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Growing Degree Day and Seed Yield Relationships in Mustard (*Brassica juncea* L.) Under Different Sowing Seasons and Locations of Turkey

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ABSTRACT

Mustard is grown in mild winter regions as late fall and in hard winter regions as late spring crop. Mustard has high degree of adaptability under wide range of climatic conditions in Turkey. Temperature is an important weather parameter affecting the growth and development of the mustard. The sum growing degree day (GDD) for a growing season is related to plant development which is depends on the accumulation of heat. The aim of this study was to determine the adaptation of mustard, under sowing seasons (spring and fall sowing) and locations in terms of crop growth (emergence, 50% flowering, physiological maturity, and sum growing degree days) and seed yield of mustard. Two-year field experiments in a split-plot design with four replications were carried out during 2013-14 and 2014-15 growing seasons at eight different ecological locations. These locations included Ankara, Aydın, Erzurum, Eskişehir, Isparta, Tekirdağ, Tokat and Şanlıurfa provinces of Turkey-as classified by Köppen-Geiger ecological conditions. The *Brassica juncea* L. (mustard seeds) were collected from wild conditions in the Konya province of Turkey. The results showed that, sowing seasons and locations significantly affected seed yield and GDD. The maximum seed yield of 3754.9 kg ha^{-1} was obtained from Tokat (warm humid) during fall sowing with total accumulated GDD of 1512.1 °C for mustard. Sum growing degree-days accumulated in different sowing seasons and locations occurred between 1132.0 °C and 2285.1 °C depending on the related ecological conditions. Fall season crop in Aydın location had the maximum growing degree days. Overall, fall season accumulated more growing degree days due to longer period of sunshine in comparison to spring season with less sunshine days resulting in longer vegetation period.

Keywords: *Brassica juncea* L.; Fall and spring sowing; Growing degree day; Mustard

1. Introduction

Mustard is used for production of vegetable oil or biodiesel production, and for extraction of vegetable in the world (Başbağ et al 2010; Mao et al 2012). Mustard is generally grown in mild winter climates as fall crop, in hard winter climates as spring crop (Wu et al 2011). Two species of mustard *Sinapis alba* L. and *Sinapis arvensis* L. widely found in Turkey belong to Cruciferae family. These grow widely in Turkey as weed and could be commercially exploited for production of biodiesel (Blackshaw et al 2011; Kayaçetin et al 2016). Seed yield and oil quality of mustard depend on genetic, ecological conditions and agronomic factors interactions among them (Johnson et al 2003). Temperature is a major factor that affects and determines crop growth, development and productivity (Qadir et al 2007; Kaleem et al 2009; Singh & Lallu-Singh 2014). Mustard plant behave differently under different sowing seasons and environmental conditions that are based on temperature prevailing during the crop life cycle. Variation in maximum and minimum temperature largely alters the growth pattern of the crop by affecting the duration as well as onset of different phenophases. Quantification of the effect of temperature on crop growth can best be evaluated by GDD (mean ambient temperature minus the threshold temperature required for survival of crop). This quantification helps to quantify the thermal requirement for the start of different phenophases of crops (Dutta et al 2011). There are certain base temperatures for each plant species (Morrison et al 1989). Different sowing seasons and locations might cause different environmental conditions from emergence to maturity. The accumulation of GDD determines the maturity of crop and yield. According to Miller et al (2001) mustard cultivars are available, each with specific GDD requirements, for emergence 110-136, for flowering 680-750, for maturity ranging from 1510 to 1610 growing degree days using a 5 °C base temperature. The best growth of mustard occurs between 12 and 25 °C. The optimum temperature for maximum and minimum growth and development are estimated at just over 20 °C and 5 °C in the same order. GDD has influenced the productivity and profitability of mustard under different weather conditions in locations and sowing seasons (Ghosh & Chatterjee 1988; Wahhab et al 2002).

The target of this study was to determine the adaptation of mustard, in two sowing seasons (spring and fall) and differently selected Köppen-Geiger ecological locations of Turkey in terms of crop growth (emergence, 50% flowering, physiological maturity, and sum growing degree days) and seed yield.

2. Materials and Methods

The study was conducted during the growing seasons of 2013-14 and 2014-15 under the Ankara (warm tempetare climates, dry summer, warm summer-Csb), Aydın (warm tempetare climates, dry summer, hot summer-Csa), Erzurum (snow climates, fully humid, warm summer-Dfb), Eskişehir (snow climates, summer dry, warm summer-Dsb), Isparta (warm tempetare climates, dry summer, hot summer-Csa), Tekirdağ (warm tempetare climates, dry summer, hot summer-Csa), Tokat (snow climates, summer dry, warm summer-Dsb) and Şanlıurfa (arid climates, steppe, cold arid-BSk) Köppen-Geiger ecological conditions of Turkey (Kottek et al 2006; https://en.climate-data.org 2018).

The seeds of mustard used in this study were selected from the plants growing under wild conditions in the Konya province. The identification of the plants was carried out by Department of Biology, Gazi University, Ankara, Turkey. Treatment combinations were arranged in a split-plot design with 4 replication, at all locations during both years. The effect of locations was studied in the main plots and fall-spring sowing in the sub-plots. Plot length was 5 m and consisted of 10 rows (30 cm). The sowing dates were determined for favorable climatic conditions at all locations. Nitrogen, phosphorus and sulphur fertilizers were applied at the rate of 100, 50 and 35 kg ha^{-1} in the form of diammonium phosphate, ammonium nitrate and ammonium sulfate respectively (Pyare et al 2008). The total quantity of phosphorus and sulphur fertilizer was applied at the time of sowing. Total nitrogen fertilization was applied in two equal doses, at the time of sowing and rosette formation. No irrigation was done to the experimental plots during the two years study period.

The soil samples took from each location at a depth of 0-20 and 21-40 cm during two analysed for the minerals, organic contents texture, the saturation percentage, total salts, pH, lime, phosphorus, potassium and organic contents. The soil samples charachteristics belonging to each experimental areas are shown in Table 1. All soils had low organic contents in range of low inorganic matter (Table 1).

Table 1- Physical and chemical soil charachteristics of the experimental areas sampled at depth of 0-20 and 21-40 cm

Location	*Year*	*Depth (cm)*	*Texture*	*Saturation percentage (%)*	*Total salt (%)*	*pH*	*Lime (%)*	*Phosphorus (P)*	*Potassium (K)*	*Organic Contents (%)*
Ankara	2013-14	0-20	Clay loam	64.0	0.041	7.79	28.12	6.63	162.04	1.31
		21-40	Clay loam	63.0	0.035	7.85	27.40	4.87	149.86	1.31
	2014-15	0-20	Clay loam	63.0	0.028	7.75	31.45	7.35	234.55	0.90
		21-40	Clay loam	63.0	0.037	7.76	24.82	7.81	219.99	1.49
Aydın	2013-14	0-20	Loam	49.0	0.017	8.00	14.23	22.29	52.61	0.53
		21-40	Loam	49.0	0.017	8.06	13.98	17.17	50.13	1.16
	2014-15	0-20	Clay loam	51.0	0.028	7.90	13.29	19.17	77.10	1.30
		21-40	Clay loam	51.0	0.029	7.96	16.41	15.86	63.00	1.45
Erzurum	2013-14	0-20	Loam	50.0	0.018	7.93	5.94	11.23	105.60	0.64
		21-40	Clay loam	51.0	0.018	7.98	6.20	12.77	92.44	0.53
	2014-15	0-20	Clay loam	54.0	0.450	7.80	5.99	9.61	109.02	0.97
		21-40	Clay loam	52.0	0.254	7.84	5.17	9.68	86.15	1.20
Eskişehir	2013-14	0-20	Clay loam	61.0	1.000	8.08	10.99	8.59	132.00	3.45
		21-40	Clay loam	60.0	0.836	7.99	8.06	8.51	136.00	3.87
	2014-15	0-20	Clay loam	58.0	0.043	7.57	22.55	7.96	105.60	1.53
		21-40	Clay loam	58.0	0.039	7.71	20.17	8.25	102.24	1.71
Isparta	2013-14	0-20	Loam	45.0	0.011	7.88	31.19	7.08	40.74	0.26
		21-40	Clay loam	53.0	0.014	7.83	30.44	5.04	89.27	0.14
	2014-15	0-20	Loam	43.0	0.011	7.88	30.55	3.69	145.90	0.67
		21-40	Loam	42.0	0.008	7.93	32.93	4.68	149.86	0.99
Tekirdağ	2013-14	0-20	Clay loam	53.0	0.022	7.88	8.10	5.18	92.44	0.13
		21-40	Clay loam	52.0	0.022	7.83	8.21	4.05	40.74	0.25
	2014-15	0-20	Clay loam	57.0	0.032	7.30	0.74	7.32	57.70	1.61
		21-40	Clay loam	56.0	0.016	7.62	0.74	6.57	52.61	1.37
Tokat	2013-14	0-20	Loam	46.0	0.015	7.74	11.85	7.44	43.01	0.40
		21-40	Loam	46.0	0.018	7.79	11.28	5.16	34.21	0.55
	2014-15	0-20	Clay loam	51.0	0.022	7.64	11.65	8.05	65.72	1.27
		21-40	Loam	49.0	0.023	7.57	15.41	5.39	32.14	1.18
Şanlıurfa	2013-14	0-20	Clay loam	69.0	0.045	7.68	30.00	6.01	160.80	1.74
		21-40	Clay loam	68.0	0.053	7.73	30.00	2.63	72.00	1.49
	2014-15	0-20	Clay loam	54.0	0.023	7.98	32.93	4.05	102.24	0.75
		21-40	Clay loam	55.0	0.026	8.02	32.78	1.85	71.31	0.25

Data were obtained from Soil Fertilizer and Water Resources Institute

Daily maximum and minimum temperature value (%) of the 2013-14 and 2014-15 vegetation periots of mustard are presented in Table 2; Montly rainfall, minimum and maximum temperatures values recorded during mustard development in experimental areas are presented in Figure 1. During

Table 2- Monthly maximum and minimum temperature value (%) of the 2013-14 and 2014-15 vegetation periods of mustard

	September				*October*				*November*			
Location	*2013-14*		*2014-15*		*2013-14*		*2014-15*		*2013-14*		*2014-15*	
	Max.	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
Ankara	25.14	11.03	25.18	13.48	19.33	4.86	19.21	8.65	15.30	2.980	12.51	3.54
Aydın	32.01	16.99	31.35	18.22	25.64	11.17	26.57	14.53	20.16	9.90	19.34	9.36
Erzurum	21.29	3.93	23.01	5.18	13.49	-2.45	14.92	2.48	8.27	-4.63	6.78	-5.04
Isparta	26.22	10.45	24.89	11.71	19.14	3.76	19.53	7.56	15.64	3.17	13.06	2.12
Tekirdağ	25.55	17.17	24.97	16.78	18.08	11.02	19.12	12.35	15.93	9.90	14.40	8.72
Tokat	25.72	11.34	27.56	14.02	18.78	5.53	20.36	9.49	15.11	4.15	12.13	3.02
	December				*January*				*February*			
Location	*2013-14*		*2014-15*		*2013-14*		*2014-15*		*2013-14*		*2014-15*	
	Max.	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
Ankara	3.71	-4.51	9.54	3.00	7.33	0.07	5.00	-1.86	11.73	0.52	7.94	0.47
Aydın	13.27	3.60	16.38	8.63	16.00	7.50	12.74	4.75	17.10	6.46	14.33	5.53
Isparta	7.14	-3.35	10.7	2.86	9.41	-0.30	6.27	-1.59	12.12	-0.14	7.81	0.05
Tekirdağ	9.66	3.18	12.31	6.84	11.16	5.32	9.17	2.82	11.64	5.66	10.04	4.28
Tokat	2.56	-4.21	10.81	3.64	9.50	-0.06	6.90	-1.33	13.18	3.06	10.31	1.88
Şanlıurfa	9.66	3.18	12.31	6.84	11.16	5.32	9.17	2.826	11.64	5.66	10.04	4.28
	March				*April*				*May*			
Location	*2013-14*		*2014-15*		*2013-14*		*2014-15*		*2013-14*		*2014-15*	
	Max.	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
Ankara	14.58	2.76	12.56	3.05	19.77	7.28	14.90	3.41	22.61	10.59	23.28	10.80
Aydın	19.38	7.98	17.75	7.89	23.36	11.64	21.98	9.38	27.83	15.07	29.58	15.50
Erzurum	8.22	-3.40	4.52	-7.12	14.24	0.66	11.10	-0.35	18.45	4.60	17.33	3.09
Isparta	12.95	1.95	11.70	2.26	17.26	5.30	15.33	2.81	20.76	8.71	22.75	8.82
Tekirdağ	14.10	6.36	11.40	6.01	17.18	10.03	15.80	7.74	21.61	13.61	22.85	14.56
Tokat	16.02	4.88	13.72	3.74	22.60	8.64	16.27	5.38	24.47	11.60	24.54	10.83
Şanlıurfa	14.10	6.36	11.40	6.012	17.18	10.03	15.80	7.74	21.61	13.61	22.85	14.56
	June				*July*				*August*			
Location	*2013-14*		*2014-15*		*2013-14*		*2014-15*		*2013-14*		*2014-15*	
	Max.	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
Ankara	26.52	13.41	24.57	13.31	32.31	18.29	31.19	16.97	32.93	18.41	31.60	17.78
Aydın	32.65	18.84	31.31	18.42	36.08	21.23	37.62	22.05	37.05	22.36	37.58	22.61
Erzurum	23.51	6.31	24.28	6.79	29.25	11.44	29.50	10.05	30.54	11.66	29.67	10.92
Isparta	26.42	12.51	24.82	11.28	31.32	16.23	31.28	15.96	32.35	16.39	31.23	16.17
Tekirdağ	26.16	17.70	25.80	17.32	29.17	20.17	29.51	19.92	30.08	20.89	30.47	21.75
Tokat	27.97	14.00	26.11	14.60	31.95	17.50	29.21	15.59	32.79	18.91	31.31	18.46
Şanlıurfa	26.16	17.70	25.80	17.32	29.17	20.17	29.51	19.92	30.08	20.89	30.47	21.75

Data were obtained from the Directorate of State Meteorological Observatory at Ankara the vegetation period in 2013-14 and in 2014-15. There was total of 302.2 and 603.0 mm, average temperature of 11.4 °C and 12.3 °C, and an average humidity of 55.5% and 69.3% in Ankara. There was total of 302.2 and 603.0 mm, average temperature of 17.9 °C and 17.4 °C, and an average humidity of 58.6% and 63.9% in Aydın. There was total of 317.7 and 467.9 mm, average temperature of 6.4 °C and 6.4 °C, and an average humidity of 65.3% and 68.4% in Erzurum. There was total of 257.4 and 571.9 mm,

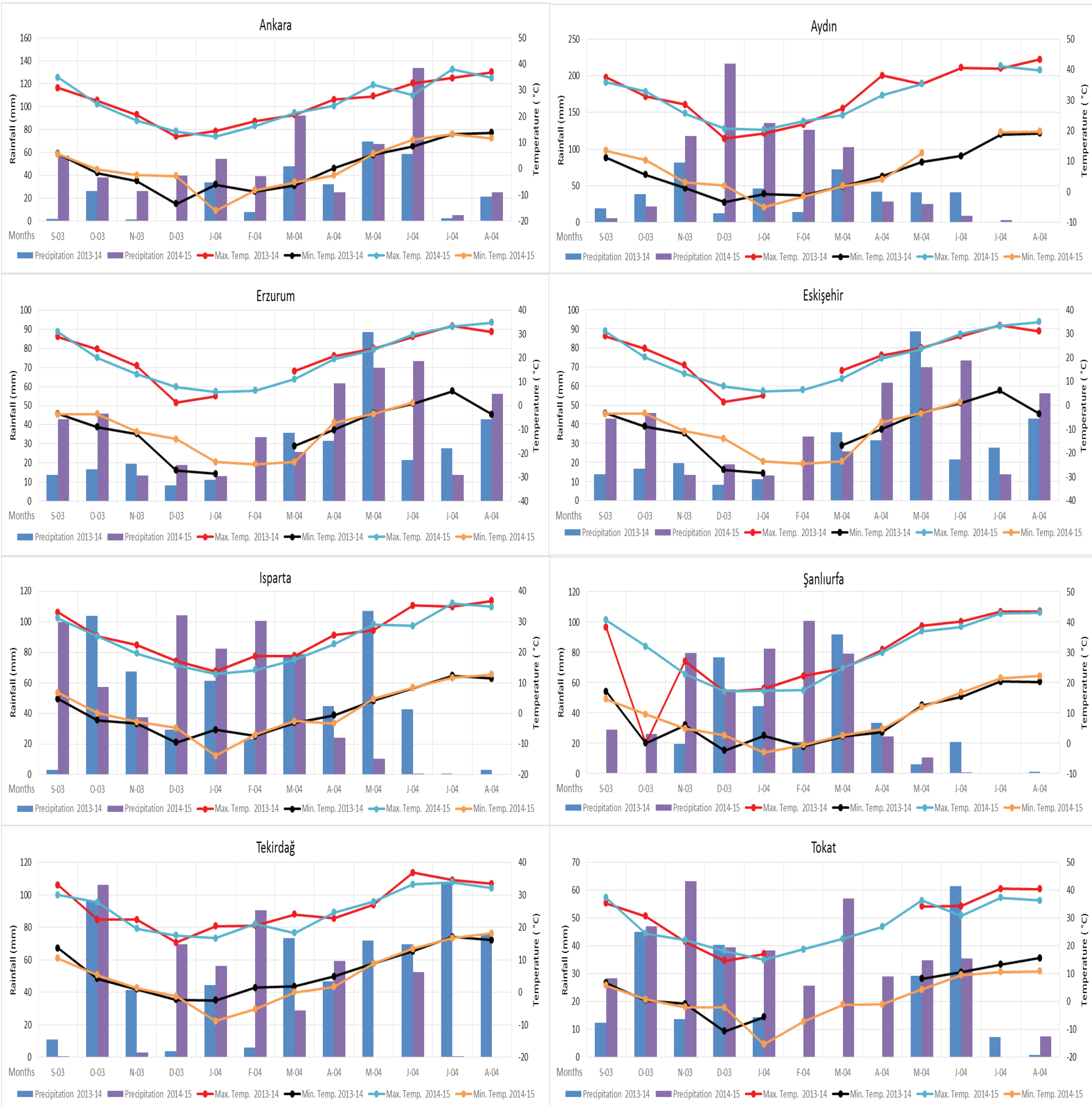

Figure 1- Monthly rainfall, minimum and maximum temperatures values recorded during mustard development in experimental areas (S, September; O, October; N, November; D, December; J, January; F, February; M, March; A, April; M, May; J, June; J, July; A, August)

average temperature of 12.7 °C and 11.1 °C, and an average humidity of 62.2% and 73.3% in Eskişehir. There was total of 565.9 and 596.6 mm, average temperature of 12.6 °C and 11.9 °C, and an average humidity of 57.1% and 63.4% in Isparta. There was total of 647.9 and 468.7 mm, average temperature of 15.4 °C and 14.5 °C, and an average humidity of 77.1% and 78.1% in Tekirdağ. There was total of 224.8 and 406.7 mm, average temperature of 14.4 °C and 13.3 °C, and an average humidity of 52.1% and 62.4% in Tokat. There was total of 313.8 and 487.0 mm, average temperature of 18.6 °C and 18.9 °C, and an average humidity of 41.4% and 50.6% in Şanlıurfa (Figure 1).

Emergence, 50 percent flowering and physiological maturity were identified based on visual observations. Growing degree days requirement for attaining different phenological events were calculated from weather data recorded through out crop life cycle by the following equation (Berti & Johnson 2008).

$$GDD = \Sigma \left[\left[(T_{max} + T_{min}) / 2 \right] - T_{base} \right]$$

T_{max} and T_{min} are daily maximum and minimum air temperatures in degree centigrade, respecticely. T_{base} is the 5 ºC base temperature for mustard development (Stannard et al 2000). Daily maximum and minimum air temperature data from eight locations are used in the study. GDD were accumulated by adding each day's GDD contribution as the season progressed.

Seed yield data were subjected to analysis of variance (ANOVA) using the MSTAT-C computer Statistical software. The significant differences among group means were separated using Duncan's Multiple Range Test.

3. Results and Discussion

Effects of sowing season and locations on growing degree days from emergence to maturity and seed yield of mustard are presented in Table 3. Emergence, flowering, maturity, sum growing degree days and seed yield of mustard varied according to sowing seasons, years and locations. Sum growing degree-days were accumulated between 1473.0 °C and 2098.9 °C during 2013-14 and 1132.0 °C and 2008.2 °C during 2014-15 under conditions of varied ecological conditions.

In fall sowing, no results could be obtained because of cold damage at Ankara, Eskişehir and Isparta locations during 2013-14. No emergence was noted at Erzurum, despite irrigation for both years due to high coldness.

The seed yield (1847.5 kg ha^{-1}) of the second year was higher than the first year (1146.9 kg ha^{-1}) (Table 3). This differences were occured due to higher rainfall during the growing period of plants during second year. Degree days from sowing to emergence in all locations was earlier at Tokat and Şanlıurfa compared to other locations during 2013-14, whereas it was earlier at Ankara compared to other locations during 2014-15. Flowering was earlier at Tokat compared to other locations during 2013-14, at Ankara compared to other locations during 2014-15. Degree days from sowing to maturity at all locations was earlier at Tokat during 2013-14, at Ankara in 2014-15 compared to other locations. Different locations exhibited differences for growing degree days (GDD) accumulation during both years. Sowing season is important for higher seed yield. Soil moisture is the major constraint for seed germination as well as for plant establishment and plays a key role under rainfed conditions, besides temperature. Statistically significant differences were found between the two consecutive years in terms of seed yield of mustard. The highest seed yield (1962.5 and 3754.9 kg ha^{-1}) was obtained at Aydın and Tokat, and the total GDD of mustard accumulated between 1473.0 and 2098.9 °C during 2013-14 and 1132.0 and 2008.2 °C during 2014-15, respectively. Total GDD of mustard increased at Aydın during both years, but its seed yield did not increase during both years. Aydın location had higher rainfall during the growing period of plants in the second year (791.0 mm) compared to the first year (407.8 mm). However, the seed yield in the second year was lower compared to first year due to diseases and long drought period before flowering (İptaş & Kolsarıcı 1988). At Tokat location, rainfall during the growing period

Table 3- Effects of sowing season and locations from emergence to maturity on growing degree days and seed yield of mustard

Year	*Sowing Season*	*Location*	*Sowing date*	*Emergence date*	*Flowering date*	*Harvest date*	*Emergence (ºC)*	*Flowering (ºC)*	*Maturity (ºC)*	*Sum growing degree-days (ºC)*	*Seed yield (kg ha⁻¹)*
2013-14	Fall sowing	Aydın	25-Oct-2013	15-Nov-2013	06-Mar-2014	10-Jun-2014	237.5	573.7	1287.7	2098.9	1962.5a
		Şanlıurfa	31-Oct-2013	12-Nov-2013	25-Mar-2014	22-May-2014	137.5	688.0	837.3	1662.8	1235.0b
		Tekirdağ	02-Oct-2013	24-Oct-2013	21-Mar-2014	17-Jun-2014	206.1	692.0	969.7	1867.8	876.7bc
		Tokat	08-Oct-2013	25-Oct-2013	06-Apr-2014	09-Jun-2014	137.4	511.6	824.0	1473.0	513.3c
						Mean	179.6	616.3	979.7	1775.6	1146.9
						Max.	237.5	692.0	1287.7	2098.9	1962.5
						Min.	137.4	511.6	824.0	1473.0	513.3
										$Fvalue_{location}$	47.9007**
										CV (%)	26.31
	Spring sowing	Ankara	16-Apr-2014	29-Apr-2014	14-Jun-2014	4-Aug-2014	108.4	453.3	872.6	1434.3	1831.9a
		Aydın	20-Mar-2014	28-Mar-2014	20-Apr-2014	15-Jul-2014	83.8	251.0	1633.4	1968.2	330.8de
		Erzurum	24-Apr-2014	18-May-2014	11-Jul-2014	18-Aug-2014	220.7	653.7	697.0	1571.4	126.2e
		Eskişehir	08-Apr-2014	24-Apr-2014	02-Jun-2014	22-Jul-2014	120.7	445.6	835.8	1402.1	1587.0b
		Isparta	21-Mar-2014	10-Apr-2014	03-Jun-2014	19-Jul-2014	90.7	466.5	745.1	1302.3	768.9c
		Şanlıurfa	26-Feb-2014	07-Mar-2014	26-Apr-2014	16-Jun-2014	70.5	545.7	950.1	1566.3	104.8e
		Tekirdağ	04-Apr-2014	19-Apr-2014	22-May-2014	26-Jul-2014	114.8	356.8	1143.5	1615.1	474.2d
		Tokat	05-Mar-2014	21-Mar-2014	07-May-2014	7-Jul-2014	79.5	461.2	940.5	1481.2	152.5e
						Mean	111.1	454.2	977.3	1542.6	672.0
						Max.	220.7	653.7	1633.4	1968.2	1831.9
						Min.	70.5	251.0	697.0	1302.3	104.8
										$Fvalue_{location}$	11.7733**
										CV (%)	31.43
2014-15	Fall sowing	Ankara	14-Oct-2014	02-Nov-2014	26-May-2015	15-Jul-2015	71.3	440.5	620.2	1132.0	3225.5b
		Aydın	03-Nov-2014	22-Nov-2014	18-Feb-2015	26-Jun-2015	204.7	483.0	1597.4	2285.1	922.8e
		Eskişehir	14-Oct-2014	27-Oct-2014	08-May-2015	30-Jun-2015	108.9	557.0	709.3	1375.2	1267.5d
		Isparta	23-Oct-2014	05-Nov-2014	07-May-2015	13-Jul-2015	73.9	442.4	879.6	1395.9	1328.0cd
		Şanlıurfa	27-Oct-2014	11-Nov-2014	10-Apr-2015	1-Jun-2015	136.4	763.8	778.8	1679.0	1516.8c
		Tekirdağ	16-Oct-2014	02-Nov-2014	20-Apr-2015	8-Jul-2015	152.6	734.2	1121.4	2008.2	916.7e
		Tokat	14-Oct-2014	25-Oct-2014	04-May-2015	29-Jun-2015	96.3	607.1	808.7	1512.1	3754.9a
						Mean	120.6	575.4	930.8	1626.8	1847.5
						Max.	204.7	763.8	1597.4	2285.1	3754.9
						Min.	71.3	440.5	620.2	1132.0	916.7
										$Fvalue_{location}$	65.3092**
										CV (%)	15.44
	Spring sowing	Ankara	01-May-2015	12-May-2015	22-Jun-2015	10-Aug-2015	84.6	452.5	795.5	1332.6	585.4b
		Aydın	17-Apr-2015	24-Apr-2015	7-Jun-2015	09-Jul-2015	70.4	731.3	669.1	1470.8	146.0d
		Erzurum	15-May-2015	30-May-2015	30-Jun-2015	01-Sep-2015	141.2	407.4	879.8	1428.4	624.2b
		Eskişehir	04-Mar-2015	06-Apr-2015	11-Jun-2015	10-Jul-2015	100.1	650.1	423.5	1173.7	295.4c
		Isparta	17-Mar-2015	10-Apr-2015	1-Jun-2015	17-Jul-2015	56.5	434.9	673.1	1164.5	574.0b
		Şanlıurfa	27-Feb-2015	12-Mar-2015	3-May-2015	09-Jun-2015	88.2	473.8	688.5	1250.5	311.5c
		Tekirdağ	16-Apr-2015	30-Apr-2015	10-May-2015	15-Jul-2015	110.1	121.0	1068.6	1299.7	82.8d
		Tokat	28-Feb-2015	17-Mar-2015	30-May-2015	06-Jul-2015	76.5	592.9	573.4	1242.8	2862.3a
						Mean	91.0	483.0	721.4	1295.4	685.2
						Max.	141.2	731.3	1068.6	1470.8	2862.3
						Min.	56.5	121.0	423.5	1164.5	82.8
										$Fvalue_{location}$	192.1848**
										CV (%)	19.03

**, P<0.01 significantly different according to the Duncan. Data was the means of 4 replications of plants during the second year (406.7 mm) was higher compared to the first year (224.8 mm). Low temperatures at flowering and maturity during 2014-2015 prolonged vegetation period and provided suitable environmental conditions for good growth (Schuster & Taghizadeh 1981; Kondra et al 1983). Due to higher regular and sufficient rainfall (90.75 mm) during the flowering and maturity (March-April-May-June) of second year growing season compared to the first year (56.5 mm) at Tokat locations. The second year seed yield was higher compared to the first year. The results of the previous studies support that the differences in yield could be derived from various years and locations which have different ecological conditions including air temperature, precipitation and agronomic practices (Saran & Giri 1987; Shafii et al 1992; Walton & Bowden 1999).

In spring sowing, the seed yield (685.2 kg ha^{-1}) of the second year was higher compared to the yield of the first year (672.0 kg ha^{-1}) (Table 3). This differences was a result of raising rainfall and air temperature during the growing period of plants.

Comparing GDD from sowing to emergence among all locations; it varied. It was earlier at Şanlıurfa and Isparta during 2013-14 and during 2014-15 compared to other locations in the same order. Flowering was shorter at Aydın compared to other locations during 2014. Flowering was shorter at Tekirdağ compared to other locations in 2015. Degree days from sowing to maturity within all locations was obtained earlier at Erzurum and Eskişehir during 2014 and 2015 compared to other locations.

Statistically significant differences were found between the two consecutive years in terms of seed yield of mustard. The highest seed yield (1831.9 and 2862.3 kg ha^{-1}) was obtained at Ankara and Tokat locations. The total GDD of mustard at Ankara and Tokat was obtained between 1302.3 and 1968.2 °C during 2014 and 1164.5 and 1470.8 °C during 2015, respectively. Sum GDD of mustard was observed the highest at Aydın during both years, but without increase in seed yield. The germination, growth, flowering stages, and ripening periods of the plants were determined as by temperatures and genetic factors. Environmental factors, especially temperature during the growing period of the plants is important. Especially, during flowering and ripening, as high temperatures and water stress caused decreases in seed yield (Hocking et al 1997; Kaleem et al 2010). The threshold temperature during flowering, resulting in seed yield losses, was 29.5 °C and high mean maximum temperature during vegetative development caused a reduction in induction of number of flowers for all of the tested Brassica species (Malcolm et al 2002). The precipitation of 69.2 and 58.6 mm during flowering, began and continued through May and June until the maturity of capsules after fertilization that affected positively during 2014. Erzurum had the highest altitude among locations; where the plants were not able to complete theire vegetative growth and entered generative phase at an earlier stage of growth that resulted in non development of their morphological features before generative maturity, therefore this affected completation of grain formation and yield. Thus, the grains were quite weak and feeble (Amirnia et al 2012). Varying results in yields among locations clearly demonstrated that, these differences among locations could be due to varying air temperatures, precipitation (Sra 1978; Christensen et al 1985; Walton & Bowden 1999).

Variation in maximum and minimum temperature largely alters the growth pattern of the crop by affecting the duration as well as onset of different phenophases. Quantification of the effects of temperature on crop growth can best be evaluated by GDD (mean ambient temperature minus the threshold temperature required for survival of crop). This quantification helps to know the thermal requirement for the start of different phenophases of crops (Dutta et al 2011). According to Miller et al (2001) mustard cultivars are available, each with specific GDD requirements, for emergence 110-136, for flowering 680-750, for maturity ranging from 1510 to 1610 growing degree days using a 5 °C base temperature. It is a cool loving crop with thermo and photo-sensitivity (Ghosh & Chatterjee 1988).

The best growth of mustard occurs between 12 and 25 °C. The optimum temperature for maximum and minimum growth and development are estimated at just over 20 °C and 5 °C in the same order. GDD has influenced the productivity and profitability of mustard under different weather conditions in locations and sowing seasons (Wahhab et al 2002).

In fall sowing, GDD were accumulated between 1473.0 and 2098.9 °C during 2013-14 and between 1132.0 and 2285.1 °C during 2014-2015. Seed yield was obtained from 513.3 to 1962.5 kg ha^{-1} during 2013-14 and from 916.7 to 3754.9 kg ha^{-1} during 2014-2015. In spring sowing, GDD were accumulated between 1302.3 and 1968.2 °C during 2014 and 1164.5 and between 1628.4 °C during 2015 depending on sowing dates under locations and ecological conditions. Seed yield in spring sowing was between 104.8 and 1831.9 kg ha^{-1} during 2013-14 and between 82.8 and 2862.3 kg ha^{-1} during 2014-2015. The results of this research showed that the locations and sowing seasons of mustard affected growing degree days for emergence, 50% flowering and physiological maturity during both years. Sum GDD of mustard increased at Aydın during both years compared to other locations, but its seed yield remained unchanged. This confirms that GDD accumulation plays a important role for higher seed yields. However, not only rainfall but also low and high temperatures are usually the most limiting factors for crop growth (Loss & Siddique 1994). Vegetative growth rate is also restricted by low temperatures (0-7 °C) in mid-winter and seed yield is adversely affected by high temperatures (25-40 °C) at the end of the season in spring and early summer (Turner et al 2001).

4. Conclusions

Different sowing seasons and locations might cause different environmental conditions from emergence to maturity. The accumulation of GDD determines the maturity of crop and yield. The target of this study was to determine the adaptation of mustard, in two sowing seasons (spring and fall) and differently selected Köppen-Geiger ecological locations of Turkey in terms of crop growth (emergence, 50% flowering, physiological maturity, and sum growing degree days) and seed yield. The Turkey is facing acute shortage of underground water levels and there is need to grow high vegetable oil producing crops suitable for biodiesel production with minimum input. This study reports the feasibility of mustard cultivation in different climatic zones of Turkey based on GDD or heat unit availability during the growing season and evaluates two years data. This evaluation report suggests minimum GDD for identifying useful sowing dates for harvesting profitable oil yield. In addition, the experimental locations lying in the North and West of Turkey were more useful, compared to the Erzurum location lying in the cold location with insufficient GDD suggesting non suitability of the location for commercial cultivation of mustard. These results clearly show that mustard is a suitable alternative crop for warm climatic regions of Turkey, irrespective of the location. It is assumed that there is a high potential of mustard for cultivation under arid climatic conditions of Turkey irrespective of the type of soil and environmental relative humidity status, if the farmers could be convinced to grow mustard in provinces that could accumulate GDD of at least 1132.0 °C. Differences among various locations might be due to the different climatic conditions that are based on prevailing temperatures during the growing period of mustard at these locations. The plants from fall sowing showed increased seed yield compared to the plants obtained from spring sowing; because mustard has tendency to mature (completes its life cycle) earlier (short duration) by accumulating less heat units.

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