Fasahat, P., Hosseinpour, M., Kakueinezhad, M., Hemayati, S.S., Laidig, F. (2023): Effect of latitude on sugar beet bolting occurrence. Agriculture and Forestry, 69 (2): 181-190. doi:10.17707/AgricultForest.69.2.14

DOI: 10.17707/AgricultForest.69.2.14

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EFFECT OF LATITUDE ON SUGAR BEET BOLTING OCCURRENCE

SUMMARY

Sugar is one of the sources of energy supply in the country's basic commodity basket. The two distinguish crops namely sugar cane and sugar beet are used for sugar production in Iran. Although sugar beet is mainly grown as a spring crop but the autumn-sown sugar beet cultivation is growing to overcome water shortage. In this study, the effect of latitude on bolting occurrence in four research stations, with wide latitude difference, during the period of 2011 to 2018 was evaluated. Data were collected from 58 value for cultivation and use (VCU) trials including registered cultivars and advanced breeding material. Results showed that the highest bolting percentage was recorded in regions with high latitude including Moqan followed by Mashhad. Beside the results, it could be observed that other factors such as number of cold days during winter and especially the planting date may influence bolting occurrence. To the best of our knowledge, this is the first study evaluating the effect of different latitudes on sugar beet bolting percentage in Iran.

Keywords: autumn planting, bolting, latitude, sugar beet

INTRODUCTION

Iran is one of the countries in the world that, in terms of climate diversity, in addition to producing sugar from sugar beet and sugar cane, it is possible to plant sugar beet in both spring (in cold temperate regions) and autumn (in tropical and warm temperate regions). Currently, due to limited water resources, it is not possible to develop spring sugar beet cultivation. The most important indicators of priority and superiority of autumn-sown sugar beet cultivation compared with

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.
Recieved:29/01/2023 *Accepted:16/06/2023*

spring cultivation are the use of rainfall during the growth period, higher yield, fewer pests and diseases, and especially less water demand and high water use efficiency. This issue becomes doubly important because the lack of water resources is the most important challenge and limiting factor in the production of agricultural products in the country (Fasahat *et al.*, 2018; Saeedi and Ziaee, 2020). The development of autumn-sown sugar beet cultivation and the supply of a part of sugar beet needed by sugar factories in areas that are facing limited water resources can be very important in the sustainability of sugar beet production in those areas. The autumn cultivation of sugar beet in Iran was initially started in Dezful region, and many studies have been conducted on various aspects of agronomy, quality and other characteristics of autumn-sown sugar beet during the past years. Results of studies confirm that autumn sugar beet can be introduced as an important crop in the rotation system of susceptible areas (Orazizadeh *et al*. 2020). Currently, the most important challenge in spring crops is the lack of water resources and the uncertainty of supplying the amount and time of water needed by the plant. This problem is gradually developing in different regions, and even in regions that did not have problems in this regard before, it is becoming the main limitation in the production of agricultural products. Although in the future due to the escalation of water shortage, there is a possibility of reducing the area under cultivation of spring crops, including spring sugar beet, but in recent years, by changing the geography of production, sugar factories supply their sugar beet from areas with less drought restrictions. Thereby, the share of eastern regions in the country in sugar beet production decreased from 47.6% to 24.2% and the share of western regions in sugar beet production increased from 21% to 41.2% (Fasahat *et al*., 2020; Taleghani *et al.*, 2020; Rezaei and Fasahat, 2022).

With all the advantages that autumn-sown sugar beet cultivation has over spring one, one of the major limitations for autumn cultivation is the bolting occurrence. Sugar beet is a biennial plant and the incidence of frost in winter followed by long days in spring causes the sugar beet to bolt and flower (Milford and Burks, 2010). In addition to severe reduction in final yield via reduction in sugar content and root yield, the bolting occurrence in early plant growth stage may also disturb sugar beet harvester, slowing down the cutting and slicing blades in the sugar factory due to hardening and fibrosis root shape and increasing the probability of seed scattering (cause the growth of sugar beet as weed in following years) (Longden and Scott, 1980; Longden, 1989). As a result, bolted sugar beet plants are not suitable for sugar production, and these sugar beets are only dry products with a high percentage of shoot and a small amount of root. Some concerns such as water use efficiency, long growing season of sugar beet followed by sequential drought and water shortage especially in the southern regions of Iran has highlighted the vital role of autumn-sown sugar beet cultivation for sugar supply. With the above-mentioned information, in this study, for the first time the effect of latitude on sugar beet bolting occurrence in main locations of the country that are considered for autumn-sown sugar beet cultivation was evaluated.

MATERIAL AND METHODS

Data collection

In this study, data were taken from 3464 observations based on plots from 58 VCU trials performed in four research stations across Iran during the period of 2011 to 2018. The data set comprised 121 diverse sugar beet genotypes including registered cultivars and advanced breeding material and from 8 harvest years. Within one year and location up to 3 different trials were available, however mostly only one trial was grown. The geographic area represented includes Mashhad (Torbat-e-Jam), Moqan (Parsabad), Dezful and Shiraz (Darab) where most of the autumn-sown sugar beet cultivation is done (Fig. 1).

Fig. 1. Location of four research stations in Iran

General characteristics of the trial locations such as longitude/latitude, the average temperature and rainfall during the studied period are presented in Table 1 and 2.

Table 1. Characteristics of the trial locations

No.	Location	Longitude	Latitude	Sea level (m)	No. of trials	No. of observations (plots)
1	Moqan (Parsabad)	47°46'E	39°36'N	67	8	392
2	Mashhad (Torbat-e-Jam)	60°48'E	35°12'N	838	14	800
3	Dezful	48°24'E	32°21'N	121	22	1344
4	Shiraz (Darab)	54°33'E	28°45'N	1185	14	928

Climatically, the Moqan location is expected to have a colder climate than the location Shiraz. However, the high altitude of Shiraz compared with Moqan has moderated the temperature conditions in this location compared with its latitude.

Table 2. Characteristics of the temperature and rainfall during the period of 2011 to 2018

Location	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Moqan (Parsabad)												
Temp-Max (ºC)	17.96	19.13	23.73	27.08	32.28	37.23	38.48	37.69	33.60	28.00	20.38	16.95
Temp-Min (ºC)	-6.64	-4.20	-1.01	2.58	10.23	14.61	17.00	16.54	12.04	6.14	-0.46	-3.34
Average monthly temperature	5.66	7.46	11.36	14.83	21.25	25.92	27.74	27.11	22.82	17.07	9.96	6.81
Monthly rainfall (mm)	22.08	28.52	24.21	14.34	27.00	24.65	5.38	4.12	25.83	44.39	21.58	18.08
Seasonal rainfall (mm)		74.81			65.98			35.32			84.04	
Mashhad (Torbat-e-Jam)												
Temp-Max (ºC)	18.58	19.73	26.58	31.26	37.04	39.40	40.20	38.16	35.05	31.85	24.31	19.61
Temp-Min (ºC)	-8.08	-7.66	-2.44	3.75	10.99	15.26	17.85	14.01	10.06	1.79	-3.46	-8.83
Average monthly temperature	5.25	6.03	12.07	17.51	24.01	27.33	29.03	26.09	22.56	16.82	10.43	5.39
Monthly rainfall (mm)	14.03	29.09	22.76	17.93	11.15	0.04	0.00	0.10	0.00	5.19	14.04	6.99
Seasonal rainfall (mm)		65.88			29.12			0.10			26.22	
Dezful												
Temp-Max (ºC)	22.59	25.54	30.49	37.79	44.44	48.00	50.56	48.58	44.88	39.55	30.09	24.18
Temp-Min (ºC)	1.81	3.25	6.54	9.43	16.95	19.96	23.50	23.35	19.09	13.35	8.16	3.03
Average monthly temperature	12.20	14.39	18.51	23.61	30.69	33.98	37.03	35.96	31.98	26.45	19.13	13.60
Monthly rainfall (mm)	44.18	21.29	33.06	15.34	16.07	0.00	0.00	0.25	0.25	11.25	50.26	37.02
Seasonal rainfall (mm)		98.53			31.42			0.50			98.53	
Shiraz (Darab)												
Temp-Max (ºC)	22.48	23.31	27.11	33.54	39.76	43.21	43.86	42.81	39.90	35.25	27.88	24.01
Temp-Min (ºC)	-0.35	1.50	4.24	9.39	15.44	17.93	22.75	20.99	16.58	10.71	5.15	0.23
Average monthly temperature	11.06	12.41	15.68	21.46	27.60	30.57	33.31	31.90	28.24	22.98	16.51	12.12
Monthly rainfall (mm)	45.25	85.55	41.52	9.67	2.30	0.05	6.19	2.31	0.74	0.38	30.56	10.67
Seasonal rainfall (mm)		172.31			12.02			9.24			41.61	

Each VCU trial was conducted in a randomized complete block design with four replications. Based on the number of entries, 2-4 check cultivars were added to the trial. Each plot had three 8 m rows and counting of the bolted plants was performed at the plot level. The bolting percentage was calculated as the number of plants that bolted in each plot divided by the number of all plants × 100. The trials were managed according to local agronomic practices.

The following model was used:

$$y_{ijklr}=\mu+G_i+Y_j+L_k+(YL)_{jk}+(YL/T)_{jkl}+(YL/T/B)_{jklr}+(GY)_{ij}+(GL)_{ik}+(GYL)_{ijk}+\varepsilon_{ijklrh}$$

where y_{ijkrh} represents the percentage of bolting plants in the ijklrhth plot, G_i is the effect of the ith genotype, Y_j of the jth (harvest) year, L_k of the kth location, $(YL/T)_{jkl}$ of the lth trial within year j and location k, $(YL/T/B)_{ijklr}$ of the rth block within trial l of year j and location k, $(GY)_{ij}$ the interaction between genotype i and year j, $(GL)_{ik}$ the interaction between genotype i and location k, $(GYL)_{ijk}$ is the interaction between genotype, year and location and ε_{ijklrh} is the residual error. The main effects for locations L_k and μ were considered as fixed, while the other effects were assumed to be random and independent with constant variance for each effect.

RESULTS AND DISCUSSION

In the present study, the average bolting percentage during the studied period was 15.06% with minimum and maximum of zero and 100, respectively (Fig. 2). As it has been shown in Table 3, the effect of Mashhad, Shiraz, and Moqan locations on bolting percentage was significant. The highest bolting percentage was observed in Moqan (36.67%) followed by Mashhad (28.82%), Shiraz (13.77%), and Dezful (1.47%), respectively (Fig. 2, 3). The long-term meteorological data show that the average monthly minimum temperature of Moqan and Mashhad decreases to less than zero during winter, in Dezful it was above zero and falls below zero only in the coldest month of the year (January) in Shiraz location (Table 2). The average maximum monthly temperature in Moqan location during July and August was lower than Mashhad, Dezful and Shiraz locations (Table 2). In total, the average annual temperature of Moqan, Mashhad, Dezful and Shiraz locations were 16.5, 16.8, 24.7 and 21.9°C, respectively (Table 2). The long-term average of total annual rainfall in location Moqan was more than all locations, however the seasonal distribution of rainfall in Mashhad was more balanced than other locations.

Table 3. The effect of location on bolting percentage and standard error comparison among locations

Location	Bolting (%)		
	Mean	SE	*P* value
Mashhad	28.82^b	7.18	0.0001
Shiraz	13.77^c	8.91	0.0312
Moqan	36.67^a	10.15	0.0003
Dezful	1.47^d	7.06	0.9459

n.s. = not significant; Least square means with the same letter are not significantly different at the 0.05 probability level. P >|t| is the probability that the mean is greater than 0.

The pairwise tests for the least squares means of bolting percentage in studied locations showed that only Dezful had significant ($p < 0.05$) difference with Mashhad and Moqan and no difference was observed among other locations (Table 4).

Table 4. Pairwise tests for the difference between least squares means of bolting percentage for studied locations

Location	Dezful	Moqan	Shiraz
Mashhad	0.0023	0.6248	0.3002
Shiraz	0.0986	0.1849	
Moqan	0.0030		

n.s. = not significant, P >|t| is the probability that the mean is greater than 0.

The means, medians, quartiles, maximums and minimums of observations based on plots from VCU trials are presented in Fig. 2.

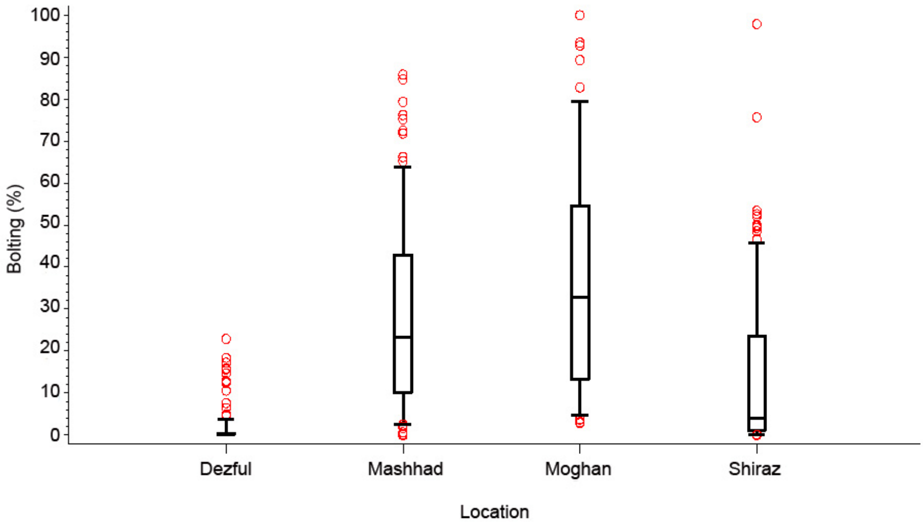

Fig. 2 Means and variation of bolting percentage from VCU trials performed in four locations during the period of 2011 to 2018.

Sugar beet is considered as a crop of temperate locations with main area of cultivation being between 30° and 60° N in Asia, Europe, and North America (Cooke and Scott 1993); however, studies showed that the maximum yield can be achieved at latitudes between 30° and 40° and decrease swiftly between 40° and 55° (Loomis and Gerakis, 1973). This has also influenced the life cycle of wild beets of the genus Beta (*B. vulgaris* ssp. *vulgaris*) so that under Mediterranean climate (southern latitudes), they exhibit an annual life cycle without need of vernalization, while sugar beets (*ssp. vulgaris*) and wild beets in northern latitudes are mainly biennial and require vernalization for flower induction (Letschert, 1993; Van Dijk *et al*., 1997; Boudry *et al*. 2002; Melzer *et al*. 2014). In addition, Hoft *et al*. (2018) reported later flowering of accessions from northern latitudes than those from southern latitudes. Kuroda *et al*. (2019) explained the high frequency of annual haplotypes among sugar beets in Japan as a result of relatively low latitude compared with Unites States and Europe.

Fig.3. Photos taken from different locations including a) Dezful (by Dr. Hasanvandi), b) Mashhad (by Dr. Rezaei), c) Moqan, and d) Shiraz (by Dr. Bazrafshan)

In this study, the latitude of Moqan is high which stimulates the bolting occurrence. In a study by Farahmand *et al.* (2013), the possibility of autumn-sown sugar beet cultivation in Moqan location was evaluated through three planting dates including 23rd September, 12th October, and 1st November with two cultivars susceptible and resistant to bolting. Their results showed that the effect of cultivar on bolting was significant ($P < 0.01$). The bolting percentage was strongly affected by planting date and with the delay in planting, the rate was reduced so that the average of bolting percentage in susceptible and resistant cultivars was 82% and 5%, respectively.

Same condition was observed for Mashhad. As it could be seen in Table 2, Mashhad followed by Moqan experienced more cold days/temperatures than Dezful and Shiraz which stimulates bolting occurrence. In a study by Mohamad Yosef *et al.* (2016), 47 half-sib families of sugar beet with three controls were evaluated at Torogh station (36°12'N and 59°40'E and 985 m above sea level) in Mashhad. Results showed that the effect of genotype on bolting percentage was significant ($P < 0.01$) with an average bolting percentage of 69.7 in a range of 0-97.62%.

The number of cold days in Dezful are less which is not enough for bolting induction. In contrast, Shiraz experience cold days during winter and long days in spring which provides suitable condition for bolting occurrence. The correlation between the number of cumulative hours of vernalization and the bolting percentage showed that with increasing the total cumulative hours of vernalization, the bolting percentage increases. This relationship was not statistically significant from the time of planting to 100 days old, and then the linear significant relationship between the number of hours of cumulative vernalization with the bolting percentage ($p<0.05$) and from the thirteenth week after (planting) to the end of the growing season ($p<0.05$) was reported (Taleghani *et al*., 2013). Therefore, it can be inferred that a significant difference between bolting percentage in the years and also different planting dates is due to the low total vernalization temperature received by the plants. For example, in Dezful region, due to the low total number of vernalization hours received, the bolting percentage varied between 0-70%. In a three-year study by Ashraf-Mansouri *et al.* (2013), three sowing dates including 27th September, 17th October, and 6th November was evaluated in Fasa location (28°58´N and Longitude 53°41´E with 1300 m elevation above sea-level) in 2005-08.

Results showed that sowing on 27th September led to the highest bolting (18.4%) whereas 17th October and 6th November had the lowest bolting by 5.420% and 2.870%, respectively. Year had significant effect ($p<0.01$) on root yield and bolting percentage. Since early sowing in locations with resembling condition to Fasa may subjected plants to longer cold weather, it contributes to the augment of the number of bolted plants. However, in later sowing, this period is shorter and as a result, the bolting percentage decreases. Van Dijk *et al.* (1997) averred that flowering time in southern parts is controlled by day length and warm temperatures. Riihimäki and Savolainen (2004) reported same condition for southern populations of *Arabidopsis lyrata* compared with northern ones in all environmental conditions including a common garden experiment and in the field. Therefore, sensitivity to vernalization is geographically structured so that the southern accessions are more sensitive to vernalization duration than northern ones (Stinchcombe *et al.* 2005). In a study by Yoshie (2014), the genetic difference in bud formation time was evaluated in *Taraxacum officinale* plants grown at three different latitudes (26, 36, and 43°N). It was shown that at high temperatures, the inhibition of flower bud formation follows a descending trend with latitude from north to south.

CONCLUSIONS

Due to the gradual warming of the earth, in the future it is anticipated that the autumn cultivation of sugar beet may replace the spring cultivation. Studies on the mechanism of flowering in plants show that the bolting stimulation is mainly due to factors such as day length, vernalization, and internal physiological factors of the plant such as size or growth rate (which itself can be related to environmental factors such as temperature). In this study, evaluation of bolting occurrence in different latitudes showed that the trend was ascending in accordance with latitudes with exception of Dezful in where the cold days' number was few.

The breeding programs for producing tolerant cultivars to bolting is in progress in different countries however, cultivar adaptability to latitudes as well as planting dates are main factors to be considered.

ACKNOWLEDGEMENTS

This paper is dedicated to Mr. Mohsen Aghaeezadeh for his 30-years effort on sugar beet breeding and cultivation.

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