد حصاد (13تشرين اول و 2 تشرين ثاني و 23 تشرين ثاني لحساب الكتلاز (CAT) و مالديالديهايد (MDA) وبعض الصفات الحقلية . اظهرت النتائج بالنمو الخضري الكثيف ودرجات الحرارة العالية ادت الى زيادة نشاط CAT و كمية MDA . و القيمة العالية لها كانت عن 1700−1900 عند درجة النمو اليومي (GDD). استجابت التراكيب الوراثية الى فترات نمو خضري مختلفة . افضل التراكيب الوراثية للموسم الصيفي كانت Paya', 'IR7', 'Pars' . كانت نسبة السكر الابيض (WSY) لجميع التراكيب الوراثية في الموسم الربيعي اقل من الخريفي 28.3 − 50.5 % في السنة الاولى و 5.3 − 32.4 % في السنة الثانية . تفوق التركيبين الوراثين 'Paya و IR7 في نسبة (WSY) وانتجت 70 % من الحاصل . اضافة الى ذلك انتجت التراكيب الوراثية نسبة سكر عالي في 23 تشرين ثاني بسبب تفوقها في حاصل الجذور السكر الخام وحاصل السكر الابيض. بناء على نتائج الدراسة الزراعة الصيفية مع الدورة الزراعية مع الحبون تعد المصول النقدي.

كلمات مفتاحية: السكر الخام، السكر الابيض، حاصل الجذور، الدورة الزراعية

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INTRODUCTION

Temperature rise has influenced crop production all around the world by increasing drought frequency, but some parts of Africa and the Middle East are especially at risk (38, 43). Vegetation cover in countries like Iran has been influenced by climate change and the resulting summer heat waves and droughts, without the possibility to shift crop cultivation to other parts of the year effectively (7, 11, 31). Most regions utilize a wide range of adaptive measures in agronomy (e.g. irrigation, nutrition, tillage methods, and so on) to alleviate the adverse impacts of climate change on crop production. Sowing date adjustment is a strategy in focus that can play a significant role in accommodating crops and mitigating the negative effects of climate change (3, 21, 49). It has been hypothesized that yield potential is influenced by the length of radiation absorption period, photosynthesis rate, and total evapotranspiration so that increasing this period will contribute to increasing crop yield (5, 16). For any changes in sowing dates, crop water use efficiency should be first measured (8; 34). Like many other crops, sugar beet is well fitted in rotations with other crops, and various methods have been proposed to reduce water use in sugar beet cultivation. Examples include developing drought-tolerant cultivars (49), selection for yield and secondary traits (8, 29), deficit irrigation (25, 28), and plant selection and breeding approaches to achieving genotypes with shorter growth period (8, 17). However, these cultivars inhibit crop yield loss by late-season stresses (34). These cultivars cannot be recommended for regions with a long growth period. So, breeding programs had better focus on cultivars with a flexible growth period than early-maturing cultivars by considering the environmental conditions (2, 41, 44). Also, many researchers have proposed to change the sowing date to escape from drought at sensitive growth stages, which is root swelling in sugar beets. A negative impact of stress in all plants is the increased synthesis of reactive oxygen species (ROS), which degrades DNA, lipids, proteins, and other biomolecules (48). The products of the biodegradation caused by the peroxidation of lipids and amino acids are malondialdehyde (MDA) and dityrosine, respectively. So, these two compounds are commonly measured as biomarkers of degradation by heat and drought stress. In normal conditions, cells have an efficient and adequate antioxidant defensive system against ROS. Antioxidant enzymes play a critical role in the adaptability and survival of plants during stress (49). In stressful conditions, ROS synthesis, however, outweighs the plants' capability to handle them and this causes oxidative damages and has negative impacts on plant growth and yield (39). In addition, heat and drought in sugar beets reduce root yield, raw sugar, and sugar yield and increases α-amino significantly, but they have a very slight impact on sodium and calcium (although root sodium content increases and sugar percentage decreases by extensive irrigation). On the other hand, farmers are highly willing to maximally use land and radiation by sowing an early-maturing plant that is adaptive to deficit irrigation and produces adequate yield (as intermediate summer sowing) between two consecutive autumn crops (11). The intermediate summer sowing between two autumn crops (e.g. wheat, barley, and canola) as a cash crop is prevailing in many parts of Iran. In summer sowing, crop yields decline as growth period shortens. But, this yield loss has been partially controlled in recent years by the introduction of early-maturing cultivars. However, the summer sowing of many economically valuable plants, like sugar beets, still needs to be studied (44). So, although it is assumed that the summer sowing of sugar beets reduces water use owing to the shortening of the period in which irrigation is required, it is predicted that the crop yield may decline because early harvest of sugar beets in cold temperate regions is a major factor responsible for the loss of their yield and sugar content (33). The issue of crop yield and quality decline is a critical point in deciding on the use of this approach to decreasing water use because the final crop is harvested at the end of the growing season and the distinction between different sugar beet cultivars during the growing season is not precisely revealed for the improvement of sound crop management. Thus, the present study aims to compare the intensity of heat-induced oxidative damage and root biomass accumulation trend in spring and summer sowing and to assess the efficacy of summer sowing, water use efficiency, and yield and quality of sugar beet cultivars in different sowing dates in a cold temperate region of Iran.

MATERIALS AND METHODS

Experimental site and plant growth conditions: The field experiment was conducted on clay-loam soil at the Motahari Sugar Beet Research Station, Karaj, Iran as a factorial arrangement based on randomized complete block design with four replications during 2017−2018. The area is located at latitude 35°59' N and longitude 51°6' E with an altitude of 1312 m above the sea level. To simplify the comparison of the growing season weather, the monthly total precipitation and temperature were considered from March to December at the Karaj Agricultural Research Farm (Figure 1). To determine soil characteristics, soil sampling was performed before the experiment. To do this, field soil sampling was done from the depth of 0−30 cm at eight spots. Then, the collected samples were sent to the laboratory to determine soil texture and chemical composition. Properties of experimental soil samples are given in Table 1.

Experimental treatments and soil preparation: A factorial experiment was applied based on randomized complete block design (RCBD) with four replication, it involved sugar beet cultivars and sowing and harvesting dates with four replications. The six sugar beet cultivars from Betaseed included 'IR7' (G1), 'Pars' (G2), 'Paya' (G3), 'Jolgeh' (G4), '261*276.P.77.SP.19' (G5), and '(7112*261)*5RR-87-HF.33' (G6). These cultivars were selected based on their disease tolerances, resistance to bolting, high yield potential, and suitability for energy beet production (personal communication, Steve Libsack). There were two sowing dates: spring (April 20, 2017 and April 23, 2018) and summer (Jun 22, 2017 and Jun 25, 2018). Harvesting dates included October 13 (H1), November 2 (H2) and November 23 (H3). To prepare the seedbed, the soil was disked followed by rotary tillage. Each plot included 6 sowing rows of 8 m length and 50 cm spacing. At the harvesting time, after removing the first and 6^{th} rows of each plot and 0.5 m from both ends of each row, an area of 14 m^2 was harvested. Fertilization included a pre-plant application of 82 kg ha^{-1} N (as urea), 37 kg ha^{-1} P (as triple superphosphate), and 56 kg ha^{-1} K (as Potassium sulfate) and again at 4−6 weeks after sowing, which varied due to the weather conditions and early season growth patterns of the sugar beets among site-years.

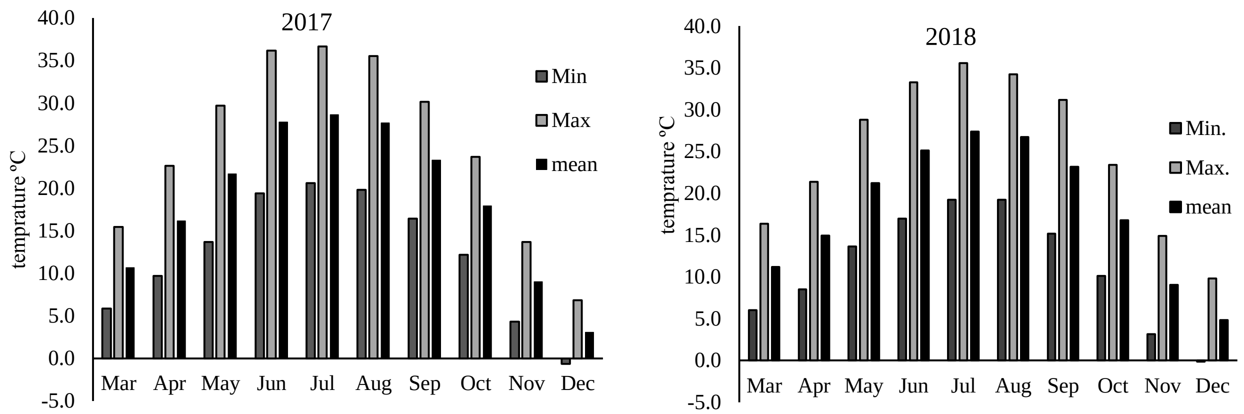

Figure 1. Monthly precipitation and temperature from April to December for the growing season (2017–2018) at the Motahari Sugar Beet Research Station, Karaj, Iran

Table 1. Physical and chemical characteristics of the soil during the two−year study

Year	Depth (cm)	Ammonia N	Nitrate N	P	K	pH	EC	OC	Clay	Silt	Sand	texture	Na	Ca	Mg
		(mg kg^{-1})					(dS m^{-1})	(%)					(meq L^{-1})	(mg kg^{-1})	
2017	0−30	8.29	30.5	28.3	563	7.7	1.1	1.3	32.8	40.6	26.5	C.L	8.48	3.08	4.01
	30−60	8.4	18.3	16.4	895	7.8	1.65	1.5	23.3	51.3	25.4	Si.l	38.2	5.9	5.3
2018	0−30	6.75	12.3	20.5	620	7.8	1.71	1.34	27.6	45.6	26.6	C.L	7.13	7.84	6.54
	30−60	6.44	9.4	18.2	649	7.8	1.34	1.37	36.6	41	22.4	C.L	6.56	4.88	5.6

After sowing, irrigations were performed normally until the 4−leaf stage. Then, a Class−A evaporation pan was mounted and the irrigations were performed with the schedule provided in Tables 2 and 3 based on 90 mm of evaporation. A WSC−flume type IV was mounted at the entrance of water into the farm and a WSC−flume type III was mounted at its exit and Eq. (1) and (2) were used to calculate water quantity.

$$Q = 0.00372 \times H^{2.63} : \text{III flume type} \quad (1)$$

$$Q = 0.0294 \times H^{2.102} : \text{IV flume type} \quad (2)$$

in which Q denotes the quantity of water flowing into the farm and H denotes water height in the WSC−flume (cm). Water use efficiency (WUE) was calculated by Eq. (3).

$$WUE = \frac{SY}{WU} \quad (3)$$

in which SY denotes sugar yield (g) and WU denotes the quantity of water use (m^3) (14).

Root growth trend

To take care of the marginal effect, plants were sampled from the middle of the plots. One month after emergence, to check the trend of the root growth, the plants were harvested and after removing their roots and leaves, their fresh and dry weights were recorded. The measurement times, presented in Table 3, were based on the growing degree day (GDD), which is calculated by minimum daily temperature T_{min}, maximum daily temperature T_{max}, and base temperature T_b of the plant growth. The numerical value of GDD expresses the thermal efficiency of the growth days in plant evolution (6). We calculated GDD using Eq. (4) based on the daily accumulation from the first irrigation (i) until the harvest time (n) assuming a base temperature of 3°C (27):

$$GDD = \sum_{i=1}^{n} \left[\frac{T_{\max} + T_{\min}}{2} \right] - T_b \quad (4)$$

in which if T_{max} was greater than 30°C, it would be assumed to be 30°C and if T_{min} was lower than 2°C, it would be set at 3°C.

Catalase (CAT) and malondialdehyde (MDA) calculations

CAT and MDA were measured in five steps according to Table 3 from the second to sixth sampling steps.

Catalase (CAT) activity measurement. The 200 µl reaction mixtures containing 100 mM phosphate buffer (pH 7.2), 100 mM H_2O_2, and 50 µl of the sample were used. Reduction of H_2O_2 was monitored by reading the absorbance at 240 nm for 3 min. The specific activity was detected by using the molar extinction coefficient of 36 M^{-1} cm^{-1}. The CAT activity was expressed as µmol of H_2O_2 oxidized per mg of protein per minute at 25° C (Aebi, 1984).

Malondialdehyde (MDA) measurement. For measurement of MDA, 0.2 g fresh leaf tissues were ground in 5 ml of 0.1% TCA. After centrifuging at 4,000 rpm for 20 min, 2.5 ml 0.5% thiobarbituric acid (TBA) in 20% TCA were added to the supernatants. Extracts were incubated in a water bath at 95° C for 30 min and immediately cooled in ice. Afterwards, all samples were centrifuged at 4,000 rpm for 30 min and the absorbance was measured at 532 nm and 600 nm. The MDA concentration was calculated by subtracting the non-specific absorption at 600 nm from the absorption at 532 nm using an absorbance extinction coefficient of 155 mM^{-1} cm^{1} (36). At harvest time, plants from an area of 1 m^2 were sampled after removing 0.5 m from both ends of the plots and two borderline rows to account for the marginal effect. The samples were, then, placed in plastic bags immediately and were sent to the plant physiology laboratory of Sugar Beet Seed Institute to record their traits. In the laboratory, different parts of the plants (including leaves, crowns, and roots) were separated and their fresh and dry weights (after oven-drying at 105 °C for 24 h) were determined (28). After the roots were rinsed in the laboratory, an automatic device was used to prepare root pulp. Then, 26 g of the pulp was mixed with 177 ml of dilute lead acetate solution to get a transparent extract. All these operations were performed in a Venema G_2. The infiltrated extract was poured into specific glasses and was sucked into the sugar beet quality analysis device (Betalyzer) by a sucker and its sugar percentage was determined. Sugar percentage was determined by polarimetry, sodium (Na) and Potassium (K) content by flame-photometry, and amino-nitrogen (amino-N) by spectrophotometry. After the values were determined, white sugar content, raw sugar yield, and white sugar yield were calculated with the method of Reinfeld et al. (1974):

MS = 0.343 (Na +K) + 0.09 (α-amino-N) – 0.31

WSC = SC – MS

RSY = SC × RY

WSY = WSC × RY

Table 2. Irrigation scheduling in spring and summer cultivation in during plant growth at 2017 and 2018

2017	Spring sowing	4/21	4/29	5/17	6/3	6/17	7/1	7/14	8/1	8/11	9/4	9/26
	Summer sowing	6/23	6/3	6/14	8/1	8/11	9/4	9/26				
2018	Spring sowing	4/27	5/3	5/23	6/14	6/25	7/10	7/23	8/7	8/18	9/8	10/3
	Summer sowing	6/23	6/30	7/14	8/1	8/11	9/4	9/26				

Table 3. Sampling time under spring and summer sowing in plant growth based on days after planting (DAP) and GDD

Order of sampling	DAP (day)				GDD (◦C)			
Year	2017		2018		2017		2018	
Sowing time	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
1	35	29	30	27	537	592	470	454
2	70	61	64	54	1242	1239	1114	1017
3	97	86	92	81	1802	1725	1698	1568
4	134	92	131	96	2549	1823	2499	1858
5	175	112	166	109	3268	2151	3120	2047
6	195	132	190	133	3487	2370	3399	2326
7	216	153	210	153	3603	2486	3557	2484

in which WSC represents white sugar content (%), SC represents sugar content of the roots (%), RSY denotes raw sugar yield or white sugar yield (t ha^{-1}), RY shows root yield (t ha^{-1}), and WSY denotes white sugar yield (t ha^{-1}).

Statistical analyses

An analysis of variance (ANOVA) was carried out in the SAS9.3 software package (SAS Institute Inc., Cary, NC) using the ANOVA procedure. The table of ANOVA includes the simple and interactive effects of sowing date, harvest date, and beet cultivars. Wherever the interaction of the factors was significant, the results were presented for the interactive effects, and the simple effects of the factors were ignored. Means were compared by the Least Significant Differences (LSD) test at the $p \leq 0.05$ level.

RESULTS AND DISCUSSION

Sugar beet root growth trend

The results showed that the maximum root growth in the first year was achieved for all cultivars from 134 DAP (GDD = 2584) until 195 DAP (GDD = 3521) in the spring sowing and from 92 DAP (GDD = 1823) until 132 DAP (GDD = 2370) in the summer sowing. But, in the second year, an increase was observed in the root growth of G3, G4, and G6 and a decrease in the root growth of G1, G2, and G5 after 166 DAP (GDD = 2130). In most root growth steps, G4 had the highest root weight in both sowing dates. The second highest root weight was related to G3 in the spring sowing and G5 in the summer sowing (Figure 2). In summary, the maximum root growth was within 130−190 DAP in the spring sowing and 90−135 DAP in the summer sowing, so any stresses within these time frames would reduce root and sugar yields severely. Plants are threatened in these periods with various stresses, e.g. water deficiency, high temperatures, and hot winds, which farmers are unable to control (5). In most studies on comparing spring and summer sowing of sugar beets under climatic conditions that have been similar to our study, the highest dry matter and leaf areas have been obtained from the early sowing, which has resulted in significantly higher root and sugar yields (40).

Trend of catalase (CAT) activity and malondialdehyde (MDA) variations

The results for MDA measurement of sugar beet cultivars during their growth period revealed that it was increased in all cultivars in the spring sowing from 572 GDD to 1277 GDD, but from 1277 GDD until 3303 GDD, the rate of MDA synthesis almost reached a plateau in all cultivars except for G6 (Figure 3). In the summer sowing, the rate of MDA variations was ascending until 1823 GDD for all cultivars, but it started to decline in G2 and G4 and increase in G3, G5, and G6 from 1823 GDD to 2151 GDD (Figure 4). The results of the measurement of CAT activity indicated that in the spring sowing, the maximum CAT activity was observed in all cultivars from 1277 GDD to 1836 GDD except for G4 whose activity was peaked at 1836 GDD and started to decline after that. The highest CAT activity at different growth steps was observed in G1 and the lowest in G4 until 1836 GDD and G2 after 1836 GDD (Figure 5). But, in the summer sowing, CAT activity was increased in all cultivars except for G5 from 572 GDD until 1725 GDD at different rates, and then they went down. In most steps, the highest CAT activity was observed in G5 whose maximum activity was obtained at 1823 GDD (Figure 6). The results indicated that although cultivars exhibited various CAT activity when sown in spring or in summer, the maximum CAT activity in the spring sowing (152 µmol min^{-1} mg^{-1} protein for G1) did not differ from that of the summer sowing (163 CAT activity (µmol min^{-1} mg^{-1} protein for G5) significantly. CAT is the most important antioxidant enzyme that is activated when a plant is exposed to stress (18, 37). The occurrence of stress during plant growth periods is unavoidable in Iran's climate, especially in hot months, so it will be useful to change the sowing date to avoid the coincidence of sensitive growth steps with stressful conditions (16).

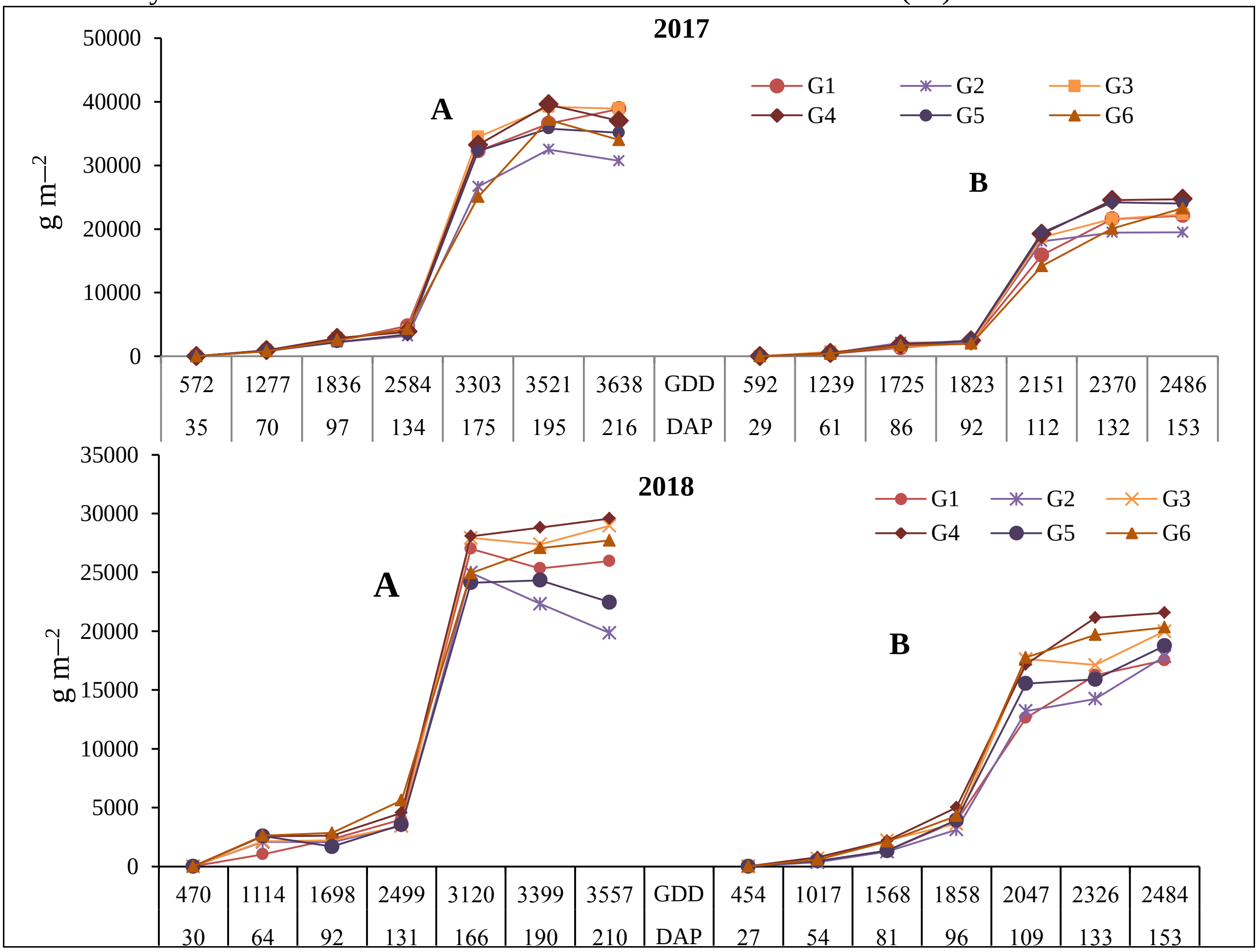

Figure 2. The trend of root growth of sugar beet cultivars in spring sowing (A) and summer sowing (B) based on DAP and GDD in 2018

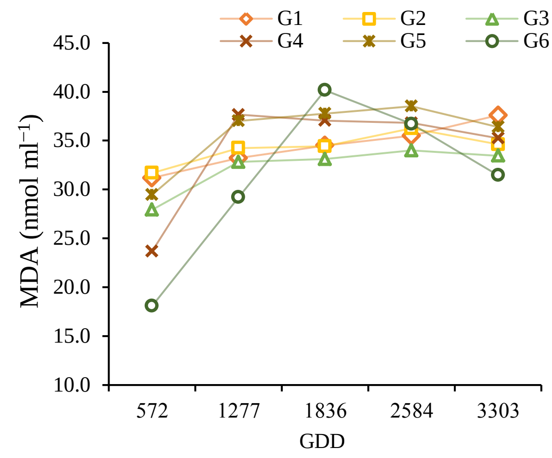

Figure 3. The trend of MDA in sugar beet cultivars based on GDD in normal sowing

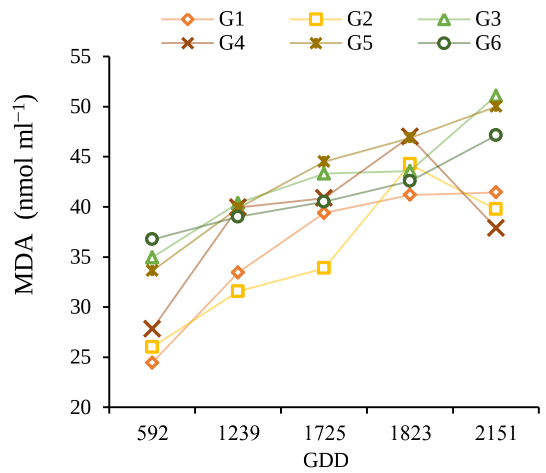

Figure 4. The trend of MDA in sugar beet cultivars based on GDD under delayed sowing

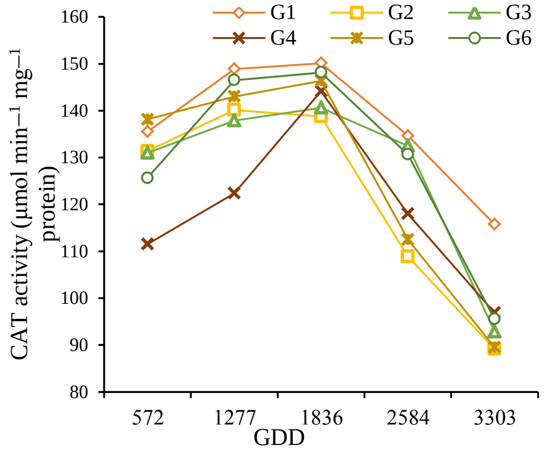

Figure 5. The trend of CAT activity in sugar beet cultivars based on GDD in normal sowing

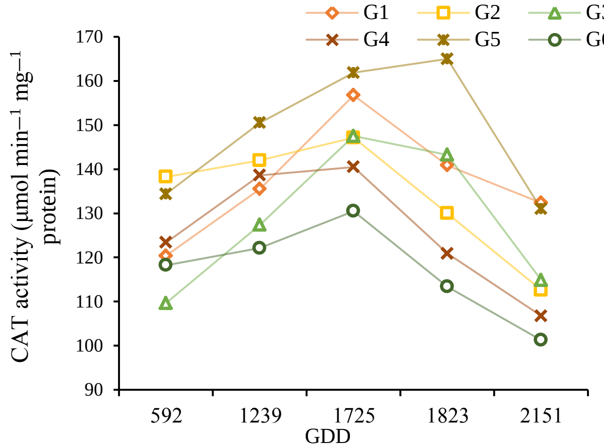

Figure 6. The trend of CAT activity in sugar beet cultivars based on GDD in delayed sowing

It was proven by the measurement of CAT and MDA so that the trend of CAT activity was consistent in the spring-sown plants, but MDA was increased until 1860 GDD and then started to decrease. In the summer sowing, CAT activity increased until 1720 GDD and then started to decrease whereas MDA had an ascending trend in most cultivars. So, it can be inferred that the plants were exposed to stress and that the summer sowing encountered stress to a greater extent than the spring sowing. These results are consistent with the reports of Webster et al. (47) and Spinoni et al. (43). The ascending trend of MDA and the bell-shaped trend of CAT in most cultivars in the summer sowing can be attributed to MDA accumulation induced by stressful high temperatures of hot summer months and the termination of CAT activity. In an assessment of the stress tolerance of plants, Zandalinas et al. (49) pointed to an increase in MDA in stressful conditions and stated that there might be a direct relationship between more efficient antioxidant mechanisms and the delay in the initiation of MDA accumulation.

Leaf dry weight (LDW)

Table 4 shows that LDW was significantly influenced by the interaction of G × H in both years, S × H in the first year, and S × G in the second year. Based on the comparison of means for the interaction of S × G, the summer sowing increased LDW by 2.6−14.1% in G2 and G4 and by 6.2−18.5% in the other cultivars. Also, the comparison of means for the interaction of S × H indicated that in both spring and summer sowing, LDW was decreased as harvest time was extended. Also, it was found about the interaction of G × H that in both years, LDW was increased from the first to third harvest in G2 and G4 in both years, but it was decreased in the remaining cultivars (Table 4). Leaf production in sugar beets is a function of environmental conditions, nutrition, genetics, and growth period length, and in addition to leaf number and area, leaf duration is also important (47).

Curcic et al. (5) reported the decline of leaf number and weight in summer sowing. Also, Kenter et al. (20) found that the leaf and root growth of sugar beets were increased with temperature rise during the first 65 days of sugar beet growth, but the relationship between the environmental temperature and growth rate diminished from 121 to 145 days after sowing. However, it should be noted that the rise of environmental temperature impairs dry matter accumulation in C_3 plants (24).

Crown fresh weight (CFW)

The results of ANOVA revealed that the simple effect of S, G, and H in both years and the interactive effect of S × H were significant on CFW (Table 4). In both years, the summer sowing was related to lower CFW than the spring sowing and the later harvests increased CFW significantly versus the subsequent harvest dates. The interaction of S × H, also, showed that the third harvest had higher CFW in both spring and summer sowing and that the harvest dates in spring sowing had higher CFW than that in the summer sowing. Among the sugar beet cultivars in both years, G6 had the lowest CFW of 421 g m^{-2} in 2017 and 314 g m^{-2} in 2018 (Table 2). Similarly, Nagib et al. (30) concluded that delayed harvest increased CFW, especially in late-maturing cultivars. According to Loel and Hoffmann (24), earlier sowing dates produced higher crown dry weight and root yield was significantly correlated to crown weight, total dry matter, and leaf weight. Reinsdorf et al. (35) argue that genotypes with higher resistance and more sugar concentration have smaller crowns.

Root dry weight (RDW) and root yield (RY)

The results showed that the interactions of G × H and S × G in both years and S × H in the first year were significant for RDW (Table 4). The examination of S × G revealed that delayed sowing reduced RDW by 32.5−51.2% in the first year and 24.3−38.2% in the second year and the lowest and highest decline was for G2 and G5 in the first year and G1 and G4 in the second year, respectively. However, a look at G × H showed that delayed harvest increased RDW, but this increase was greater in the first year than in the second year although RDW in the first and second harvest dates (H1 and H2) were much lower in the first year than in the second year. The interaction of S × H also showed that in both sowing dates, harvest postponement increased RDW remarkably so that it reached from 604 g m^{-1} in the first harvest to 6157 g m^{-1} in the third harvest in the spring sowing and from 394 g m^{-1} to 3401 g m^{-1} in the summer sowing (Table 4). RY was almost 25.4% higher in 2017 (86.4 t ha^{-1}) than in 2018 (64.3 t ha^{-1}) (Table 5). Given the significance of year in dictating sugar beet yield potential and the marginal impact of agronomic factors on it (32) and almost equal water use in two experimental years (11265 and 11017 m^3 ha^{-1} in 2017 and 2018, respectively), the higher RY of 2017 can be related to the suitability of climatic conditions during plant growth period. The results of ANOVA showed that the interaction of S × G × H was significant for RY in both years (Table 5). Although RY of cultivars showed various responses to sowing and harvest dates, RY of all cultivars was decreased when sowing was delayed, whereas the RY of some cultivars was higher in the second harvest than in the third harvest and this difference was more remarkable in the spring sowing date (Figure 7). The main effect of harvest date also implies that in the first year, RY was higher in the second harvest date than in the first and third harvest dates, but in the second year, the second and third harvest dates did not differ significantly. Delayed sowing reduced yield at all harvest times, and the decrease was 32.6% in the first harvest (H1), 42.0% in the second harvest (H2), and 44.7% in the third harvest (H3) compared to similar harvest dates under spring sowing (Table 5). On the other hand, different genotypes responded to the shortening of the growth period differently. The best genotypes for summer sowing, determine by mixing two components of the weakest response to delayed sowing and the highest yield in summer sowing conditions, were found to be ‘Paya’, ‘IR7’, and ‘Pars’. It has been documented by preceding studies that yield escalation by earlier sowing is more significant in years with appropriate climatic conditions (5, 13, 17). Assuming that the response of RY to growth period duration is linear (19; 40; 46), the comparison of spring sowing (April 9−19) and summer sowing (June 21−30) showed that each day delay in sowing in the

Karaj region, Iran would cost 400 kg ha^{-1} on RY, which is much higher than 200 kg ha^{-1} RY per each day delay in the Netherlands (42) and 134−162 kg ha^{-1} in Turkey (4, 21). This is, however, in full agreement with previous studies in the region (13). The amount of RY decline in this study is consistent with the reported values, which is about 6−9% (4). Irrespective of the type of mathematical relation, the length of growth period has always been regarded as one of the main factors describing RY variations (10, 40).

Table 4. The effect of sowing and harvest date on crown fresh weight (CFW), leaf dry weight (LDW) and root dry weight (RDW) of sugar beet genotypes in 2017 and 2018

S.O.V	DF	CFW ($g m^{-2}$)		LDW ($g m^{-2}$)		RDW ($g m^{-2}$)	
		2017	2018	2017	2018	2017	2018
Block	3	15458ns	132928**	9334ns	7982ns	83831ns	384742ns
sowing date (S)	1	3470800**	846706**	258858**	16139ns	28800624**	12947291**
Genotype (G)	5	193030.**	51842*	12341ns	15580*	81647ns	641387**
Harvest date (H)	2	1309941**	263495**	650178**	123378**	192768380**	106802616**
S × G	5	14635ns	29323ns	7406ns	12357*	180861ns	167197ns
S × H	2	275768**	37917ns	42297**	3884ns	16248425**	8148128ns
G × H	10	25518ns	9889ns	639251**	11259*	100496ns	249695*
S × G × H	10	15003ns	25575ns	8001ns	2058ns	115013ns	78907ns
Error	105	49549	22346	623	6362	195074	156517
Sowing time							
S1 (20−Apr)		716a	476a	301a		2579a	5293a
S2 (22−Jun)		406b	322b	240b		1453b	3654b
Genotype							
G1 (HF33)		640a	430a		366a		4245bc
G2 (SP19)		602ab	436a		340ab		3850c
G3 (PARS)		542a-c	385ab		299b		4688b
G4 (PAYA)		657a	424a		343ab		4584b
G5 (JOLGE)		504bc	408a		372a		4181c
G6 (IR7)		421c	314b		230c		5293a
Harvest time							
H1 (13−Oct)		443b	364b	304a	283b	498c	3620b
H2 (2−Nov)		490b	393b	256b	428a	772b	4857a
H3 (23−Nov)		750a	470a	252b	319b	4778a	4944a
S × G							
G1S1					336d	2739a	5314c
G1S2					396a	1371cd	3242h
G2S1					365b	2330b	4545de
G2S2					316e	1575c	3155h
G3S1					281f	2703a	5644b
G3S2					316e	1525c	3732fg
G4S1					348cd	2606a	5219c
G4S2					339d	1487c	3948f
G5S1					359bc	2526ab	4791d
G5S2					385a	1509c	3572g
G6S1					223g	2574a	6313a
G6S2					237g	1255d	4274e
S × H							
S1H1 (176 Day)		531b		345a		604d	
S1H2 (196 Day)		632b		296ab		979c	
S1H3 (217 Day)		987a		265bc		6157a	
S2H1 (113 Day)		356c		265bc		394d	
S2H2 (133 Day)		349c		238c		567d	
S2H3 (154 Day)		513b		219c		3401b	
G × H							
G1H1				337a	410a	478b	3232h
G1H2				306a-c	363b	803b	4602e
G1H3				266a-d	306e-g	4884a	4900cd
G2H1				226cd	321c-f	507b	3336h
G2H2				276a-d	339b-e	692b	3963g
G2H3				300 a-c	362b	4659a	4251f
G3H1				336a	317d-g	516b	3862g
G3H2				260a-d	295fg	777b	4960c
G3H3				262a-d	281gh	5049a	5242b
G4H1				340a	369b	521b	3708g
G4H2				317ab	357bc	773b	5257b
G4H3				253a-d	342b-e	4846a	4786c-e
G5H1				309a-c	309e-g	442b	3291h
G5H2				310a-c	354b-d	742b	4588e
G5H3				334a	367b	4869a	4665de
G6H1				233b-d	246hi	529b	4291f
G6H2				204d	234i	849b	5771a
G6H3				189d	214i	4365a	5819a

***, ** and ns are significant at levels of 5%, 1% and non-significant, respectively. In each column, mean values followed by the same letter(s) are not statistically different based on the LSD test at $P < 0.05$**

Root sugar content (SC):The results revealed that the interactions of S × H and S × G in both years and G × H in the second year were significant for SC (Table 5). The comparison of means for S × H indicated that although there was not a significant difference between the second and third harvests in both spring and summer sowing, they outperformed the first harvest significantly. In addition, based on the comparison of the means for the main effect of the sowing date, the summer sowing had higher SC than the spring sowing. Among the cultivars, G6 had the highest SC in both years. With respect to the interaction of S × G, SC was higher in most cultivars, except for G6, in plants sown in the summer. The SC of cultivars differed among harvest dates so that the second and third harvest dates were related to higher SC than the first, and G6 had the highest SC (16.8%) in the second harvest date. It can be said that postponing harvest from 139 DAP to 161 DAP increased SC by 1.78 units (Table 5). Various studies have reported that SC increases in response to delays in sowing (26; 32; 34). Cakmakci and Oral (4) also asserted that SC was increased by 0.07 units per each day delay in harvest. It seems that since 75% of root dry matter includes sucrose (40), the reason for the higher sugar content at delayed harvest is the increase in the root dry matter percent. Also, in another study, postponing the harvest time improved sugar beet quality but SC loss and technical quality of sugar beet after harvest and during storage in silo were the minimum in early sowing and delayed harvest (26).

Raw sugar yield (RSY) and white sugar yield (WSY): Based on the results, the interaction of S × H and S × G in both years and G × H in the first year were significant for RSY (Table 5). Means comparison for S × G indicated that RSY of all cultivars was higher in the spring sowing than in the summer sowing by 30.7−46.5% in the first year and 21.1−35.3% in the second year. The highest RSY in both years was produced by the spring-sown G6 plants (12.99 t ha^{-1} in the first year and 10.67 t ha^{-1} in the second year). Likewise, the interaction of S × H indicated that in both spring and summer sowing, RSY was increased with the delay in harvest; i.e. it was significantly higher in the second and third harvest dates than in the first harvest date, but there was not a significant difference between the second and third harvest dates. It should be noted that RSY was increased by 25.5 and 26.0% when the harvest of the spring-sown plants was postponed by 20 and 40 days, respectively whereas these values were 31.1% and 31.6% increase for the summer-sown plants. However, in the second year, 20 and 40 days postponement of harvest increased RSY of the spring-sown plants by 5.91 and 12.3% and that of the summer-sown plants by 22.2 and 28.33%, respectively. So, delayed harvest can partially improve RSY in summer sowing. Means comparison for the interactive effect of G × H revealed that RSY of the beet cultivars was higher in the second and third harvest than in the first harvest, but no significant difference was observed between the second and third harvests in all cultivars except for G6, although most cultivars had higher yields in the third harvest than in the second harvest. The highest yield of raw sugar was 11.95 t ha^{-1} produced by G6 at the third harvest (Table 5). The interaction of S × G and G × H in both years and S × H in the second year brought about significant differences in WSY (Table 5). Under the interaction of S × G, delayed sowing decreased WSY by 28.3−50.5% in the first year and 5.3−32.4% in the second year. The highest decline of yield was in G6 and the lowest in G2 in both years. In fact, different genotypes showed different responses to the shift in the sowing date from spring to summer. The highest capability of sustaining RSY in the summer sowing conditions was for the genotypes ‘Paya’ and ‘IR7’ and the highest WSY under the summer sowing conditions was related to ‘IR7’ (Table 5). It has already been reported that the range of differences among genotypes is decreased when sowing is retarded (23). It is, thus, reasonable to recommend the use of late-maturing genotypes for early sowing dates and early-maturing genotypes for late sowing dates or early harvest dates. Research on the effect of environmental factors on the growth and yield of six sugar beet cultivars in 62 sites showed that the sowing date was generally the most influential factor on the interaction of cultivar × environment (15). Means comparison for the interaction of G × H indicated that all cultivars had higher WSY in the second and third harvest than in the first harvest in both years, but the highest WSY was in the third harvest for some cultivars and in the second harvest for the other cultivars. In both years, the highest WSY was obtained from G6 whose WSY was 9.46 t ha^{-1} in the third harvest in 2017 and 7.66 t ha^{-1} in the second harvest in 2018 (not differing from that of the third harvest, 7.35 t ha^{-1}, significantly). However, it should be noted that although the second and third harvests did not differ significantly, the second harvest had 6.3% higher WSY than the third harvest in the spring sowing and the third harvest had 11.8% higher WSY than the second harvest in the summer sowing (Table 5). The results show that the harvest at 161 DAP was the best for sugar beets in the Karaj region. On the other hand, RSY in the second year was higher than that in the first year by 33.04% in the spring sowing and 10.33% in the summer sowing. Given the significance of total intercepted radiation and environmental temperature at different growth stages for sugar yield (12, 26, 31), this difference may partially be attributed to the appropriate climatic conditions of 2017. In 2017, the average monthly temperature was 1.9°C, 0.8°C, and 2.4°C (1.69 °C on average) higher in March-April, April-May, and May-June than their counterparts in 2018, respectively (Figure 1). Since the rate of sugar yield decline with the decrease in temperature is 10% per °C over this period (41), it can be inferred that the lower RSY and WSY in 2018 versus 2017 was related to the difference in the climatic conditions of these two years. The interaction of S × H showed that the second harvest in the spring sowing and the third harvest in the summer sowing had higher yields than the other harvests (Table 5). Overall, RSY and WSY were 35.5% and 33.8% lower in the summer sowing than in the spring sowing, respectively. As per one day delay in sowing, WSY was reduced by 2.24 g m^{-2} in 2017 and by 1.08 g m^{-2} in 2018, whilst Hoberg et al. (15) reported over 3 g m^{-2} decline of yield as per one day delay in sowing in the Netherlands. In Ireland, a month delay in the sowing of sugar beet (from early-March to early-April) resulted in about 1.1 t ha^{-1} decline of sugar yield (9). Similar findings in Turkey (4) revealed that when sowing was retarded by one week, sugar yield was decreased by about 8.3−9.7%. The different rates of sugar yield decline with the delay in sowing in different studies may be associated with the part of the growing season that the plants have missed. For example, the rate of sugar yield loss in April and May was estimated to be 4 and 15 g sugar per m^2 per day delay in sowing (42). In total, the decline of sugar yield by late sowing of sugar beets has been proven by Kirchhoff et al. (21).

Quality of sugar beet extract: Na, K and amino-N concentrations of the extracted juice of sugar beet cultivars, which represent sugar quality, were influenced by sowing and harvest dates and their interaction (Table 6). The results revealed that the most important factor underpinning the components of juice quality was the harvest date as only the main effect of harvest date was significant on all qualitative traits in both years whereas the sowing date influenced Na content in the second year and K content in both years. The interaction of S × H showed that both in spring and summer sowing conditions, the first harvest had higher Na, K and amino-N content than the other harvests, but their concentrations were significantly higher in summer sowing than in spring sowing (Table 6). The increase in K and N content of sugar beet roots in summer sowing has been reported by Lauer (23), Larney et al. (22), and Webster et al. (47), too. This has been attributed to the increase in K uptake compared to the internal consumption of the element in delayed sowing (5). On the hand, the interaction of S × G for the qualitative traits revealed that although some cultivars did not exhibit any statistically significant differences between spring and summer sowing, Na content in summer sowing was lower than that of the normal sowing for all cultivars except for G2 in both years whereas G1, G4, and G5 in the summer sowing and G2, G3, and G6 in the normal sowing produced higher K and amino-N. In addition, the interaction of G × H for the qualitative traits indicated that all sugar beet cultivars in the first harvest showed higher Na content in 2017, higher K content in 2018 and higher amino-N in both years than the second and third harvests. Furthermore, the comparison of the main impact of the harvest time indicated that in all qualitative traits, the first harvest had the highest mean value and the third harvest had the lowest mean value. In fact, as harvest time was postponed, K and amino-N content of the roots were decreased (Table 6). Sugar beet root quality is influenced by many factors such as genotype, organic matter, soil nutrients, and agronomic operations like N application (25). The highest concentrations of such elements as N, Na, and K in roots reduce sugar content.

Table 5. The effect of sowing and harvest date on root yield (RY), sugar content (SC), raw sugar yield (RSY) and white sugar yield (WSY) of sugar beet genotypes in 2017 and 2018

S.O.V	DF	RY (t ha^{-1})		SC (%)		RSY (t ha^{-1})		WSY (t ha^{-1})	
		2017	2018	2017	2018	2017	2018	2017	2018
Block	3	204ns	47ns	0.745ns	6.021**	2.76 ns	1.39ns	0.15ns	0.84ns
Sowing date (S)	1	36167**	11100**	21.1**	35.2**	687**	200**	16.33**	79**
Genotype (G)	5	310**	870**	34.3**	46**	4.56*	34**	433**	35**
Harvest date (H)	2	30310**	10437**	63.0**	26**	624**	219**	67.6**	115**
S × G	5	1285**	82ns	7.69**	6.4**	5.05*	4.69*	8.06**	5.95**
S × H	2	3555**	1295**	20.3**	25**	51.2**	10.1**	0.92ns	3.7**
G × H	10	103ns	65ns	0.83ns	11.9**	8.64*	1.62ns	12.24**	1.07ns
S × G × H	10	1693**	585**	1.26ns	0.87ns	1.53ns	1.03ns	0.53ns	0.59ns
Error	105	127.5	72.8	1.51	1.227	1.98	1.572	0.317	1.033
Sowing time									
S1 (20−Apr)		86.2a	64.3a	13.12a	13.36b	11.6a	8.58a	8.14a	5.45a
S2 (22−Jun)		49.1b	43.7b	13.96a	14.25a	6.80b	6.24b	4.74b	4.25b
Genotype									
G1 (HF33)		67.6a-c	52.0b	13.8b	13.7b	9.28ab	7.05c	6.67b	4.47bc
G2 (SP19)		61.2c	46.9c	14.0b	13.5b	8.51b	6.30d	6.09c	4.03c
G3 (PARS)		71.7a	57.9a	13.1c	13.6b	9.21ab	7.85b	6.11c	5.04b
G4 (PAYA)		71.9a	58.6a	12.8c	12.6c	9.21ab	7.37bc	5.98c	4.36c
G5 (JOLGE)		68.7ab	50.5bc	13.1c	13.5b	9.03b	6.78cd	6.00c	4.27c
G6 (IR7)		64.0bc	57.3a	15.5a	15.9a	10.09a	9.12a	7.89a	6.92a
Harvest time									
H1 (13−Oct)		60.1b	52.3b	12.3c	12.7b	7.34b	6.57b	5.00b	3.79b
H2 (2−Nov)		73.1a	54.1a	14.0b	14.5a	10.13a	7.80a	7.10a	5.31a
H3 (23−Nov)		69.6a	55.2a	14.8a	14.2a	10.21a	7.83a	7.22a	5.44a
S × G									
G1S1		89.8ab		13.4c-e	13.14de	12.11a	8.56bc	8.51b	5.24bc
G1S2		45.5d		14.1c-e	14.17b-d	6.45c	5.54f	4.62d	3.69d
G2S1		74.9c		13.5b-e	12.47e	10.07b	7.03de	7.09c	4.12d
G2S2		47.5d		14.5bc	14.59b	6.97c	5.56f	5.07d	3.94d
G3S1		93.8a		12.5e	13.31c-e	11.73ab	9.33b	7.61bc	5.83b
G3S2		49.7d		13.6b-e	13.94b-d	6.70c	6.36ef	4.60d	4.23cd
G4S1		91.5a		12.6e	12.38e	11.60ab	8.33bc	7.55bc	4.76b-d
G4S2		52.5d		12.9de	12.82e	6.83c	6.42ef	4.39d	3.95d
G5S1		86.0ab		13.3c-e	12.83e	11.44ab	7.58cd	7.62bc	4.56cd
G5S2		51.5d		12.9de	14.23bc	6.63c	5.97ef	4.36d	3.96d
G6S1		80.2bc		15.9a	16.07a	12.99a	10.66a	10.84a	8.14a
G6S2		47.9d		14.8b	15.76a	7.20c	7.59cd	5.35d	5.69b
S × H									
S1H1 (176 Day)		76.6b	62.4a	12.5c	12.3d	9.48b	8.03b		4.72b
S1H2 (196 Day)		92.0a	64.6a	13.8b	14.1ab	12.67a	9.18a		5.966a
S1H3 (217 Day)		89.4a	64.0a	14.4b	13.6bc	12.82a	8.52ab		5.645a
S2H1 (113 Day)		43.5d	39.1c	12.0c	13.0cd	5.20d	5.10d		2.85c
S2H2 (133 Day)		53.9c	43.4bc	14.2b	14.9a	7.58c	6.47c		4.66b
S2H3 (154 Day)		49.8cd	48.3b	15.3a	14.8a	7.61c	7.13c		5.23ab
G × H									
G1H1		60.2a-c	49.5h-k		12.3de	7.08d		4.91de	3.268d
G1H2		72.7ab	52.0f-h		14.3 a-e	10.34ab		7.39bc	4.870bc
G1H3		70.0ab	54.4e-g		14.4a-d	10.40ab		7.39bc	5.271bc
G2H1		55.9bc	47.7i-k		12.3de	7.15cd		5.10de	3.213d
G2H2		65.0a-c	45.7k		14.1a-e	9.24a-d		6.60b-e	4.171cd
G2H3		62.7a-c	47.1jk		14.3a-e	9.16a-d		6.54b-e	4.710bc
G3H1		66.5a-c	56.9c-e		12.6c-e	7.63b-d		4.86de	4.052cd
G3H2		76.0ab	55.6d-f		14.3a-e	10.18a-c		6.75b-d	5.253bc
G3H3		72.8ab	61.2ab		13.9a-e	10.20a-c		6.71b-e	5.801b
G4H1		64.3abc	56.6c-e		11.5e	7.42b-d		4.77de	3.173d
G4H2		77.2a	62.5a		13.4b-e	10.00a-d		6.47c-e	5.260bc
G4H3		74.5ab	56.8c-e		13.0b-e	10.21a-c		6.69b-e	4.656bc
G5H1		64.6 a-c	49.6h-k		12.2de	7.43b-d		4.68e	3.287d
G5H2		75.4ab	50.3h-j		14.4a-d	10.11a-d		6.80b-d	4.670bc
G5H3		66.2a-c	51.5g-i		14.0a-e	9.55a-d		6.51b-e	4.843bc
G6H1		49.1c	53.4e-h		15.3a-c	7.30b-d		6.29c-e	5.742b
G6H2		71.6ab	58.4b-d		16.8a	11.02a		8.53ab	7.662a
G6H3		71.6ab	60.1a-c		15.7ab	11.95a		9.46a	7.351a

***, ** and ns are significant at levels of 5%, 1% and non-significant, respectively. In each column, mean values followed by the same letter(s) are not statistically different based on the LSD test at $P < 0.05$.**

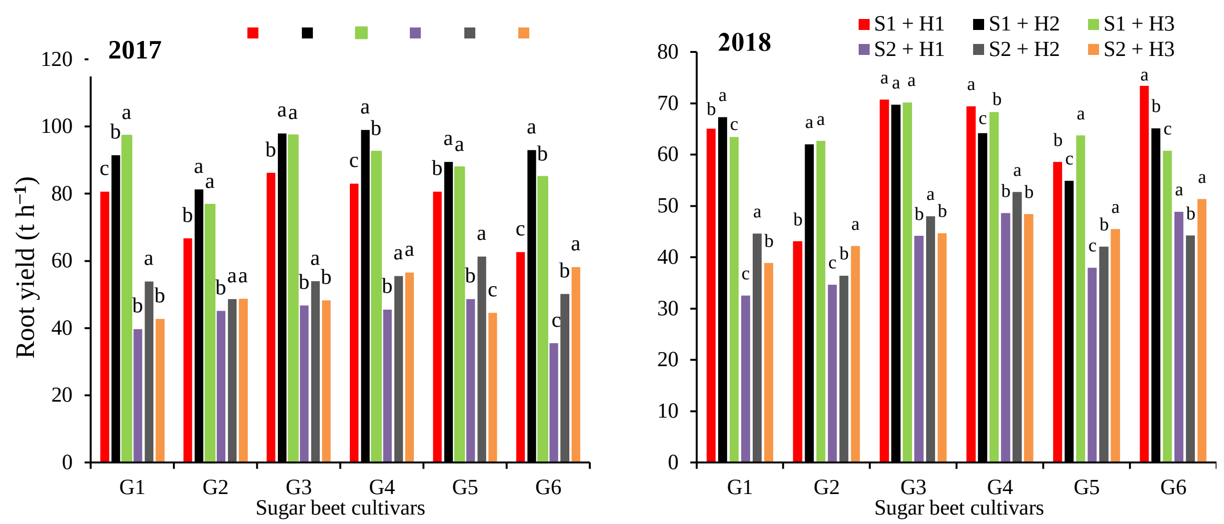

Figure 7. Means comparison of the interactive effect of S × G × H on root yield in 2017 and 2018

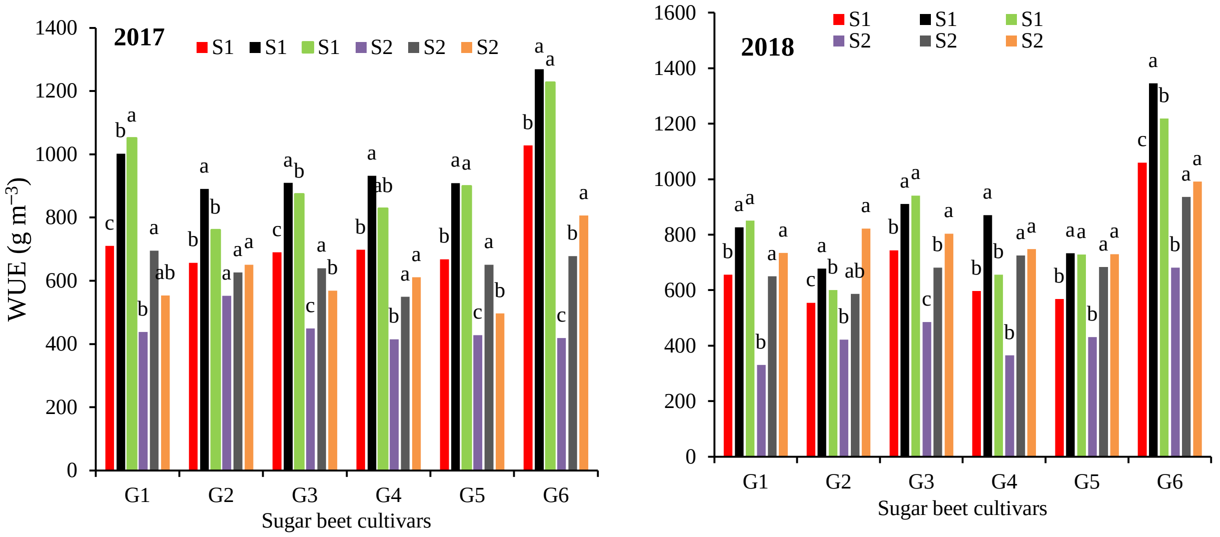

Figure 8. Means comparison for the interactive effect of S × G × H on WUE in 2017 and 2018

Among the cultivars, 'IR7', which had the highest sugar content, had the lowest N content. This inverse relationship between sugar content and root K content has been reported by other researchers too (10, 15, 22, 32). That the extension of growth period reduces these elements is caused by the full assimilation of nutrients and their mobilization to the shoots and crowns, but when growth period is shortened, there is not adequate time for assimilation and mobilization of nutrients absorbed from the soil (35).

Water use efficiency (WUE)

The amount of water use was almost equal in the two experimental years (11265 and 11017 m^3 ha^{-1} in 2017 and 2018, respectively), but since RSY was higher in the first year (6.74 t ha^{-1}) than in the second year (6.08 t ha^{-1}), the first year had higher WUE than the second year (805 g m^{-3} versus 607 g m^{-3}; Table 6). Also, the interaction of S × G × H was significant for WUE in both years (Table 6). Figures 9 and 10 show that the sugar beet cultivars (except for G2 and G5 in the second year) had significantly higher WUE in the spring sowing than in the summer sowing. In addition, the second harvest was related to the highest WUE in G2, G3, and G4 in the spring sowing and in G1, G3, and G5 in the summer sowing, whereas no significant difference was observed between the second and third harvests in G5 and G6 in the spring sowing and G2 and G4 in the summer sowing (Figure 11) whereas, in the second year, the second and third harvests had higher WUE than the first harvest for all cultivars although there was not a statistically significant difference between the second and third harvests for some cultivars. The highest WUE was obtained from the spring-sown G6 plants at the second harvest (1269 g m^{-3} in the first year and 1345 g m^{-3} in the second year) and from the summer-sown G6 plants at the third harvest (806 g m^{-3} in the first year and 991 g m^{-3} in the second year). In addition, among the studied cultivars, G2 was the most stable (in terms of WUE difference between 2017 and 2018) and G6 was the least stable (Figure 8).

Table 6. The effect of sowing and harvest date on Na, K, amino-N, and WUE of sugar beet genotypes in 2017 and 2018

S.O.V	DF	Na (meq 100 g^{-1} root)		K (meq 100 g^{-1} root)		Amino-N (meq 100 g^{-1} root)		WUE (g m^{-3})	
		2017	2018	2017	2018	2017	2018	2017	2018
Block	3	0.598ns	0.176ns	3.82**	0.491ns	1.93*	0.235ns	2365ns	30153ns
Sowing date (S)	1	0.066ns	3.809**	163.8**	51.2**	0.033ns	0.906ns	3713007**	807601**
Genotype (G)	5	1.64**	0.099ns	2.083**	6.35**	0.871ns	4.74**	193544**	621671**
Harvest date (H)	2	11.92**	2.932**	4.23**	24.7**	19.4**	2.503**	648756**	905669**
S × G	5	1.350**	1.925**	0.604ns	0.267ns	1.35*	2.53**	94542**	84157*
S × H	5	2.877**	7.060**	0.166ns	19.3**	1.602*	2.85**	9059ns	147103**
G × H	10	0.745**	0.156ns	0.147ns	47.4**	1.87*	3.61**	11419**	14063ns
S × G × H	10	0.572ns	0.217ns	0.291ns	0.611ns	0.200ns	0.414ns	18202**	378276**
Error	105	0.289	0.443	0.569	0.614	0.491	0.809	4380	27089
Sowing time									
S1 (20−Apr)		4.628a	3.894a	4.861b	6.038b	3.49a	5.049a	889a	808a
S2 (22−Jun)		4.692a	3.407b	6.995a	7.231a	3.66a	5.054a	568b	658.b
Genotype									
G1 (HF33)		4.826ab		5.711b	6.690ab		4.646cd	741b	675bc
G2 (SP19)		4.325cd		5.657b	6.611b		5.128bc	690c	611c
G3 (PARS)		4.643bc		6.06ab	6.820ab		5.718a	688 c	761b
G4 (PAYA)		4.751bc		5.915b	6.975ab		5.127bc	672 c	660.c
G5 (JOLGE)		5.265a		6.448a	7.067a		5.223ab	675 c	646c
G6 (IR7)		4.154d		5.772b	5.643c		4.469d	905a	1045a
Harvest time									
H1 (13−Oct)		5.504a	4.077a	6.182a	7.417a	4.076a	5.237a	596c	574b
H2 (2−Nov)		4.404b	3.566b	6.000a	6.479b	3.791b	5.122ab	812a	805a
H3 (23−Nov)		4.076c	3.311b	5.601b	6.007c	2.859c	4.796b	778b	819a
S × G									
G1S1		4.625bc	4.328ab		5.958de	3.43a-c	4.530de	921b	778bcd
G1S2		4.275bc	4.223a-c		6.555b-d	3.578a-c	5.005 b-d	770c	572e
G2S1		4.232bc	3.009e		6.370cd	4.040ab	6.064a	825bc	611e
G2S2		4.911b	3.968b-d		6.347d	3.553a-c	4.697c-e	820bc	610e
G3S1		5.841a	4.959a		5.928de	3.382bc	5.105 b-d	826bc	865bc
G3S2		3.888c	2.88e		5.068e	3.557a-c	4.895 b-d	1175a	656de
G4S1		5.027ab	3.914b-d		7.421ab	2.904d	4.762 c-e	562de	708.cde
G4S2		4.376bc	3.105de		7.578a	3.797a-c	5.251b-d	610de	612e
G5S1		5.055ab	3.331c-e		7.271a-c	2.948d	5.372a-c	552de	677de
G5S2		4.59bc	3.209de		7.603a	4.132a	5.556ab	525e	615e
G6S1		4.841bc	3.576b-e		7.295ab	3.616a-c	5.340a-c	525e	1208a
G6S2		4.269bc	3.308de		6.218d	3.175c	4.042e	635d	883b
S × H									
S1H1 (176 Day)		5.094b	4.158ab		6.190c	4.188a	5.514a	697c	742b
S1H2 (196 Day)		4.728b	3.975ab		6.087c	3.595b	5.011ab	894a	985a
S1H3 (217 Day)		4.062c	3.665b		5.837c	2.988c	4.624b	833ab	941a
S2H1 (113 Day)		5.912a	4.533a		8.744a	3.987ab	5.233a	452.d	450d
S2H2 (133 Day)		4.079c	2.897c		6.772b	3.734ab	4.960ab	717bc	640c
S2H3 (154 Day)		4.089c	2.841c		6.177c	2.730c	4.969ab	805abc	614c
G × H									
G1H1		5.912a			7.205a-e	3.855a-c	4.635c-e	574ef	
G1H2		4.268c-e			6.576c-f	3.611b-e	4.600c-e	848abc	
G1H3		4.299c-e			6.288d-f	2.446g	4.605c-e	802bc	
G2H1		4.767cd			7.806ab	4.051a-c	5.681ab	604d-f	
G2H2		3.926de			7.000b-e	3.913a-c	4.905b-d	758c-e	
G2H3		4.283c-e			6.395c-f	3.098d-g	4.798b-d	706c-f	
G3H1		5.807ab			7.463a-c	4.325a	5.991a	569ef	
G3H2		4.238c-e			6.758b-e	3.771a-e	5.706ab	775cd	
G3H3		3.885de			6.240d-f	2.866fg	5.457a-c	721c-f	
G4H1		5.801ab			8.156a	4.437a	5.506a-c	557f	
G4H2		4.377c-e			6.546c-f	4.240ab	5.102a-d	740c-f	
G4H3		4.073c-e			6.223d-f	2.851 fg	4.983b-d	720c-f	
G5H1		6.420a			7.211a-d	4.116a-c	5.295 a-c	548f	
G5H2		4.935bc			6.552c-f	3.583b-e	5.176a-d	780bcd	
G5H3		4.443cd			6.071ef	2.798 fg	4.987b-d	698c-f	
G6H1		4.681cd			6.661c-e	3.810a-d	5.282a-c	723c-f	
G6H2		4.313c-e			5.445fg	3.491c-e	4.276de	973ab	
G6H3		3.470e			4.823g	3.097e-g	3.848e	1018a	

***, ** and ns are significant at levels of 5%, 1% and non-significant, respectively. In each column, mean values followed by the same letter(s) are not statistically different based on the LSD test at *P* < 0.05.**

The most important environmental factor is the water supply, which is affected by soil type, climatic conditions, and the actual rate of precipitation. Limited water supply influences leaf and root growth dramatically and leaf senescence is accelerated and its regeneration is limited with the increase in high temperatures and the failure to supply adequate water (3, 7, 45). Since Iran is located in a semi-arid region of the world, WUE is an important factor for sugar beet cultivar selection. On the other hand, a goal of the attempts to find the best sowing and harvest dates is to achieve the maximum WUE.

CONCLUSIONS

1. The results indicated that in the spring and summer sowing, most cultivars exhibited maximum CAT and MDA in 1700−1900 GDD, so sound management of plants in this period can reduce yield loss by heat stress.
2. Sugar accumulation in the summer sowing was 23% lower than that in the spring sowing. However, various cultivars responded to the changes in sowing date differently, and the cultivars ‘Paya’ and ‘IR7’ could preserve 85% of their yields.
3. If it is assumed that the condition for the summer sowing is the enhancement of WUE, the results showed that the summer sowing had no advantage over the spring sowing when considering the further decline of crop yield in the summer sowing vis-à-vis the amount of water use.
4. Nonetheless, if summer-sown sugar beets in rotation with grains are considered a cash crop and there is no limitation on supplying their water requirement, the summer sowing can then be recommended to farmers to earn good profits.

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