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Variations trend of climate parameters affecting on grape growth (Case study: Khorasan Razavi Province)

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Abstract
The present study aims to investigate the structure and trend of climate parameters affecting grape growth in Khorasan Razavi (north eastern Iran) in the period of 1991-2015 in 8 weather stations. Effective climate elements such as temperature, precipitation, the number of hot days, the number of frost days, sunshine hours and parameters such as maximum temperature, annual average of temperature and precipitation, the growing season and phenological stages were calculated, and their effects on the quality of grapes were assessed. In general, the results indicated the warming in the growing season with a significant increase in great accumulation indices, particularly the increase in the maximum temperature, mean temperature, the number of days with maximum temperature bigger than 90^{th} percentile, and the number of days with the maximum temperature greater than 30 °C. Precipitation during the growth period particularly in the germination and blooming for all stations is reduced. This issue indicates potential soil moisture stress during this vital growth stage. Analyzing the crop evapotranspiration (ETC) indicated that because of warming, demands for water in the region have increased from 10% to 20%. These observations along with the continuation of global warming indicate that grape growth with favorable quality is impossible without adopting adaptations to the future climate changes.

Keywords
climate change, grape, phenology, precipitation, temperature.

1. Introduction
During recent decades, a lot of researchers have investigated the nature and effect of climate changes in different regions of the world (Houghton, 1996; Rosenzweig & Parry, 1994; Seinfeld & Pandis, 2016; Visser, 2008). Assessing and predicting effects of climate changes on different agricultural industries particularly climate-sensitive products during global warming are among these studies. Efficiency of agricultural products is related to climate conditions to a great extent. Therefore, this issue is possible via understanding agricultural climate prevailing in each region (Boote & Allen Jr, 1990; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004; Siwar, Alam, Murad, & Al-Amin, 2009; Slater, Peskett, Ludi, & Brown, 2007).

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First of all, these studies are merely scientific in nature without investigating a particular product. For example, in agro climatic reports of West Africa conducted by (Sivakumar, 1988), daily weather information based on moderate 10-days periods during 1961 to 1990 was used. The yearly, monthly, and 10-days precipitation patterns are investigated during the wet and dry periods (Amerine & Winkler, 1944) using the Thermal Index of Winkler, defined five great regions in California according to different daily temperature groups. (Jackson & Cherry, 1988) indicated that in rainy regions, the productivity rate of grapes gets lower. (Riou, 1994) presented an index for indicating the balance of soil-water potential used for the potential of quality of grapes in different climates. (Bowen & Hollinger, 2004) presented a model for determining appropriate areas for sowing a large number of agricultural products in Illinois State.

(Wielgolaski, 2003) studied the time of bud break, flowering, and fruit set for a number of trees in West Norway. He concluded that temperature has the highest effect on the growth of plants. (Tonietto & Carbonneau, 2004) studied the categorization based on the mentioned objectives for 29 countries in the form of 97 regions. (Sansavini & Lugli, 2005) studied Sweet Cherry Breeding Programs in Europe and Asia and evaluated the fruit quality traits such as size, flavor, flesh firmness and color. Campos-Vargas et al. (Campos-Vargas et al., 2006) probed effects of damages caused by seasonal frosts on size, color, and taste of a kind of peach tree in Chile. (Sameshima, Hirota, & Hamasaki, 2007) investigated the risk of frost for soybean in Japan. Using a one-kilometer lace network, they indicated this risk based on the potential of the occurrence of frost in the form of a map. (Khokhar, Hadley, & Pearson, 2007) investigated the effects of the duration of spring frost on the productivity of onion plants. The results of investigating thermal stress caused by climate changes by using the GAZE model on four key products (wheat, rice, corn and soybeans) in the world show that the most areas under the influence of thermal stress are in latitudes of 40 and 60 degrees north, including Central and East Asia, the capital of North America and northern parts of India (Teixeira, Fischer, van Velthuizen, Walter, & Ewert, 2013). The results of evaluating the effects of climate warming on the apricot tree phenology in springs in China conducted by (Guo, Dai, Wang, Xu, & Luedeling, 2015) showed that with the increase in temperature, especially in winters, spring phenological stages occur earlier and faster.

In Iran the first research in the field of agricultural climatology was mentioned as a study of the country's meteorological organization in cooperation with the company Quanta on the conditions of cultivation of 15 important Iranian crops (Quanta, 1975). In this research, the role of climatic elements and physical land factors has been studied on the products. Data analysis has provided a map of susceptible areas for cultivation. (Dinpajoh & Movaheddanesh, 1996) showed that two factors of temperature and precipitation about 88% of data changes for agricultural purposes Justifies using principal component analysis (PCA) from 123 climate-geographic variables from 77 meteorological stations in Iran.

One of the important products in Iran is grape, so that Iran ranked 11th in the world in grape production. This crop plays a great role in the agricultural industry in Iran and particularly in Khorasan Razavi Province. In Iran, grape has an important position in horticultural products occupying 11.8% of the total fruit production area in the country (Khoshroo, Mulwa, Emrouznejad, & Arabi, 2013). The cultivating area of the vineyards of the country in 2014 is about 302 ha/ha, with the account of dispersed grapevines, of which 92.1% are fertile trees. Fars province is in the first place with 20.8% of the fertility level of the vineyards of the country. The provinces of Khorasan Razavi and Qazvin have been ranked next to 12.2% and 11.2% of the country's grapes, respectively. The average yield per hectare of rainfed grapes was 1832 kg with the highest and lowest dryland yields with 1249.8 and 364.7 kg / ha, respectively belonging to Gilan and Khorasan Razavi provinces (Jahad Agriculture, 2015).

Investigating the grape crop (in the form of raisins) regardless of its quantity of harvest, its quality principally depends on natural and human factors. (Coombe, 1986) considers climate as one of the natural effective factors. Among climatic factors, the heat index is the factor affecting the production cycle of grapes. This factor is effective on the quality and quantity of grape production. In its growth period taking from 5 to 6 months, grapes need enough light and heat to about 18 °C. The favorable temperature for the growth of grapes in the growing season is from 10 to 30 °C. Therefore, grapes require about 1000 Growing Degree Hourly (GDH). This factor also has great effects on the aroma, color, and quality of grapes (Jackson & Lombard, 1993). (Kliewer & Torres, 1972) identified the effect of heating degree nights on the color of grapes. However, the groundwater depth in the soil is effective on quality of grapes.

Shortage of water has positive effects on quality of grapes (Blanco-Ward, Queijeiro, & Jones, 2015). (Ramos, Jones, & Martínez-Casasnovas, 2008) investigated the structure and trend of climate parameters affecting the production of grapes in three main southern stations in Spain and concluded that changes in a lot of temperature parameters has moderate to strong relationship with parameters of grapes such as earlier growth of grapes in the three regions. The only proper research, which has beendone on grapes in Iran belongs to (Heidari & Saeedabadi, 2009) in relation to the multi-criteria climatic classification of grape areas in Iran, according to (Tonietto & Carbonneau, 2004) identified 16 climatic groups of grape cultivars. But, the main objective and innovation of this research is to study the structure and trend of climate parameters affecting the growth of grapes and identify areas susceptible to grape cultivation with regard to climatic factors in Khorasan Razavi province and using the statistics of all synoptic stations of the province.

2. The study area

Khorasan Razavi province is located at the northeast of Iran. It is adjacent to Turkmenistan northerly and northeasterly, to Afghanistan easterly, to South Khorasan province southerly, and to Semnan province westerly. The study region is located within the longitude and latitude of 56° 19” to 61° 16” E and 33° 52” to 37° 42” N (Fig. 1).

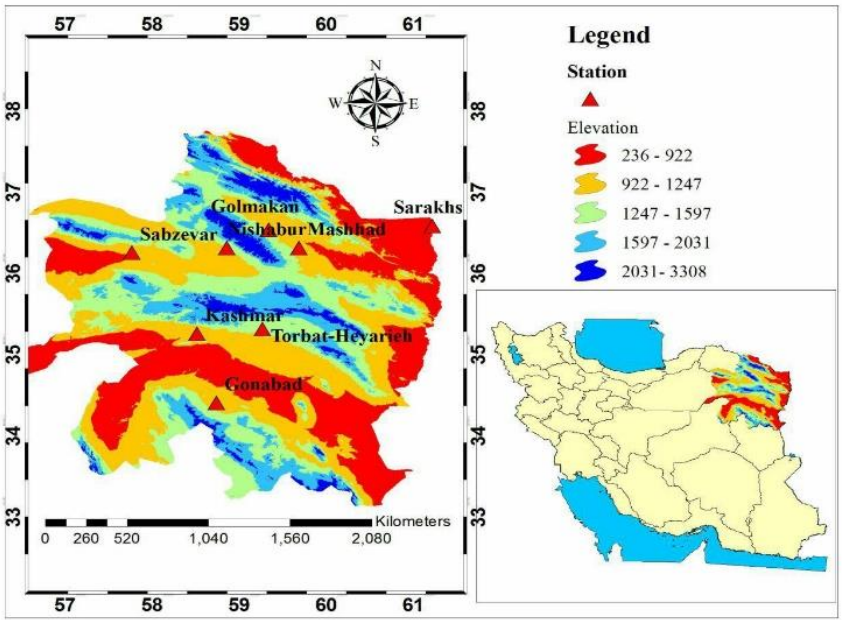

Fig. 1. Location of the study area

3. Materials and Methods

In this research, we will use the checked information on grape varieties of the White grapes variety, which was measured at the Golmakan-Mashhad Agricultural Research Center Station, as the representative of the grape varieties. Temperature and precipitation have significant roles in cultivation and growth of grapes. Temperature has a great role in the date of cultivation, and production of different stages in the growth to harvest of grapes. Also, the role of precipitation and soil moisture are significant for growth of grapes. The data used for extraction of bioclimatic and extreme temperature indices for grape cultivation are identified in Table 1 in terms of yearly time scale, the growing season, and important periods of grape cultivation.

Table 1. Indicators of temperature and precipitation effective in grape growth (Ramos et al., 2008)

No.	Variable	Description
		Temperature indices
1	GSTavg	Average growing season temperature (March to October)
2	GSTmax	Average growing season maximum temperature (March to October)
3	GSTmin	Average growing season minimum temperature (March to October)
4	NDTmin90p	Yearly number of days with minimum temperature>90th percentile
5	NDTmax90p	Yearly number of days with maximum temperature>90th percentile
6	NDTmin10p	Yearly number of days with minimum temperature<10th percentile
7	NDTmax10p	Yearly number of days with maximum temperature<10th percentile
8	FD	Frost occurrence; number of days with minimum temperature<0 °C
9	FFL	Frost-free period length; number of days between dates with temperature<0°C
10	ND25	Number of days with Tmax> 25°C
11	ND30	Number of days with Tmax> 30°C, critical temperature for optimum growth
12	WI	Winkler index (Winkler et al., 1974)
13	HI	Huglin index (Huglin, 1978)
14	DTR	Daily temperature range during ripening (Tmax–Tmin; June and July)
		Precipitation indices
1	P_{yearly}	Total yearly precipitation
2	Pgs	Total growing season precipitation (March to October)
3	Pmax	Maximum 1 d precipitation total
4	Dpl(d)	Maximum yearly drought period
5		Rainfall during
	P-I	Stage I: budbreak
	P-II	Stage II: budbreak to bloom
	P-III	Stage III: bloom to Grow Sour
	P-IV	Stage IV ripening (véraison to harvest)
	P-V	Stage V: : post-harvest
	P-VI	Stage VI: dormant period
6	NP95p	Number of days with precipitation >95th percentile (very wet days)
7	%P95p	Percentage of yearly precipitation recorded on very wet

For collecting required data, firstly, variables of minimum, maximum, and average growing season temperature were collected from each station. Then, stages of phenological development of grapes and quality of grapes were obtained via the Winkler Index and Huglin's Heliothermal Index. After that, the number of days, whose minimum and maximum temperatures were bigger than the 90th percentile and smaller than 10th percentile, were calculated. The occurrence of frost was evaluated using the days whose minimum temperatures were smaller than 0 C°. Moreover, the duration of the frost-free period and the investigation of the heat stress with days with bigger than 0 °C and 30 °C was determined respectively. The Winkler Index was obtained via the subtracting the base temperature of grapes (10 °C) from the average temperature in Equation (1).

$$WI = \sum_{march}^{october} (T_m - 10) \quad (1)$$

where T_m indicates the average daily temperature.

According to this index, regions lower than 2500 Growing Degree Day (GDD) is at the first class, regions within 2501 to 3000 GDD are in the second class, regions within 3001 to 3500 GDD are in the third class, regions within 3501 to 4000 GDD are in the fourth class, and those higher than 4000 GDD are in the fifth class (Albert Julius Winkler, 1962). The solar heat index or Huglin's Heliothermal Index (Huglin, 1978) identifies the solar thermal potential level for the grape growing season. This index gives more weights to the maximum temperature for March to April. This index can be obtained from Equation (2).

$$HI = \sum_{march}^{october} k \frac{(T_m - 10) + (T_{max} - 10)}{2} \quad (2)$$

where T_m is the average daily temperature and T_{max} is the maximum daily temperature. K is the heat component indicating the average day length in relation with latitude. In other words, K is the day length coefficient changing as 1 to 1.06 in the north hemisphere within latitudes 40° to 50° N (regarding the location of Iran within latitudes 25° to 40° N, this coefficient is as 1).

According to Huglin's index, regions lower than 1200 GDD are in the temperate climate group, regions within 2101 to 2400 are in the mildly warm climate group, those within 2401 to 3000 are in the warm climate group, and regions higher than 3001 are in the very hot climate group. According to (Blanco-Ward et al., 2015), these two bioclimatic indices whose calculation is based on changes in the GDD are among the most expansive indices for grape cultivation and presentation of general guidelines for the potential quality of grapes. Finally, the diurnal temperature range (DTR) during the ripeness of grapes (June and July) was calculated. The result is the difference between the maximum and minimum daily temperatures and the investigation of the trend of important factors in the quality of grapes.

Regarding the low precipitation regimes in arid and semi-arid areas, to evaluate accessible water for growing grapes in different periods, the data of precipitation in stations was yearly used. In addition, the rate of precipitation in different stages of the growing season, the maximum total precipitation in one day, the number of days with precipitation more than the 95^{th} percentile (a very wet day), the rate of yearly precipitation recorded in a very wet day, and the maximum of the length of yearly drought (maximum of the number of consecutive days without Precipitation in a year), were calculated (Hidalgo, 2002).

Temperature greater than 30 °C can result in heat stress, early blooming, grain loss, and the activation of enzymes involved in reducing the quality and taste of grapes. The Winkler index was also calculated for March to October by considering the average monthly temperature. The non-parametric Mann-Kendall test with approximation of normal distribution was employed for assessing the present trend in data related to temperature. In addition, to investigate the homogeneity of time series of the precipitation data, the SNHT test (Standard Normal Homogeneity Test) developed by (Alexandersson, 1986) was employed. With regard to arid and semi-arid climate of the region and its low precipitation summers, evapotranspiration and its process were investigated. To do so, the hour data were used for calculating evapotranspiration with the FAO Penman-Monteith method. These data included data of temperature, precipitation, humidity, wind speed and sunshine hours for each station from 1991 to 2015 extracted from Meteorological Organization of Iran, and Crop Evapotranspiration (ET_C) using the crop coefficient (K_C) suggested in FAO Journal, No. 56. To calculate the extraterrestrial radiation, the equation presented in (Allen, Pereira, Raes, & Smith, 1998) was used. It should be noted that to identify outliers, the data which had more than three standard deviations from the mean were deleted.

4. Results and Discussion

As discussed in the previous section, in the present research, two Winkler index and Huglin's index were used for calculating the GDD and the starting date of grape phenological stages. Because of avoiding repetition, only the results related to Huglin's index are discussed in the present study. Table 2 indicates the starting date of grape phenological stages based on Huglin's Heliothermal Index in each station. The first stage, which starts from the advent of bud breaks to leaf-bearing stages, starts earlier in Gonabad station and later in Nishabur station than other stations. The shortest period of grape growth is in Sarakhs station and its longest period is in Golmakan station. In addition, the shortest period of time for ripeness of grapes (the fourth grape phenological stage) is related to Sarakhs station, and its longest period of time is related to Mashhad and Golmakan stations. In the central areas the duration of the grape growth period, from bud break to ripeness, is from March to August. But in northern areas such as Mashhad, Golmakan, and Nishabur, because of having higher height and lower temperature, phenological stages start later than southern areas (Jones et al., 2005).

Table 2. The starting time of grape phenological stages in 8 selected stations of Khorasan Razavi Province in the period 1991-2015.

Station	Stage	Date of phenological stages	Station	Stage	Date of phenological stages
Mashhad	I.	23 March – 20 April	Golmakan	I.	23 March – 22 April
	II.	21 April – 12 May		II.	23 April – 15 May
	III.	13 May – 15 June		III.	16 May – 18 June
	IV.	16 June – 17 July		IV.	19 June – 20 July
	V.	18 July – 28 October		V.	21 July – 28 October
	VI.	29 October – 22 March		VI.	29 October – 25 March
Kashmar	I.	17 March – 14 April	Gonabad	I.	13 March – 8 April
	II.	15 April – 3 May		II.	9 April – 28 May
	III.	4 May – 7 June		III.	29 April – 31 May
	IV.	8 June – 7 July		IV.	1 June – 1 July
	V.	8 July – 3 November		V.	2 July – 8 November
	VI.	4 November – 16 March		VI.	9 November – 12 March
Sabzevar	I.	16 March – 8 April	Sarakhs	I.	18 March – 10 April
	II.	9 April – 1 May		II.	11 April – 1 May
	III.	2 May – 3 June		III.	2 May – 3 June
	IV.	4 June – 2 July		IV.	4 June – 1 July
	V.	3 July – 12 October		V.	2 July – 25 July
	VI.	13 October – 15 March		VI.	26 July – 17 March
Torbat Heydarieh	I.	21 March – 23 April	Nishabur	I.	26 March – 20 April
	II.	24 April – 11 May		II.	21 April – 15 May
	III.	12 May – 16 June		III.	16 May – 17 June
	IV.	17 June – 17 July		IV.	18 June – 20 July
	V.	18 July – 8 October		V.	21 July – 29 October
	VI.	9 October – 20 March		VI.	30 October – 25 March

Stage I: budbreak
Stage II: budbreak to bloom
Stage III: bloom to Grow Sour
Stage IV ripening (véraison to harvest)
Stage V: post-harvest
Stage VI: dormant period

4.1. Results related to the trend of temperature parameters

The results related to temperature variables for all eight study stations are represented in Table 3. For example, the trend of the average temperature was positive and significant at the 5% level in Sabzevar station, and at the level of 1% in other stations. The increase in the maximum temperature in the different stages of grape growth results in the occurrence of moisture stress, water demand, reduction in the amount of sugar and increase in the amount of acid (the increased in the sourness of grapes); therefore, crop returns to be reduced (Rapisarda, Bellomo, & Intelisano, 2001).

The trend of the maximum temperature in all stations was positive and significant at the 1% level. The trend of the minimum temperature in Kashmar station was positive and significant at the 5% level, while this trend was not significant for Sabzevar station. But it was positive and significant at the 1% level in other stations. Therefore, the average temperature, maximum temperature, and minimum temperature in the growth season have increased in all stations.

The trend of days with maximum temperatures higher than the 90^{th} percentile (hot nights) in Mashhad, Torbat-e Heydarieh, and Golmakan stations was positive and significant at the 1% level, while this increasing trend was not significant in Kashmar and Nishabur. However, it was positive and significant in Gonabad and Sarakhs at the 5% level. This trend increased only in Sabzevar station, but it was not significant. The number of days with maximum temperatures higher than the 90^{th} percentile (hot days) increased in all stations. The trend of changes in Mashhad, Golmakan, and Sarakhs stations was positive and significant at the 10% level, while this increasing trend was not significant in Kashmar, Gonabad, Sabzevar, and Torbat-e Heydarieh. It was positive and significant at the 5% level in Nishabur station. The number of days with minimum temperatures lower than 10^{th} percentile (cold nights) had the decreasing trend in Mashhad, Kashmar, Gonabad, Torbat-e Heydarieh, and Golmakan, but it had an increasing trend in other stations.

The number of days with maximum temperatures lower than 10^{th} percentile (cold days) had the decreasing trend in Mashhad, Sarakhs, Torbat-e Heydarieh, Nishabur and Golmakan, and this trend was significant at the 5% level inTorbat-e Heydarieh station. The number of frost days had the increasing trend only in Nishabur, while it had no significant increase or decrease in Sarakhs station. Other stations had decreasing trends which was significant at the 5% level in Mashhad and Golmakan.

Table 3. Statistics of Mann-Kendall test for climate variables of temperature for eight selected stations in Khorasan Razaviprovince in the period 1991-2015

Station	Variable	Tren. yr–1	MK- test		Trend. yr–1	MK-test
Mashad	GSTavg (°C)	0.10	3.48**	Golmakan	0.09	3.67**
	GSTmax (°C)	0.11	3.29**		0.11	3.62**
	GSTmin (°C)	0.08	3.95**		0.07	3.53**
	NDTmin90p	1.15	3.36**		0.70	2.95**
	NDTmax90p	1.38	3.49**		1.47	3.56**
	NDTmin10p	-0.46	-1.29		-0.46	-1.22
	NDTmax10p	-0.47	-1.40		-0.17	-0.58
	FD (days)	-0.75	-1.92*		-0.81	-2.10*
	FFL (days)	0.72	1.96*		0.83	2.13*
	ND25 (days)	1.50	3.37**		1.28	3.16**
	ND30 (days)	1.24	3.39**		1.50	3.20**
	WI(March-Oct,°C)	22.97	3.57**		17.52	3.67**
	HI(March-Oct, °C)	24.06	3.32**		18.13	3.62**
	DTR(June-July, °C)	0.02	0.99		0.05	1.90*
Kashmar	GSTavg (°C)	0.07	2.36**	Gonabad	0.07	3.23**
	GSTmax (°C)	0.07	2.56**		0.06	2.91**
	GSTmin (°C)	0.06	2.25*		0.07	3.25**
	NDTmin90p	0.50	1.50		0.55	1.87*
	NDTmax90p	0.50	1.50		0.51	1.48
	NDTmin10p	0.00	-0.12		-0.15	-0.26
	NDTmax10p	0.09	0.28		0.00	0.12
	FD (days)	0.00	-0.14		-0.45	-1.33
	FFL (days)	0.00	-0.14		0.40	1.21
	ND25 (days)	1.03	2.71**		1.00	2.97**
	ND30 (days)	1.20	2.76**		1.29	3.34**
	WI(March-Oct,°C)	19.56	3.45**		24.87	3.52**
	HI(March-Oct, °C)	20.61	3.29**		24.51	3.80**
	DTR(June-July, °C)	0.02	1.40		0.01	0.51
Sabzevar	GSTavg (°C)	0.05	2.03*	Sarakhs	0.09	3.81**
	GSTmax (°C)	0.06	2.6**		0.10	3.74**
	GSTmin (°C)	0.00	1.25		0.09	4.10**
	NDTmin90p	-0.23	-0.51		0.57	2.27*
	NDTmax90p	0.21	0.77		1.44	4.27**
	NDTmin10p	0.26	0.33		0.38	0.96
	NDTmax10p	0.20	0.44		-0.11	-0.49
	FD (days)	0.00	-0.04		0.00	0.00
	FFL (days)	0.00	0.02		0.00	-0.02
	ND25 (days)	0.68	2.01*		1.00	2.71**
	ND30 (days)	1.00	2.17*		1.26	3.70**
	WI(March-Oct,°C)	10.82	1.84*		22.21	3.97**
	HI(March-Oct, °C)	11.50	1.68*		24.14	3.94**
	DTR(June-July, °C)	0.00	0.82		0.05	1.77*
Torbat-e Heydarieh	GSTavg (°C)	0.06	3.15**	Nishabur	0.07	3.07**
	GSTmax (°C)	0.10	3.47**		0.08	3.19**
	GSTmin (°C)	0.07	3.26**		0.05	2.42**
	NDTmin90p	0.70	2.93**		0.22	0.94
	NDTmax90p	0.64	1.50		0.60	1.82*
	NDTmin10p	-0.09	-0.23		0.14	0.47
	NDTmax10p	-0.50	-1.76*		0.00	-0.19
	FD (days)	-0.28	-0.54		0.00	0.12
	FFL (days)	-0.28	-0.54		0.00	-0.16
	ND25 (days)	1.50	3.60**		1.15	3.14**
	ND30 (days)	1.17	2.74**		0.88	3.30**
	WI(March-Oct,°C)	18.32	2.92**		15.74	3.01**
	HI(March-Oct, °C)	20.84	3.34**		18.38	3.29**
	DTR(June-July, °C)	0.00	0.62		0.02	0.94

** significant at the level of 1%
* significant at the level of 5%

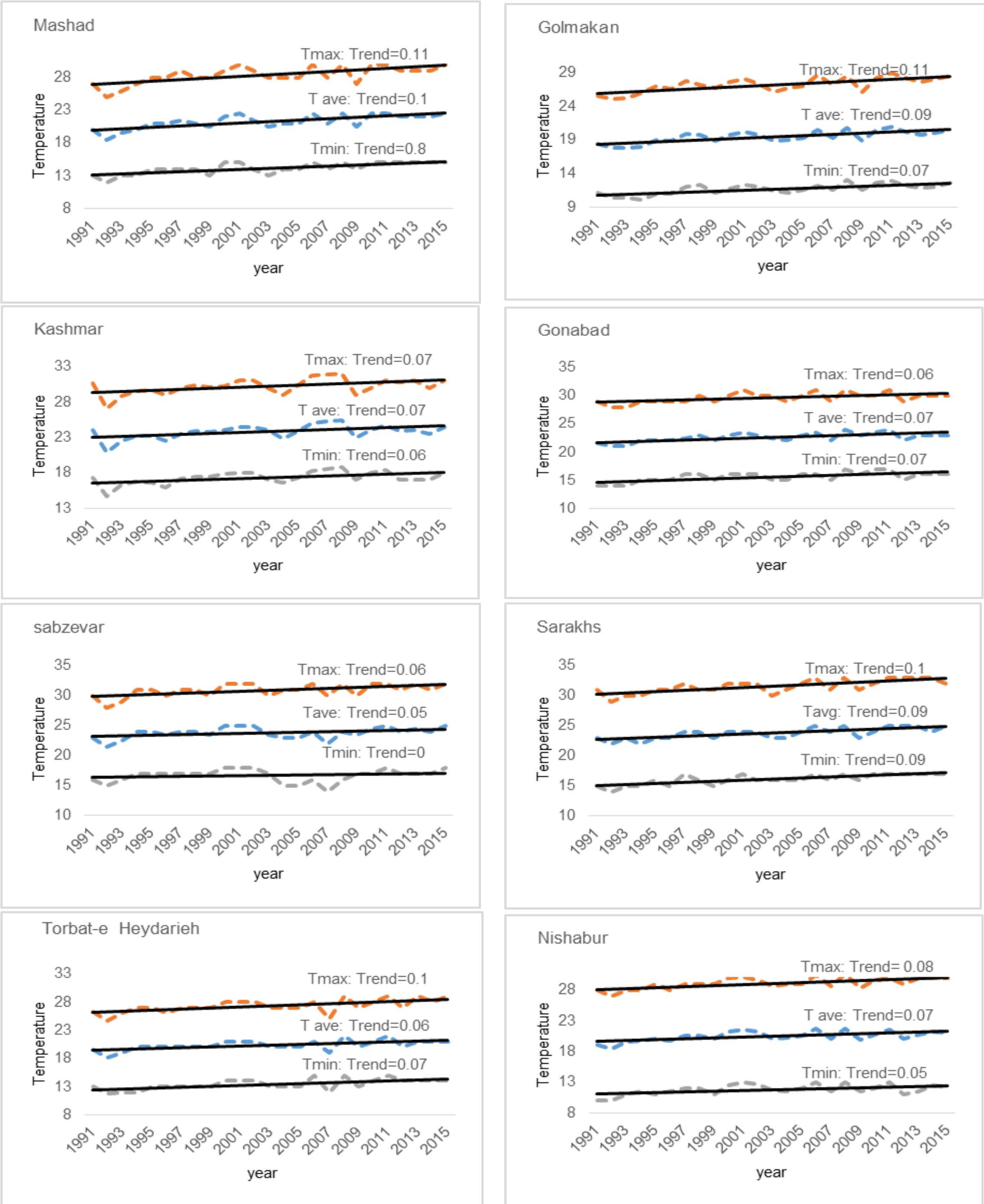

Fig. 2. Trend of temperature changes (mean, maximum, and minimum) during the growing season in the eight study stations of Khorasan Razavi province in the period 1991-2015.

The duration of the frost-free period in Gonabad, Sabzevar, Mashhad, and Golmakan stations had an increasing trend. In Mashhad and Golmakan stations, the trend was significant at the 5% level. In other stations, the trend was decreasing. The highest number of frost days was observed in Torbat-e Heydarieh, while the longest frost-free periods were in Sarakhs (331 days), Kashmar (329 days), and Sabzevar (326 days). The days with temperatures higher than 25 °C in all stations had the increasing trends. This increasing trend was significant in Sabzevar station at the 5% level, while in other stations it was significant at the 1% level. Regarding the fact that the average daily temperature from 25 to 30 °C has important roles in increasing inappropriate quality and growth of grapes particularly in ripeness months; therefore, the increase in this variable can have suitable roles in the quality of grapes and their productivity (White, Diffenbaugh, Jones, Pal, & Giorgi, 2006). Days with temperatures higher than 30 °C increased significantly in all stations. This increasing trend was significant in Sabzevar station at the 5% level, while it was significant in other stations at the 1% level. It should be noted that temperatures higher than 30 °C can result in stress in plants, early blooming, and reduction in photosynthesis. As a result, some measures should be conducted to cope with this problem. For example, sprinkler irrigation to reduce air temperature and prevent plants from imposing increases in temperature and heat stress.

Regarding the significance of light and heat in different phenological stages, particularly in the ripeness having a lot of effects on taste and color of grapes (Mattheis & Fellman, 1999), central areas such as Kashmar have more favorable climate than northern areas because of having more hot days. The results obtained by Heidari emphasize on accuracy of this subject (Heidari & Saeedabadi, 2009). Winkler index and Huglin's index had significant increasing trends in most stations. This issue indicates the increase in potential environmental heat for grape cultivation. This increasing trend was significant in Sabzevar station at the 5% level. It also was significant in other stations at the 1% level. The DTR had increasing trends at the time of ripeness of grapes (in June and July) in all stations. It also was significant in Sarakhs and Golmakan stations at the 5% level. Figure 2 indicates temperature changes in the eight study stations in the period of 1991-2015.

4.2. The trend of precipitation parameters

The trend of changes related to precipitation is presented in Table 5. As observed, the total yearly precipitation has reduced in all stations. This decreasing trend was significant in Kashmar and Torbat-e Heydarieh Stations at the 1% level, and in Mashhad and Gonabad stations at the 5% level. Total precipitation in the growing season had an increasing trend in Kashmar, but no change was observed in Nishabur. The decreasing trend was observed in other stations. The maximum one-day precipitation had an increasing trend in Sabzevar, Golmakan, and Nishabur stations. But this trend was decreasing in other stations and in Kashmar Station; the trend was negative at the 5% significance level. The number of days with precipitation higher than the 95th percentile (very wet days) had the decreasing trend in all stations. This trend was significant at the 1% level for Torbat-e Heydarieh and significant at the 5% level for Kashmar and Gonabad stations. In addition, the number of days with precipitation higher than the 95th percentile has the decreasing trend. This trend was significant at the 1% level for Torbat-e Heydarieh and significant at the 5% level for Kashmar, Sabzevar, and Gonabad stations.

The longest consecutive dry period length (DPL) was in stations Gonabad with 144 days, Sarakhs with 127 days, and Kashmar with 118 days, while in other stations, it reduced into fewer than 100 days. Days without precipitation had a decreasing trend in all stations, while the trend of changes was significant at the 5% level only in Sabzevar, Torbat-e Heydarieh, and Golmakan. The rate of precipitation in the first grape phenological stage (leaf-bearing stage) had a decreasing trend in all stations. This trend was significant at the 5% level only in Golmakan and Gonabad stations. The trend of precipitation changes in the second grape phenological stage (flowering stage) had a decreasing trend in Sabzevar station, but there was no change in Golmakan station. Other stations had a decreasing trend which was significant at the 1% level only in Golmakan station. The trend of precipitation changes in the third grape phenological stage (growth of sour grapes stage) had an increasing trend in Kashmar, Golmakan, and Nishabur stations, but there was no change in Golmakan station. In other stations, this trend was decreased. This decreasing trend was significant at the 5% level only in Golmakan station. The trend of precipitation changes in the fourth grape phenological stage (ripeness of grapes) had an increasing trend in Kashmar, Golmakan, and Nishabur stations, but there was no change in Sabzevar station. In other stations, this trend was decreased. The trend of precipitation changes in the fifth grape phenological stage (postharvest stage) had a decreasing trend in Mashhad and Golmakan stations. In other stations, this trend increased. This increasing trend was significant at the 5% level in Kashmar and Sarakhs stations. The trend of precipitation changes in the sixth grape phenological stage (sleeping stage) had a decreasing trend in all stations. This decreasing trend was significant at the 1% level in Kashmar, Sabzevar, and Torbat-e Heydarieh.

Table 4. Statistics of Mann-Kendall test for climate variables of precipitation for eight selected stations in Khorasan Razaviprovince in the period 1991-2015

Station	Variable	Trend yr^{-1}	MK- test	Station	Trend yr^{-1}	MK- test
	P_{yearly}	-4.87	-2.29*		-2.19	-1.38
	P_{gs}	-2.32	-1.5		-0.79	-1.19
	P_{max}	-0.13	-0.35		0.00	0.09
	NP95p	-0.2	-1.46		-0.17	-1.34
	%P95p	-0.05	-1.46		-0.04	-1.34
Mashhad	Dpl(d)	-0.45	-0.44	Golmakan	-1.45	-1.73*
	^{P}-I	-0.52	-1.38		-1.65	-2.22*
	^{P}-II	-0.16	-0.52		0.00	0.00
	^{P}-III	0	-0.09		0.00	0.05
	^{P}-IV	0	-0.05		0.00	0.54
	^{P}-V	-0.07	-0.54		-0.19	-0.89
	^{P}-VI	-1.71	-1.4		-2.19	-1.38
	P_{yearly}	-5.78	-2.09**		-3.48	-2.07*
	P_{gs}	0.11	0.04		-1.08	-1.12
	P_{max}	-0.5	-1.96*		-0.27	-1.33
	NP95p	-0.4	-2.13*		-0.44	-1.85*
	%P95p	-0.09	-2.13*		-0.09	-1.85*
	Dpl(d)	-2.15	-1.63		-1.64	-0.04
Kashmar	^{P}-I	-1.04	-1.63	Gonabad	-1.23	-1.72*
	^{P}-II	-0.8	-2.54**		-0.42	-0.04
	^{P}-III	0.00	0.04		0.00	-1.85*
	^{P}-IV	0.00	1.49		-0.42	-0.20
	^{P}-V	0.41	1.66*		0.00	1.15
	^{P}-VI	-3.06	-2.45**		0.08	-1.80*
	P_{yearly}	-3.27	-1.42		-1.78	-0.98
	P_{gs}	-0.89	-0.70		-0.97	-0.91
	P_{max}	0.06	0.47		-0.36	-1.42
	NP95p	-0.24	-1.60		-0.07	-0.40
	%P95p	-0.06	-1.60*		-0.02	-0.40
	Dpl(d)	-1.97	-1.84*		-1.52	-1.23
Sabzevar	^{P}-I	-0.96	-2.12	Sarakhs	0.00	-0.04
	^{P}-II	0.65	0.95		-0.29	-1.24
	^{P}-III	-0.32	-0.77		-0.17	-0.70
	^{P}-IV	0.00	0.00		0.00	-0.32
	^{P}-V	0.07	0.53		0.27	1.94*
	^{P}-VI	-2.54	-1.75**		-1.00	-0.84
	P_{yearly}	-6.97	-3.3**		-0.57	-0.28
	P_{gs}	-1.83	-1.38		0.00	0.00
	P_{max}	-0.5	-1.62		0.06	0.35
	NP95p	-0.38	-2.37**		0.00	-0.23
	%P95p	-0.08	-2.37**		0.00	-0.23
Torbat-e	Dpl(d)	-1.14	-1.87*		-0.91	-0.77
Heydarieh	^{P}-I	-0.68	-1.05	Nishabur	-0.21	-0.40
	^{P}-II	-0.27	-0.51		-0.31	-0.65
	^{P}-III	-0.15	-1.05		0.12	0.54
	^{P}-IV	0	-0.57		0.00	0.55
	^{P}-V	0	0.17		0.27	1.43
	^{P}-VI	-4.61	-2.57**		-1.36	-0.91

* significant at the level of 1%
** significant at the level of 5%

The decreasing trend of precipitation in stages 1 and 2 (leaf-bearing and flowering stages), and sometimes in the third stage (sour grape growth stage) results in the occurrence of moisture stress and water demand, reduction in the amount of sugar and increase in amount of acid (the increased in the sourness of grapes) (Rapisarda et al., 2001). Generally, after the stage of bud break, a significant decrease in precipitation was observed in most stations. This issue requires water management for eliminating needs of products. Moisture stress can disturb the process of growing plants and result in sunburn and reduction in efficiency of products. Investigating the process of increasing temperature particularly the average maximum temperature during the growing season indicates the significance and necessity of more attention to water needs of products (Christy, Norris, Redmond, & Gallo, 2006).

The increase in the number of hot days due to their negative effects on the crop returns should be managed via controlling water and other environmental investigations. Regarding

Table 4, Winkler index in Gonabad with 3140 GDD, Kashmar with 3242 GDD, Sarakhs with 3242 GDD, and Sabzevar with 3375 GDD had the highest values, respectively. These stations are in the third class of Winkler index. Mashhad with 2592 GDD is in the second class and Golmakan, Torbat-e Heydarieh, and Nishabur with GDD lower than 2500 were at the first class. In case of Huglin's index, Sabzevar with 4211 GDD, Sarakhs with 4116 GDD, Gonabad with 4050 GDD had the highest values and Golmakan with 2500 GDD had the lowest value (Table 4). In classification of climate groups of grape cultivation based on Huglin's index, Sabzevar, Sarakhs, Mashhad, Gonabad, Torbat-e Heydarieh, Nishabur, and Kashmar stations were in the very hot class, and Golmakan station with lower units was in the hot class. Table 3 indicates the trend of changes of Huglin's index in the study stations. As observed, Winkler index and Huglin's index had similar trends in all stations and the increasing trend in these indices was significant in some stations for example the increasing trend in Gonabad stations chang its climate from hot to the hottest category (A.J. Winkler, Cook, Kliewer, & Lider, 1974).

Fig. 3. The trend of Winkler index and Huglin's index in the eight study stations of Khorasan Razavi province in the period 1991-2015

4.3. Evapotranspiration and water requirement of grapes

Table 5 indicates the average precipitation and evapotranspiration of grapes in main grape phenological stages in the selected stations. As observed, in most stations, the rate of crop evapotranspiration in the first stage is 3-5%, in the second stage is 3-5%, in the third stage is 20-27%, in the fourth stage is 20-31%, in the fifth stage is 19-41%, and in the sixth stage is 9-15% of yearly average actual evapotranspiration (Table 5). Most precipitations occur at the beginning of springs and during winters. In other words, in the first and second grape phenological stages (leaf-bearing and flowering stages) in which evapotranspiration are less, the rate of precipitation is higher. This happens while that most water requirements and evapotranspiration occur in the third and fourth stages (sour grape growth and crop ripeness), but precipitation received in this time has reduced significantly; therefore, grape water requirements are not supplied and grapes suffer from moisture stress (Ramos et al., 2008). The rate of precipitation in the sour grape growth, crop ripeness, and postharvest stages is lower than grape water requirements and grapes need complementary watering for complete growth and bearing appropriate grapes.

Table 5. The average precipitation and evapotranspiration of grapes for main grape phenological stages in the selected stations of Khorasan Razaviprovince in the period 1991-2015 (ETCS.ETcA crop evapotranspiration as a percentage of yearly potential and actual evapotranspiration)

Station	Stage	Prec (mm)	ETc (mm)	ETcS. EtcA (%)	Station	Stage	Prec (mm)	ETc (mm)	ETcS. ETcA (%)
Mashhad	I	36.2	29.0	4.3	Golmakan	I	51.4	39.4	5.6
	II	25.6	27.6	4.1		II	19.5	21.5	3.1
	III	18.0	155.8	23.1		III	17.6	186.5	26.7
	IV	1.6	169.8	25.2		IV	1.3	185.3	26.5
	V	10.1	201.3	29.8		V	9.9	173.2	24.8
	VI	149.6	91.2	13.5		VI	119.2	92.5	13.2
Kashmar	I	28.2	25.4	3.9	Gonabad	I	23.5	24.1	3.4
	II	16.8	22.9	3.6		II	11.5	23.3	3.3
	III	9.5	152.3	23.6		III	7.7	166.3	23.6
	IV	1.1	153.6	23.9		IV	0.3	174.8	24.8
	V	9.2	218.2	33.9		V	5.2	249.1	35.3
	VI	123.9	71.7	11.1		VI	80.2	67.2	9.5
Sabzevar	I	25.1	44.8	5.3	Sarakhs	I	25.5	20.9	3.0
	II	162.9	26.8	3.2		II	14.5	22.3	3.3
	III	15.1	181.0	21.6		III	12.7	139.7	20.3
	IV	4.6	185.9	22.2		IV	1.2	140.8	20.5
	V	10.8	321.2	38.3		V	6.1	281.3	41.0
	VI	117.8	79.0	9.4		VI	128.1	81.8	11.9
Torbat-e Heydarieh	I	39.2	28.9	4.5	Nishabur	I	36.3	23.9	3.9
	II	23.8	25.0	3.9		II	21.3	30.0	4.8
	III	11.8	105.7	16.5		III	12.0	146.1	23.6
	IV	3.2	198.6	31.0		IV	2.1	169.8	27.4
	V	5.2	202.5	31.6		V	7.0	177.1	28.6
	VI	174.9	80.3	12.5		VI	162.8	72.4	11.7

Stage I: budbreak
Stage II: budbreak to bloom
Stage III: bloom to grow sour
Stage IV: ripening (véraison to harvest)
Stage V: post-harvest
Stage VI: dormant period

5. Conclusions

Finding result These values indicate that the climate of Kashmar, Nishabur and Mashhad is favorable for grape growth, but in some regions such as Sarakhs and Gonabad, grape growth faces problems caused by high temperature and shortage of precipitation. As (Jones et al., 2005) found that phenology–temperature relationships over the last 30–50 years for numerous varieties and locations in Europe show a 3–6 d response per 1 °C of warming. Furthermore, modeling of grapevine phenology for Syrah in France predicted earlier start of ripening by 3–5 weeks with a 2–4 °C warming (Lebon, 2002). The decreasing trend of rainfall in most stations (Nazemosadat & Cordery, 2000), and the high rate of excitatory transpiration adds to the importance and necessity of irrigation of vineyards in the province's warmer areas.

Shorter-term analysis of crop evapotranspiration (ETc) reveals that the current impact per 1 °C of growing season (March to October) warming is an increase in water demands in the region. These observations, combined with climate projections, indicate potential disruption of climate–variety balance, increasing water stress, and challenges in producing quality grape without the adoption of appropriate adaptive measures.

Therefore, the results of the present study is consistent with (Heidari & Saeedabadi, 2009). Moreover, the results of the present study in relation with the effect of climate parameters on grape growth are consistent with (Ramos et al., 2008) and (Blanco-Ward et al., 2015) which investigated the structure and trend of climate parameters affecting grape growth. In general, using the results obtained from the present study, favorable regions for grape cultivation can be identified in the study region, and the production of grapes can be enhanced based on the cultivation calendar of this valuable crop.

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