Evaluation of the Past Climate Change Effects on Potato Growth and Yield by Modeling

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Abstract

Global warming and climate change and their effects on the phenology stages and crop production have attracted researchers' attention. We investigated the impacts of climate change, phenology stages, and yield potential on the growth and development of potatoes as a stable food crop. This study used the SSM-iCrop2 simulation model methodology to investigate the climate change process, phenology stages, yield potential, and climate change's effects on potato growth and development in 19 main meteorological stations from 1991 to 2015. The meteorology stations were selected based on the area under potato cultivation to implement the GYGA protocol. The SAS program explored the trends and slopes of the evaluable parameters, and GIS maps were used to analyze and interpret the trends and slopes. The results on potato phenological stages showed that with increasing the average temperature, the length of planting period until the beginning of tuber formation in two meteorological stations, the period of tuber formation in four meteorological stations, and the whole growing period in six meteorological stations, were significantly decreased. The results also showed that the changes during the phenological stages, temperature, and radiation received during the growth caused a significant increase in yield at Shahrekord meteorological station and a substantial decrease in the other 6 meteorological stations. Based on the results, climatic factors significantly affected total yields.
Keywords: Climate Change, Modeling, Phenology, Potato, Yield

Introduction

Potato (*Solanum tuberosum* L.) is a major human food crop consumed worldwide. This plant is the fourth most important crop in terms of global production (FAO, 2018). Potatoes feed more than a billion people worldwide, from a global crop production close to 400 million metric tons (FAOSTAT 2017), and it is critical for the food security of people across South America, Africa, and Asia, including Central Asia. According to (FAO, 2018), the largest producers of potatoes in the world are China, India, Russia, Ukraine, the United States of America, and Germany. In developing countries like Iran, the nutritional importance of potatoes is much higher, and based on the yields and area under cultivation, potatoes have been assigned the second-ranked crop after wheat (Sadrghaen et al., 2010). The average per capita consumption of potatoes in Iran is more than 50 kg per year, and its consumption is increasing daily. The cultivated area of this crop in Iran is 164,000 ha, with a production of 5,164,890 tons annually, which is not enough for the growing population in the coming years (Afzalinia, 2005; FAO, 2018).

Several factors, including diseases, pests, selection and cultivation of suitable cultivars, early and late planting dates, and environmental factors, such as low and high temperatures and rainfall, affect the growth and yield of crops. The climate conditions can be named as one of the most influential growth factors in various crops, especially in potatoes (Dadrasi et al., 2022). In recent years, one of the subjects that have attracted the attention of researchers is global warming issues and their effects on crop growth (Moradi et al., 2013).

According to recorded climatic data, the average temperature of the earth's surface has increased by nearly 0.6 °C until the end of the 20th century, and according to the latest report of the Intergovernmental Panel on Climate Change (IPCC), the average global temperature will increase by 0.6 to 2.5 °C in the next 50 years. The intensity of precipitations, increase in temperature, drought, and other types of expected weather hazards affect the occurrence of phenology stages, yield, and quality of agricultural products (Qurbani and Soltani, 2014; Noman et al., 2017). Climate change can affect the stages of phenology and production of various crops (Lizaso et al., 2018). Also, one of the foreseeable consequences of climate change is reduced crop production (Zhao et al., 2017). In addition, an increase in temperature due to climate change, especially in tropical regions, can harm plant productivity. Potato is one of the crops whose physiological and ecological activities have been affected by climate change (Li and Zhang, 2020). Also, variations in temperature degrees during the growing season due to the effects of climate change can cause changes in phenology and, ultimately, in potato yield. According to Xiao et al. (2013) reports, potato water use efficiency tended to decline when temperature increased by 1.5 ºC and precipitation was < 310.0 mm. Zhang et al. (2015) indicated that the warming season significantly decreased potato yield. In another study by Li and Zhang (2020) in China, the yield decreased with each increase in temperature degree.

The results of climate change studies conducted in Iran in recent years have all confirmed that this phenomenon severely affects the growth of crops, which might decrease yields (Moradi et al., 2013). Achieving more accurate information about the phenomenon of climate change in Iran requires conducting extensive studies on a regional scale and predicting the response of the agricultural production systems of each region to these changes.

The development of modeling methods is a suitable and low-cost alternative for this type of study, which is currently receiving the attention of researchers (Jones et al., 2003). Therefore, with the output information from crop growth models, it is possible to predict the processes related to climate change with high speed and low cost. It should be noted that in simulation studies carried out on a large temporal and spatial scale, these models are the only available solution to study the effects of climate changes on a regional and global scale (Krishnan et al., 2007). Plant simulation is a mathematical representation of plant growth processes concerning the interaction between genotypes, designed to analyze plants' growth and development and the environmental variables that affect them. These models are designed to analyze the growth and development of plants and the environmental variables that affect them, and they are able to predict how changes in environmental and management conditions affect the growth, development, and yield of the plant (Dadrasi et al., 2022). This research aimed to investigate the trends of change in phenological stages, yield of potatoes, and climatic phenomena against climate changes in different meteorological stations in Iran.

Materials and Method

Study area and Selection of meteorological stations: This research was conducted in 2018 at Gorgan University of Agricultural Sciences and Natural Resources. This area is located in the Golestan province of Iran. This research included different steps that are described separately in this section. To conduct this research, first, the weather conditions of stations that have the highest level of potato cultivation were determined (Dadrasi et al., 2022). For this purpose, out of all meteorological stations in Iran, only 19 stations were selected as the essential potato producers (Table. 1). These stations are located in different provinces of Iran (Fig. 1). The selection of meteorological stations was based on the cultivated area within 100 km of each meteorological station for the potato plant. The meteorological stations with more than 1 percent of potato under cultivation were selected. The list of selected meteorological stations based on the location and the amount of under cultivation is presented in Table. 1. The selection of weather stations based on the Global Yield Gap Atlas (GYGA) protocol was done (Dadrasi et al., 2019). The GYGA (Global Yield Gap Atlas) method's superiority in selecting the stations and estimating the Yield gap of this method has been proven in the results of (Dadrasi et al., 2021) with the tracking method.

After selecting the meteorological stations, the plant growth simulation model (SSM-iCrop2), previously parameterized and evaluated in Iran, was used (Dadrasi et al., 2020). Information on weather, field management, plant characteristics such as phenological stages, leaf area, salinity stress tolerance threshold, light consumption efficiency and soil information was required to implement the model. In the report made by (Dadrasi et al., 2020), the results of parameterization and evaluation of the model and the articles used for this purpose were fully reported. Therefore, re-reporting the model's parameterization and evaluation results has been avoided.

Table 1. Geographical characteristics, names of the provinces, and the names of the selected weather stations for implementing the SSM-iCrop2 model for the potato in Iran.

Number	**Station**	**Province**	**Latitude**	**Longitude**	**Elevation**	**Level (%)**
1	ABALI	Tehran	35.75	51.88	2465.2	1.04
2	ALIGOODARZ	Loristan	33.41	49.70	2022.1	3.55
3	BIARJAMAND	Semnan	36.09	55.81	1099	0.57
4	BIJAR	Kordestan	35.89	47.62	1883	1.10
5	BOROOJEN	Chahar Mahal	31.98	51.30	2260	2.47
6	DARAN	Esfahan	32.97	50.37	2290	3.82
7	ESLAMABADGHARB	Kermanshah	34.12	46.47	1348	1.08
8	GHOOCHAN	Khorasan razavi	37.12	58.45	1287	1.10
9	GHORVEH	Kordestan	35.18	47.79	1906	1.03
10	HAMEDAN (AIRPORT)	Hamedan	34.87	48.53	1740.8	5.88
11	KERMAN	Kerman	30.26	56.96	1754	1.86
12	LALEHZAR	Kerman	29.52	56.83	2775	1.56
13	MIANDEHJIROFT	Kerman	28.58	57.80	720	3.37
14	SHAHREKORD	Chahar Mahal	32.29	50.84	2048.9	1.53
15	SHAHROUD	Semnan	36.38	54.93	1325.2	1.08
16	MARAGHEH	East Azerbaijan	37.35	46.15	1344	0.68
17	YASOUJ	Kohkiloyeh	30.70	51.56	1816	1.47
18	EDAREGORGAN	Golestan	36.91	54.41	0	0.83
19	ARDABIL	Ardabil	38.22	48.33	1335	5.67

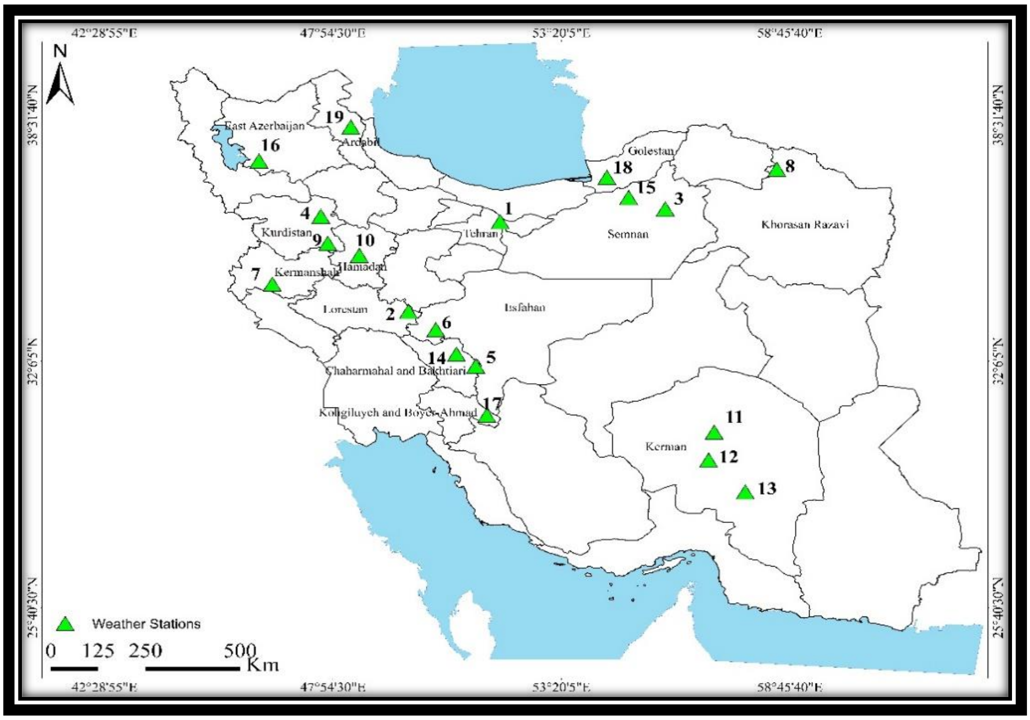

Fig 1. The geographical location of 19 meteorological stations for potato production in Iran. The numbers in the figure indicate the number of meteorological stations.

Data collection: Climatic data, including maximum and minimum temperature, daily precipitation, and solar radiation for 25 years (1991 to 2015), were collected from meteorological stations in Iran. Meteorological stations with missing data (solar radiation) were completed using the program to calculate solar radiation from temperature data (Soltani and Sinclair, 2012).

Model: The SSM-iCrop2 simulation model was used to evaluate the effects of past climate changes on potato phenology and yield. This model is designed to be used for all crops and orchards, provided that it has been parameterized and evaluated for the studied areas. The SSM-iCrop2 model can simulate phenological stages, leaf development and senescence, dry matter distribution, plant nitrogen balance, yield formation, and soil water balance. They are based on meteorological statistics (minimum and maximum temperature, amount of radiation, and precipitation) and use sub-models related to phenology, leaf surface changes, dry matter production and distribution, and soil water balance (Soltani and Sinclair, 2012).

Model run: The results of parameterization and evaluation of the potato model (SSM-iCrop2) were obtained in this research based on the data (Table 2) indicate the acceptable accuracy of the model in predicting potato phenology (Fig. 2). After entering all the information into the model, the scenario was designed, and the stages of potato phenology were simulated in the stations. Using the outputs obtained from the model, the slope of changes in climatic factors and its effect on phenological stages (from planting to the beginning of tuber formation, the stage of tuber formation, and from planting to maturity stage). The trend of changes in phenological stages, the trend of changes in climatic factors, and the average length of the period of developmental stages were investigated in this research. The regression analysis of SAS 9.4 (Statistical Analysis Software) program was used to get the trend or relationship between the year, climatic factors, phenology, and correlation between changes in phenology and climatic factors simultaneously. Then, the outputs of each desired factor to implement the following steps (drawing GIS 10.3 "Geographical Information System" maps) were prepared.

Table 2. Estimated parameters in the SSM-iCrop2 model for potatoes in Iran (Dadrasi et al., 2020).

Parameter	Abbreviation	Early maturity	Late maturity
Base temperature for development (ºC)	T_b	5	5
Lower optimum temperature for development (ºC)	T_{o1}	17	17
Upper optimum temperature for development (ºC)	T_{o2}	32	32
Ceiling temperature for development (ºC)	T_C	40	40
Thermal unit for emergence (ºC)	tuEMR	88	120
Temperature unit for beginning tuber growth (°C day^{-1})	tuBTG	440	600
Thermal unit for termination tuber growth (°C day^{-1})	tuTTG	1045	1425
Thermal unit for harvest (°C day^{-1})	tuHAR	1100	1500
Thermal unit for beginning leaf senescence (°C day^{-1})	tuBLS	1089	1485

Results and Discussion

Planting Date: In this research, the potato was cultivated in two seasons: spring and autumn. The results showed that spring planting was done on average during the last 25 years (1991-2015) in 17 meteorological stations between April 2nd and May 18th (92 to 138 Day of Year or DOY), which is the planting date range can be different according to the climatic conditions and cultivation conditions of the regions. Potato was cultivated in Ardabil and Kerman meteorological stations on April 2nd (92 DOY), but in stations such as Ghoochan and Biarjamand at the end of May (136 and 138 DOY) (Fig. 2). In the two stations of Jiroft and Edaregorgan, was cultivated in autumn. Potato was cultivated in Jiroft meteorological station on October 2nd (275 DOY) and Edaregorgan on December 12th (346 DOY). Jiroft meteorological station and Edaregorgan were planted later than the other stations due to their location and suitable climatic conditions (5 days without precipitation and with temperature above 13

°C). In other words, the Edaregorgan and Jiroft stations are located in a position that has a warm, humid, and dry climate, respectively, and unlike in the other 17 stations, the potato was cultivated in autumn.

Similarly, in spring planting, due to the location of the stations, weather conditions, and cultivation conditions, there was a 45-day planting date. Because of the stations with the colder climate, spring planting was accomplished later, but in the areas where the climate was not colder, spring planting was implemented earlier. The results obtained in this research are similar to the findings reported by Naz et al. (2022) and Gregory and Marshall (2012).

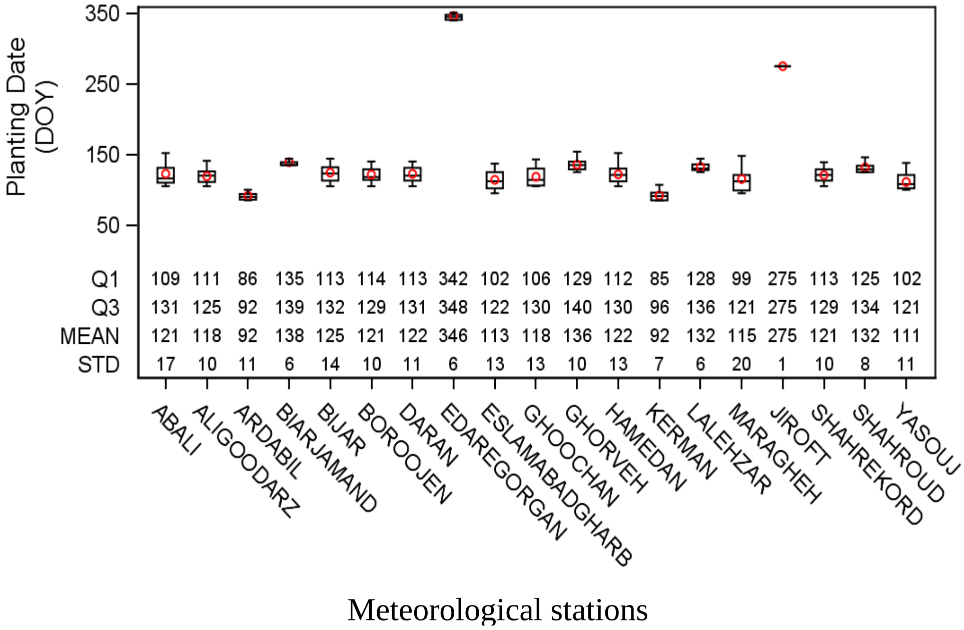

Fig. 2. Changes in potato planting dates in the regions (meteorological stations) of potato production since 1991 to 2015, (DOY: Day of Year, Q1: first quartile, Q3: third quartile, MAEN: mean and STD: standard deviation).

The Duration of the Phenology Stages

The length of the planting period until the beginning of tuber formation: The results showed that the average length of the period from planting to the beginning of tuber formation during the past years (1991-2015) in 16 meteorological stations varied between 50 and 56 days. But, it was 64, 80, and 123 days in Abali, Ardabil and Edaregorgan meteorological stations, respectively (Fig. 3a). The difference of this attribute in different meteorological stations is related to the average temperature of the period from planting to the beginning of tuber formation in these stations. Based on the obtained results, the average temperature of the period from planting to the beginning of tuber formation in 16 meteorological stations was between 17.1 and 26.3 °C (located in the optimal temperature range for potato growth, 17 to 32 °C) (Fig. 3b). But in Abali, Ardabil and Edaregorgan meteorological stations, the average of temperature was below the optimum temperature (13.2, 12.8 and 9.9 °C, respectively). For this reason, in these meteorological stations, the thermal time that is necessary to reach the beginning stage of tuber formation has been completed in a longer period. Occurrence of low temperatures during the period of planting until the beginning of tuber formation in the meteorological station of Edaregorgan due to the occurrence of planting until the beginning of tuber formation in the winter season and in Abali and Ardabil stations due to the coolness of these two regions in the spring season is coinciding with the planting season until the beginning of potato tuber formation. In Jiroft meteorological station, despite the fact that the potato was cultivated in autumn (October 2th). But, unlike the meteorological station of Edaregorgan, due to the presence of relatively warm weather (average temperature of 24.3 °C) during the period from planting to the beginning of tuber formation, the length of this course was completed faster. Our finding are similar to the results of (Tryjanowski et al., 2018) and (Naz et al., 2022) in which the relative warm weather affected potato phenology in the meteorological stations.

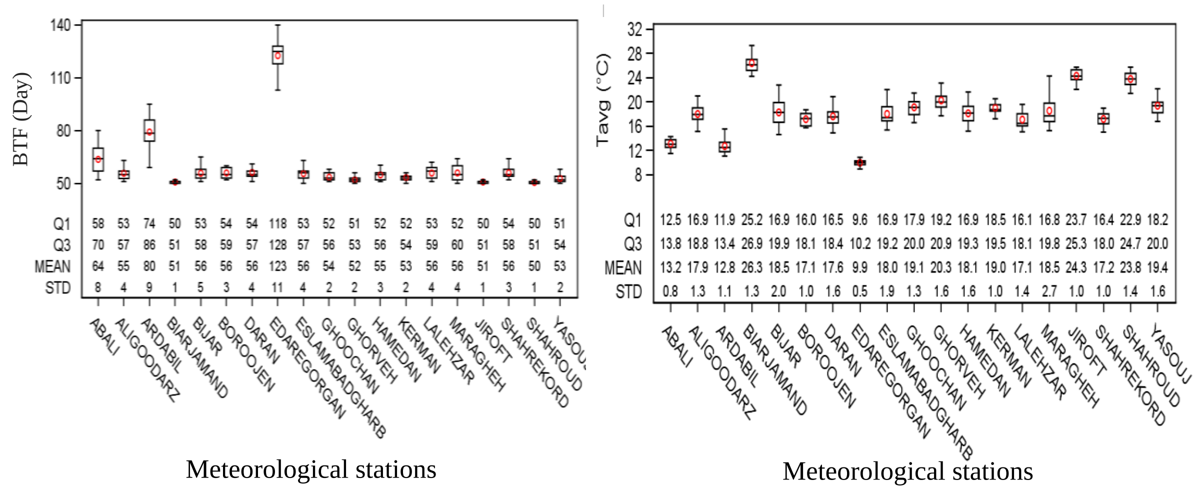

Fig. 3. Changes in the duration of the planting period until the beginning of potato tuber formation (a) and Changes in average of temperature during this period (b) in the regions of potato production from 1991 to 2015. BTF: Beginning of Tuber Formation. Tavg: average temperature.

The Length of Period of Tuber Formation

The results showed that in the last 25 years, the average length of period of tuber formation in 18 meteorological stations varied between 73 and 78 days, while in Jiroft meteorological station, the length of this period reached 96 days (Fig. 4a). Increasing of the period of tuber formation can be due to the average temperature exceeding the optimal temperature range for potato growth (17 to 32 °C) during the period of tuber formation (Fig. 4b). The average of temperature during the period of tuber formation in Jiroft meteorological station was 14.8 °C, which led to the late completion of the thermal time required for the period of tuber formation and lengthening the length of this period. Although, in other meteorological stations, the average of temperature was between 17.7 and 27.4 °C and it was in the optimal temperature range, thus, the duration of tuber formation in these meteorological stations was almost close to one another. Decreasing of the temperature's average in the period of tuber formation in Jiroft meteorological station was due to the length of this period coinciding with the winter season, while in the other meteorological stations the length of the period of tuber formation coincides with the end of June to July, where the average of temperature is relatively high. Similar results were reported by Naz et al (2022) in which the increased temperature affected the tuber formation stage to decrease.

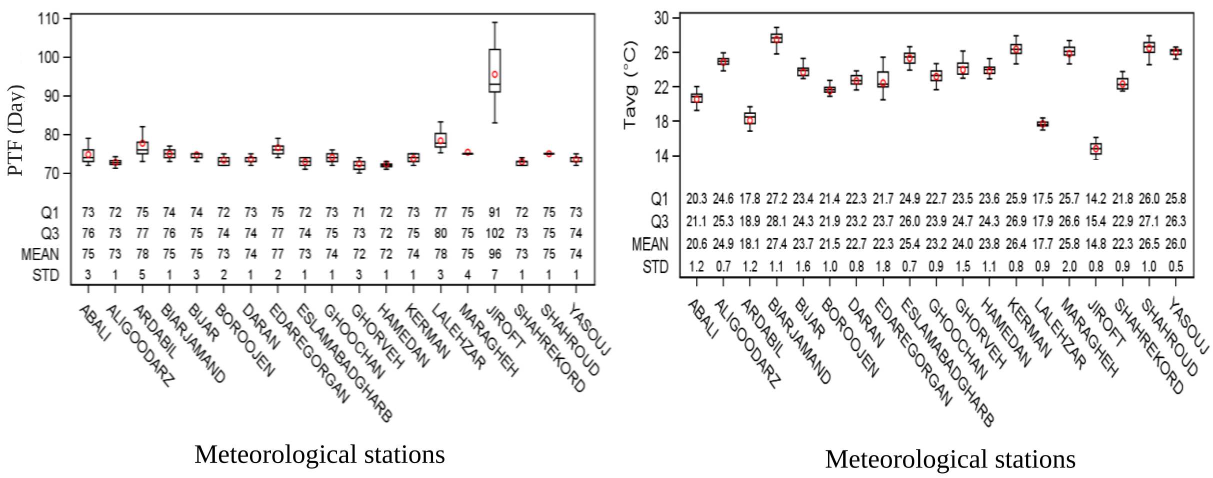

Fig. 4. Changes in the length of the potato period of tuber formation (a) and Changes in average of temperature during this period (b) in the regions of potato production since 1991 to 2015. PTF: Period of Tuber Formation. Tavg: average temperature.

The length of the whole growth period: The results showed that the potato growth period (from planting to maturity) was longer in 4 meteorological stations (Abali, Jiroft, Ardabil, and Edaregorgan), than the other 15 meteorological stations. So the average length of the whole growth period in Abali, Jiroft, Ardabil, and Edaregorgan meteorological stations was 139, 146, 157 and 200 days, respectively. In the other 15 meteorological stations, the average of the whole growth period was between 124 and 134 days (Fig. 5a). The reason for the changes in the potato growth period in these stations can be attributed to the difference in the planting date, the length of the planting period until the beginning of tuber formation and the period of tuber formation. At Jiroft and edaregorgan stations, it was cultivated in autumn and in Ardabil and Abali stations, it was cultivated in spring (Fig. 2). The lowest average of temperature during the tuber formation period and the whole growth period (Fig. 4b and 5b) in Jiroft station can confirm the long duration of the tuber formation period and ultimately the whole growth period (Fig. 4a and 5a). In addition, in Edaregorgan, Abali and Ardabil stations, due to the long period of planting until the beginning of tuber formation and tuber formation (Fig. 3a and 4a), as a result of lower average of temperature in these growth stages (Fig. 3b and 4b), the whole growth period increased found (Fig. 5a). Our findings are in almost similar to those reported by Naz et al (2022).

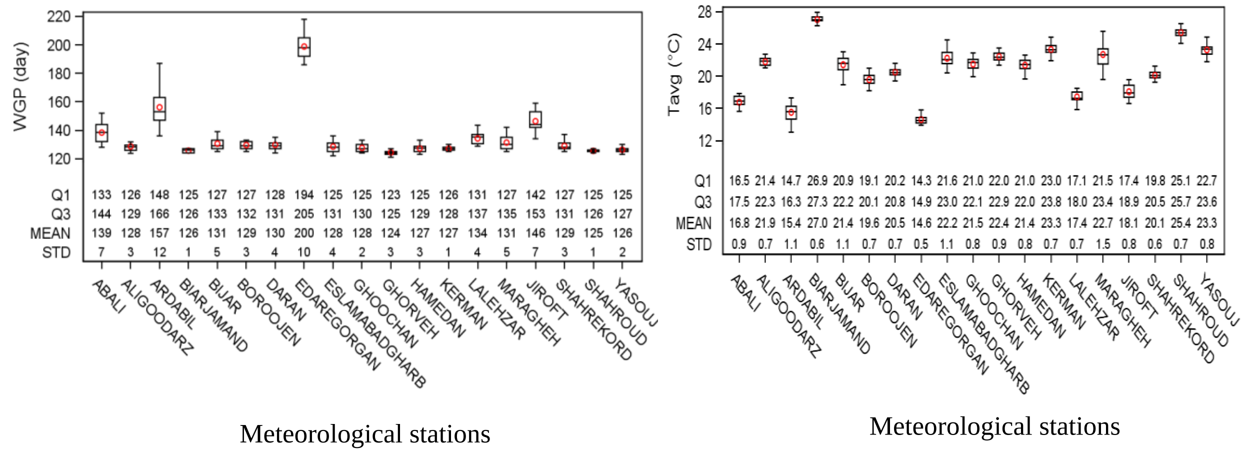

Fig. 5. Changes in the length of the whole growing period (from planting to maturity) of potato (a) and Changes in average of temperature during this period (b) in the meteorological stations since 1991 to 2015. WGP: Whole Growing Period, Tavg: average temperature.

Yield changes

In the current research, the average yield simulated for the past 25 years varied between 5221 (Biarjamand station) and 8539 (Shahrekord station) g/m^2 (Fig. 6a). The yield difference between potato production stations can be attributed to the radiation received during the growth period, the optimal upper temperature for dry matter production, the efficiency of radiation consumption and dry matter production. In Biarjamand, Jiroft, Edaregorgan and Shahroud meteorological stations, the yield value was estimated between 5221 and 5847 g/m^2. At the Jiroft meteorological station, the whole growth period was in autumn and winter. Therefore, due to the lower amount of radiation reaching the ground in these seasons, the amount of radiation received during the planting period until the beginning of tuber formation and tuber formation stage and finally the whole growth period was reduced (Fig. 6b, 6c and 6d). A further investigation has shown that the optimum temperature range for potato dry matter production in the model is 12-24 °C. While the average of temperature during the planting period until the beginning of tuber formation in Edaregorgan meteorological station was lower than the optimum temperature for the production of dry matter, and this caused a decrease in the efficiency of radiation consumption and finally a decrease in dry matter during the planting period until the beginning of tuber formation. Also, the average of temperature at Biarjamand meteorological station for both planting periods until the beginning of tuber formation and the stage of tuber formation was higher than the upper optimal temperature for dry matter production, which reduced the efficiency of radiation consumption, dry matter production and yield. Shahrekord meteorological station had the highest tuber yield (8539 g/m^2) due to the high amount of received radiation in the whole growth period and the lack of temperature limitation for dry matter production. The similar results were reported by Gregory and Marshall (2012) as our findings indicated variations in yield decrease in most of the metrological stations in both planting periods.

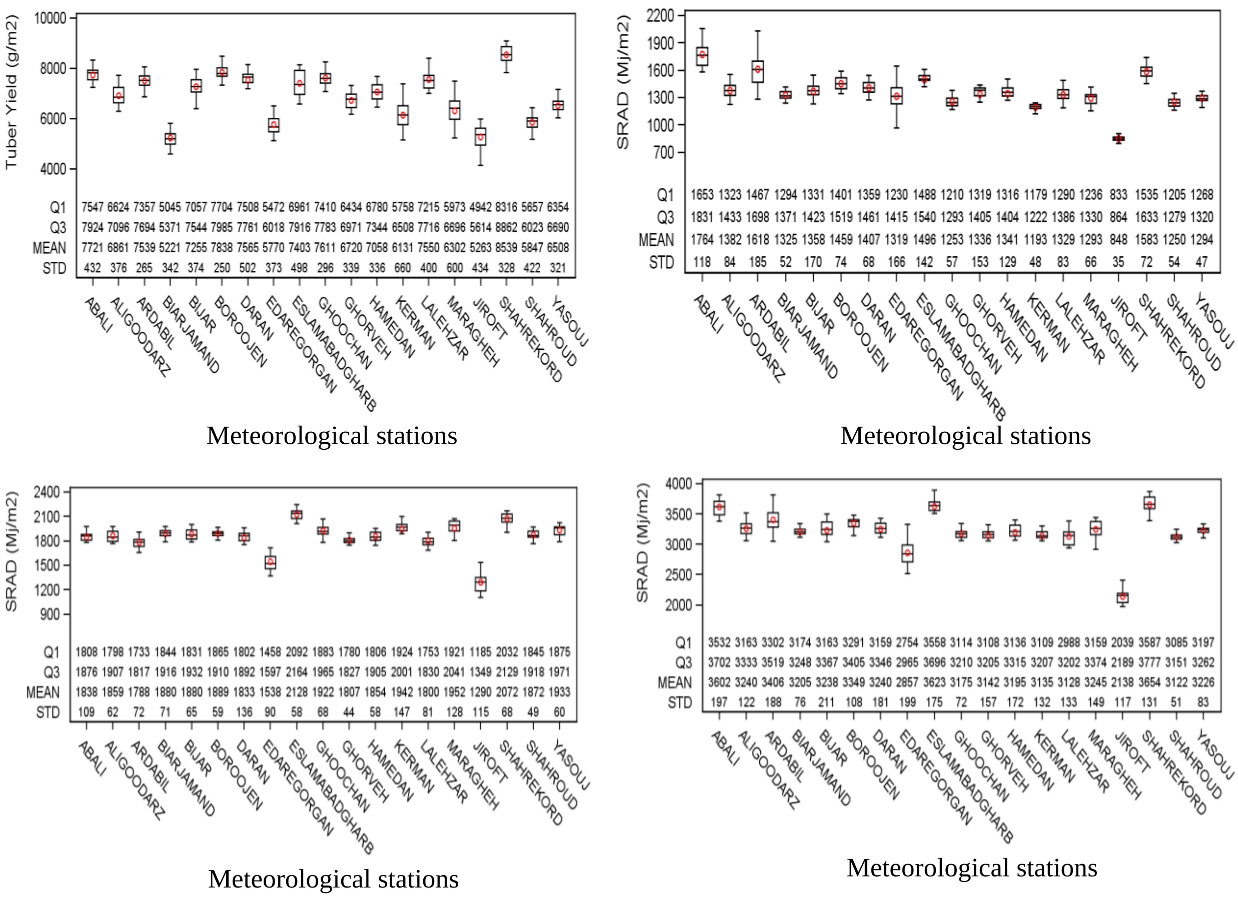

Fig. 6. The changes of potato yield (a), Changes in received radiation during the planting period until the beginning of tuber formation (b), Changes in received radiation during period of tuber formation (c) and Changes in received radiation during the whole growing period of potato (d) in the meteorological stations of potato production since 1991 to 2015. SRAD: Solar radiation.

The Trend of Phenology Changes

The results showed that the trend of phonological stages in meteorological stations was not the same during the last 25 years. There was both trends such as an increasing trend and a decreasing trend. The length of the planting period until the beginning of tuber formation in 16 meteorological stations (84.2%) had a decreasing trend, among which, the decreasing trend of Bijar and Ardabil meteorological stations was significant at 5% level (Fig. 7a). The decreasing of trend from planting to the beginning of tuber formation in Ardabil meteorological station with 0.6 days per year had high intensity and in Islamabadgharb meteorological station with 0.01 days per year, it had low intensity. A more detailed investigation showed that due to the increase in the average of temperature of planting until the beginning of tuber formation in these stations, the length of the planting period until the beginning of tuber formation decreased, because temperature plays a dominant role in determining the duration of the stages of crop growth (Craufurd and Wheeler, 2009). Also, the results showed that in 3 meteorological stations, Jiroft, Biarjamand, and Yasouj, the length of the planting period until the beginning of tuber formation increased, which was significant at the 5% level in Jiroft meteorological station. The reason of this increase in Jiroft and Biarjamand meteorological stations was due to a significant increase in the average temperature of this period from the optimal temperature range. So, with the increase of temperature from the optimal range, the intensity of the growth rate decreased, and the length of the growth period increased.

Also, based on the results that obtained from the phenology trend of 19 stations showed that in 13 meteorological stations of potato production (68.4%), the trend of annual changes in tuber formation period was decreased. The trend of decreasing in 4 Meteorological stations such us, Ghoochan, Hamedan, Yasouj and Ardabil was significant at the level of 5%. Its reason can be due to a significant increase in the average of temperature of tuber formation, an increase in the growth rate and earlier completion of degree day in these stations. During the last 25 years, the length of this period was decreased in Aligoodarz meteorological station with low intensity (0.002 days per year) and in Ardabil meteorological station with high intensity (0.4 days per year). On the other hand, in 6 meteorological stations, Abali, Biarjamand, Islamabadgharb, Kerman, Lalehzar and Shahroud, a non-significant increasing trend was shown during the tuber formation period (Fig. 7b).

According to the results, the length of the period from planting to maturity in 4 potato production stations (Biarjamand, Yasouj, Eslamabadgharb and Lalehzar) showed a non-significant increase (Fig. 7c). But, in 15 stations during this period, they showed a decreasing trend. So this decreasing trend was significant in 6 stations (Ardabil, Bijar, Ghorveh, Hemedan, Daran and Boroojen) at 5% level. The stations that experienced the decreasing trend of this period were due to the increasing trend of the total average of temperature in this period. The slope of the decrease in this period was higher in Ardabil meteorological station (1.05 days per year) and less in Kerman and Shahroud meteorological stations (0.02 days per year). Those stations that did not show significant changes during the period from planting to maturity, were due to the low-temperature range with the optimal temperature for growth. The results of other researchers also show the change in the trend of potato phenology. As In a research, the effect of climate change on potato phenology was found in 12 regions of Punjab, Pakistan and with the change in temperature due to climate change, potato phenology (Sowing to Anthesis, Anthesis to Maturity and sowing to Maturity) showed a decreasing and increasing trend. So that, on average, from planting to tuber formation, from tuber formation to maturit, and from planting to maturity were shortened by 1.9, 1.0, and 2.9 days/decade respectively (Naz et al., 2022).

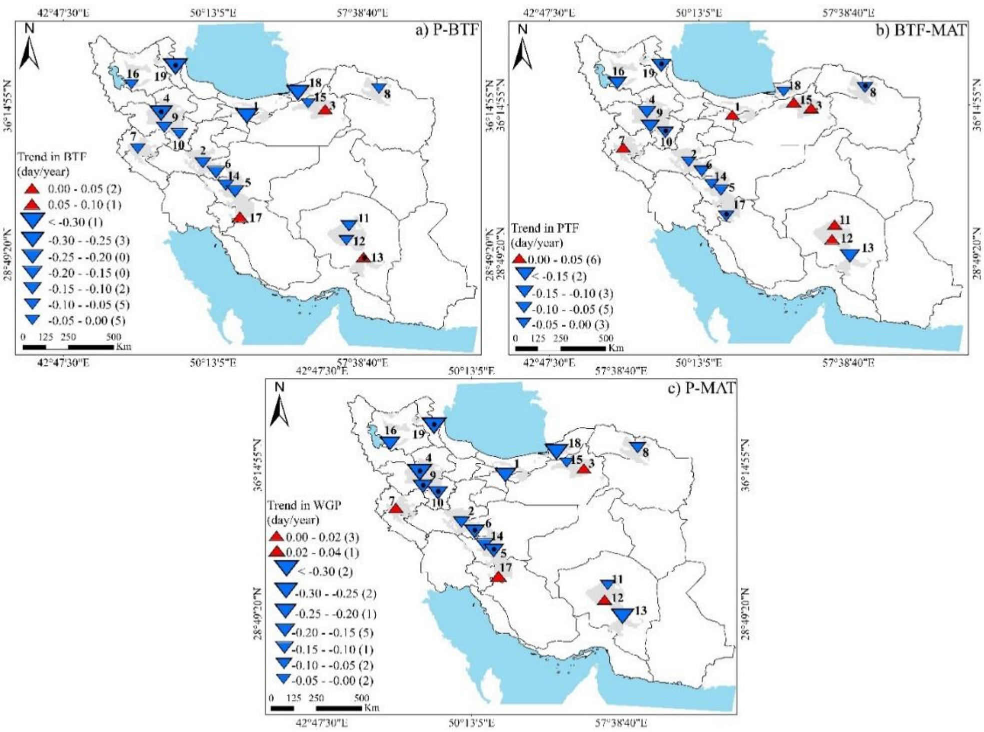

Fig. 7. Changes in the phonological stages of potation the meteorological stations of potato production from 1991 to 2015. P-BTF: from planting to the beginning of tuber formation (a), BTF-MAT: from the beginning of tuber formation to maturity (c) and P-MAT: from planting to maturity.

The red triangles indicate the increasing trend and their significance (at 5% level) is shown by the black dots in the middle of the triangle. The blue triangles indicate a decreasing trend and their significance (at 5% level) is shown by the black dots in the middle of the triangle. The numbers in the figure indicate the number of meteorological stations.

The Trend of Yield Changes

The results showed that out of 19 meteorological stations, only 6 stations had an increasing trend in yield, and this increasing trend of yield was significant only in Shahrekord meteorological station (Fig. 8). The rate of yield increase varied from 0.24 g/m^2 per year for Shahrekord meteorological station to 1.2 g/m^2 per year at Lalehzar meteorological station. The increase in yield in the Shahrekord meteorological station can be due to the significant increase in radiation received during the growth period, as well as the lack of temperature limits for the production of dry matter. In contrast, 13 stations had a decreasing trend in performance changes.Among these, 6 meteorological stations (Aligodarz, Ghorveh, Bijar, Islamabadgharb, Hamedan and Maragheh) were significant. So that, Maragheh station showed extreme decrease (1.34 g/m^2 per year) in yield changes. While this trend in Ardabil meteorological station had a lower slope (1.7 g/m^2 per year) than other meteorological stations. It should be noted that the difference in the yield trend among the potato production stations can be attributed to the length of the phenology stages, temperature, planting date, location of the stations and radiation received during the growth period.

Receiving more radiation during the growth of the tuber causes more yield, and when they receive less radiation, as a result, performance decreases. Temperature can cause changes in the yield trend, because radiation and temperature play a more important role among the types of direct and indirect mechanisms for evaluating plant growth (Walther et al., 2002). Temperature has a direct effect on the growth of a plant and thus affects the yield. With the increase in average of temperature, the anthesis and physiological maturity stages take place earlier, which reduces the accumulation of dry matter and as a result reduce the yield of plant (Abas et al., 2017). Heating shortens the whole growth stage of a plant. Likewise, the change in the phenology stages affects the plant's yield (Zhang et al., 2016). Shortening the phenology stages can reduce the accumulation of dry matter and lead to a decrease in yield. As the growth period lengthens, the yield increases, because this allows more time for the accumulation of dry matter in the reproductive stage (Tao et al., 2014). Radiation is the main climatic factor for yield fluctuations. The positive correlation of yield with temperature can be caused by the correlation between radiation and temperature. As in most of the studied areas, the increase in yield was accompanied by an increase in temperature (Zhang et al., 2010). Temperature and water content control the photosynthesis process and have a significant effect on dry matter accumulation and have a greater effect on potato tuber yield (Tryjanowski et al., 2018). At a higher temperature, the concentration of dry matter during the growth of potato tubers will be lower, and the reduction of sugar concentration will increase with the shortening of the growing season, and the tubers are harvested at higher temperatures than the current time, thus affecting the quality of the tubers (Haverkort and Verhagen, 2008).

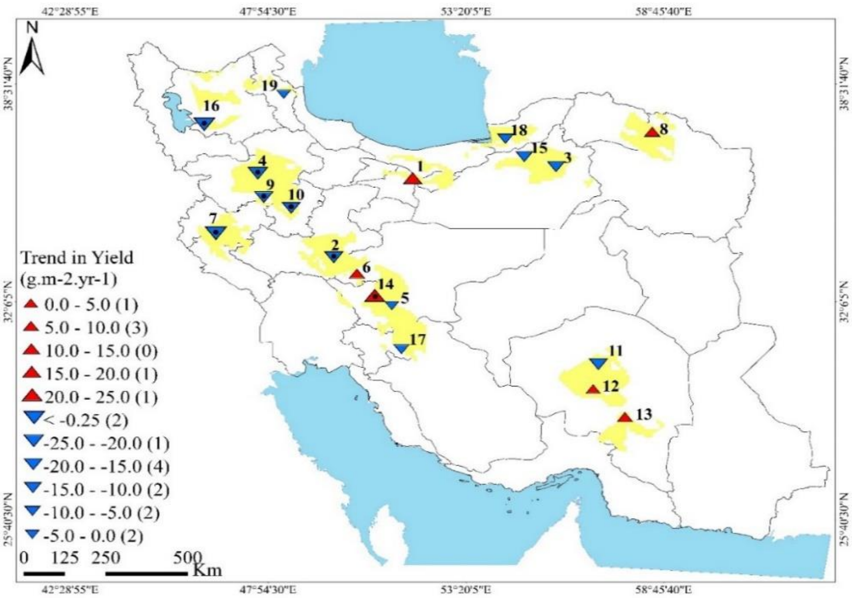

Fig. 8. The trend of potato yield changes in potato production stations during the years 1991 to 2015. The numbers in the figure indicate the number of meteorological stations.

Conclusion and Recommendation

The results of the present research study clearly show that the difference during the planting period until the beginning of tuber formation and the stage of tuber formation in meteorological stations is related to the average of temperature at planting date until the beginning of tuber formation and the stage of tuber formation at these stations. So that the average length of the planting period until tuber formation in 18 meteorological stations varied between 50 and 80 days, but with the decrease in the average of temperature during this growth period, the average length of the planting period until the beginning of potato tuber formation in the meteorological station of Edaregorgan reached 123 days. Also, the results showed that in the last 25 years, the average length of tuber formation period in 18 weather stations varied between 73 and 78 days, while the average of temperature exceeded the optimal range in Jiroft meteorological station, the length of this period reached 96 days. Likewise, the changes during the growth period (from planting to ripening) of potato in the studied stations were caused by the effect of the difference in planting date, the length of the planting period until the beginning of tuber formation and tuber formation in these stations. In general, the results of the investigations showed that the average yield difference among meteorological stations was related to the radiation received, the length of the growth period and the optimal temperature range for the production of dry matter. Thus, the highest average simulated yield was observed in Shahrekord meteorological station and the lowest in Biarjamand meteorological station. Generally, it is that the average of temperature is increasing in meteorological stations and this increase affected the phenology and yield of potato crops.

The model used in this study are a valuable tool to be used for the evaluation of climate change effect on different crops in Afghanistan geographical conditions, as the temperature and weather significantly varies in each regions. First of all, it is very essential to parametrize this model for potato and other important cash crops in Afghanistan and then we can apply it to evaluate the effects of climate change on other crops.

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