Climate change and crop physiology: A decade-long meteorological study

ABSTRACT

The purpose of the study was tolook into how the physiology of crops areaffected by climate change.The meteorological data for the most recent 10 years (2012–22) was given by the Department of Agricultural Meteorology at the College of Agriculture Vellayani.These data were examined in order to comprehend weather patterns and investigated how the climatechange, especially the temperature raise may affect plantgrowth and development. The results hasbeen shown that thephysiology of cropswereseverely affectedby the temperature stress broughtbyclimate change.

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Keywords; Climate change, Crop physiology, temperature rise

Introduction :

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Climate change is one of the most significant challenges that plant scientists are currently facing. It is the primary cause of the biotic and abiotic pressures that have negative impact on agriculture; hence, agriculture and climate change are intrinsically linked in a number of ways. It results in variations in yearly rainfall, average temperature, heat waves, changes in weeds, pests and bacteria, worldwide changes in atmospheric CO_2 or ozone levels and variations in sea level etc. The agricultural production system also affected both directly and indirectly. Direct effects include the consequences on certain agricultural production systems brought on by a change in physical attributes, such as temperature levels and rainfall distribution. When changes are made to other species, such as pollinators, pests, disease vectors, and invading species, it has an indirect effect on production. Increasing greenhouse gases concentrations are the cause of extreme climatic shifts. Carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), and ozone are examples of greenhouse gases (GHG) that contribute to the greenhouse effect. The output of greenhouse gases are anticipated to rise in the near future also.

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The atmospheric eCO_2 concentrations have increased from 280ppm preindustrial reference levels to current global levels, which is above 400 ppm. According to studies, higher carbon dioxide levels promote photosynthesis especially in C3 plants. It is known as the "CO_2 fertilization effect". But the positive direct impact of elevated [CO_2] may be countered by other climatic change effects like increased temperatures, higher tropospheric ozone concentrations, and altered precipitation patterns. The consequences of elevated atmospheric CO_2 and associated temperature and precipitation variations are were anticipated to have an impact on the distribution, relationships, and eco physiology of plants (Intergovernmental Panel on Climate Change (IPCC), (2014).The longer eCO_2 treatments may result in photosynthetic adaptation because of an increase in soluble sugars, which leads to a an imbalanced C: N ratio, faster leaf senescence, and/or limited growth rate, which affect crop yield and quality. It is believed that crop quality is a multifaceted and it is a complex topic that involves growth, assimilation,

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partitioning, storage, pre- and post-harvest, as well as nutritional, technological and environmental components (Hay & Porter, 2006). In a future high-CO_2 environment, the elemental (e.g., zinc, iodine) and macromolecular (e.g., protein) composition of plant tissues is anticipated to alter (Taub, Miller, & Allen, 2008). Crop physiologists will need to address the interests of breeders and processors more in this circumstance by analysing, characterising, and modelling changes in food quality among crop varieties and species under climate change scenarios (Hay & Porter, 2006).Hence, in this study, we examined the impact of climate change, specifically temperature rises over the previous ten years, using meteorological data from the Department of Agricultural Meteorology, College of Agriculture, Vellayani on physiology of crops.

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MATERIALS AND METHODS

The Department of Agricultural Meteorology, College of Agriculture Vellayani, Thiruvananthapurammaintains a class B agromet observatory where all the meteorological equipments are housed and the observer regularly takes observations twice a day at 7:22 a.m. and 2:22 p.m., respectively. This weather information is routinely sent to the IMD headquarters in New Delhi. In this study, we examined both average maximum and average minimum temperatures over the past ten years (2013-22) from the data recorded in the department (table 1 &2).

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RESULTS AND DISCUSSION

The data shows that over the past ten years, the maximum temperature range has been between 30°C and 35.3°C and the minimum temperature range has been between 21°C and 26.3°C. The highest maximum temperature and the greatest minimum temperature recorded in 2013 were 33.1°C and 25.4°C, respectively. All of 2013's months had a dramatic fluctuation in maximum temperatures, which ranged from 29 °C (june) to 33.1 °C. (april). Additionally, there were variations in the minimum temperature, which ranged from 21.9°C in December to 25.4°C in April. The months with the highest maximum temperature in 2014 were observed to be both march and april (32.4̊C).The minimum temperature range was 21.5̊C (january) to 25.2̊C (june).The maximum and minimum temperatures of 2014 were somewhat lower than they were in 2013. In 2015, the maximum temperature of every month's wereexceeded 30̊C and most of the months it was recorded above 31°C.The highest maximum temperature was recorded in the month of April (32.7̊C) and highest minimum temperature was recorded in May (25.3̊C). It has been noted that the maximum temperature has never dropped below 29°C since 2015.Most of the months in 2015 have crossed the minimum temperature of 24°C.The year 2016 was noted as having the highest maximum and minimum temperatures over the previous 10 years and it was in the month of april with 35.3̊C and 26.4°C respectively. So it was recorded as one of the hottest year among 2013-2022. Because, the maximum temperature from january to december in 2016 were 32.3°C,32.9°C ,34.5°C ,35.3°C ,33.8°C ,31.5°C ,31.6°C ,31.8°C ,31.8°C ,31.7°C ,32°C

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,32.3°C and the minimum temperature were 22.6°C,23.2°C, 24.7°C, 26.4°C, 24.8°C, 24.4°C,24.7°C, 24.8°C, 24.5°C, 24.3°C, 24°C, 23.6°C respectively. In 2017, the highest maximum temperature and minimum temperature was recorded in the month of april (34.2°C and 25.9°C). Most of the months, the maximum temperatures were crossed 31°C and minimum temperatures were crossed 24 °C).

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In 2018, the highest maximum temperature was recorded in the month of April (33.9 °C), and the lowest maximum temperature was recorded in August (30.3°C). The highest minimum temperature was observed in April (25.9 °C), and the lowest minimum temperature was observed in January (21.7°C). The year 2019 was recorded as the second hottest year among the past ten years, with a highest average maximum temperature of 35°C in April. The following maximum temperatures were experienced in 2019 from January to December: 32°C, 33.6°C, 34.6°C, 35°C, 34.1°C, 31.9°C, 30.8°C, 30.9°C, 30.7°C, 31.9°C, and 31.7°C.The highest maximum temperature was recorded in the month of april (35°C) and the lowest maximum temperature was recorded in the month of October (30.7 °C). In 2019, the minimum temperatures were 21.1°C, 23.6°C, 24.8°C, 25.8°C, 26.3°C, 25.4°C, .8°C, 24.2°C, 24.4°C, 24.1°C, 24.5°C, 23.8°C respectively with a highest in may (26.3°C) and the lowest in January (21.1°C). In 2020, the maximum highest temperature was recorded in april (34.2°C) and the highest minimum temperature was recorded in august (26.3°C).The majority of the months in 2020, recorded a maximum temperature above 31.5°C, with the exception of September (31.1°C) and October (31.3°C) and minimum temperature were above 23.3°C, except January(22.9°C). The month with the greatest maximum (33.8°C) and minimum (25.9°C) temperatures in 2021 was April. The lowest maximum temperatures (22.3 °C) were recorded in the months of February and October. A temperature range of 30.4°C to 33.4°C was reported for each month of the year 2022.The highest maximum temperature (33.4°C) and highest minimum temperature (24.4°C) was observed in March. The maximum temperature have crossed 33°C in both march(33.4 °C) and april(33.1°C) of 2022.Except for February (21.5 °C) and December (21.1 °C), most of the months have a minimum temperature exceeding 22.5 °C in 2022.These are the conclusions drawn from the data gathered from the Department of Agricultural Meteorology, College of Agriculture, Vellayani.According to the facts above, temperatures have risen during the last 10 years.

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Impact of elevated CO_2 on elevation of temperature and physiology of crops

The impact of climate change is a long-term concern, but it demands immediate action because greenhouse gases are accumulating in the atmosphere and there is the possibility of global temperatures rising by more than 2 degrees Celsius. Long-term global mean temperature estimates indicate an extra 1.1-4.8 °C rise over the previous 50 years, depending on the scale of future greenhouse gas emissions (Walsh *et al.* 2014). These changes in global temperature would cause further changes in the climate, resulting in an increased frequency of heat waves, fewer days of freezing temperatures, less rainfall but more intense precipitation, and a higher incidence

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of droughts and other weather extremes experienced around the world, all of which would have a negative impact on agricultural production (Dempewolf *et al.*, 2014).

CO_2 is one of the greenhouse gases, which have significant direct effects on plant development, physiology, and chemistry(Ziska, 2008).It helps to stimulate photosynthesis and water use efficiency at higher concentration (Long *et al*., 2004). Plants absorb atmospheric CO_2 and it represents not only a gain of stored chemical energy for the plant, but also supplies the carbon skeletons for the organic molecules that make up a plant's structure. Around 96% of a normal plant's dry mass is made up of carbon, hydrogen, and oxygen absorbed into organic molecules during photosynthesis (Marschner, 1995). Hence, photosynthesis is at the core of plants' nutritional metabolism, and increasing the amount of CO_2 available for photosynthesis can have a significant impact on plant growth and many other aspects of physiology. According to Ainsworth & Rogers 2007, The development of plants under increased CO_2 concentrations of 475–600 ppm results in an average 40% increase in leaf photosynthetic rates. The opening of stomata, through which plants exchange gases with the environment, are regulated by carbon dioxide concentrations. The stomatal pores in plants close when CO_2 concentrations are higher than ambient, and they open when CO_2 concentrations are lower. Water may flow out of leaves through open stomata, which also allow CO_2 to permeate into leaves for photosynthesis. So, plants can maintain a high photosynthetic rates with low stomatal conductance at higher CO_2 concentrations.Sincephotosynthesisandstomatalbehaviorarecentraltoplant metabolism,growingpl antsunderelevatedCO_2hasavarietyofsecondaryeffectsonplantphysiology.Theavailabilityofaddition alphotosynthesisallowsmostplantstogrowfasterandproducedrymatterunderincreasedCO_2levels.

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The long-term climatic change brought on by the steady increase in CO_2 concentration will balance off the increase in agricultural yield (Wei *et al*., 2019).IncreasedCO_2alsoleadstochangesinthechemicalcompositionofplanttissues.Duetoincreasedp hotosyntheticactivity, leafnon-structuralcarbohydrates(sugarsandstarches)perunitleafareaincreasedbyanaverageof30–40%underFACEelevatedCO_2 condition (Long,2005).The nitrogen content of leaves in plant tissue often declines as CO_2 levels rise and it is reported an average of 13% less nitrogen per unit leaf mass(Ainsworth&Long,2005).Thisdecreaseintissuenitrogenmaybeduetoseveralfactors such asnitrogendilutionduetoincreasedcarbohydrateconcentration,reducedmineraluptakefromthesoilbe causeof reducedstomatalconductivityandplantsabsorblesswater(Taub&Wang2008) and reducedrateofassimilationofnitrateintoorganiccompounds(Bloom*etal.*,2010).Planttissueproteinco ncentrationiscloselyrelatedtoplantnitrogenstatus. InFACEexperiments,proteinconcentrationsinwh eat,rice,barleygrains,andpotatotubersdecreasedby5–14%withincreasingCO_2(Taub*etal*.2008).Plantconcentrationsofnutritionallyimportantmineralssuch ascalcium,magnesiumandphosphorusmayalsodecreased withelevatedCO_2levels(Loladze,2002). So, the risingCO_2emissions, high temperature and associated climate changeoverthenextcenturyarelikelytoimpactbothagriculturalproductionandfoodquality.

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Temperature rise and crop physiology

Plants experience several kinds of stresses during growth and development. Temperature changes can affect agricultural productivity. Inorder to ensure food security across the globe, we must be aware of climate change, particularly high temperature.In recent years, scientists have observed a rapid rise in average temperatures across the country. According to the National Resources Defense Council's (NRDC) "Killer Summer Heat" report, the average temperature in the United States could rise by as much as 11 degrees Fahrenheit by the end of the 21st century (NRDC, 2016). Temperature is one of the key meteorological factors in crop growth and development. It impacts the away that an enzyme functions in a leaf and causes changes in the developmental stages that are directly related to crop yield (Zhu*et al*., 2018). The optimum temperature for growing crops is about 15-30°C.However temperature elevations predominantly affect plant's physiological processes particularly photosynthesis, respiration, transpiration, and yield. So, any changes in long-term mean annual temperature and extreme temperature events will probably have a big effect on physiological responses of crops and ultimately affect how much food and fuelcrops produce around the world.

The physiological damages caused by high temperatures such as leaf abscission, leaf burning, senescence and restricted root and shoot development have a significant impact on crops and ultimately reduce production. Also, it can lead to lower seed germination rates, plant emergence, weak seedling vigor, aberrant seedlings, and reduced radicle and plumule development (Bita *et al.*, 2013). Many food crops such as rice, wheat, soybean, corn, cotton, sorghum and tomato are very sensitive to high temperatures.High temperatures may disrupt a number of metabolic processes that occur in guard cells; the stomatal response is typically regulated by transpiration rate, photosynthetic rate, plant water status, and vapour pressure deficit (Urban *et al.*, 2017).High temperatures increase the rate of evapotranspiration throughout the vegetative and reproductive stages, which restricts the amount of water that plants can take in. This effects dehydration, which inhibits growth of both the individual organs and the entire plant (Fahad *et al*., 2017).High temperature stress can affect crop's seedling stage in mung bean, and wheat as well as the reproductive stage in wheat and other cereals (Akter *et al*.,2017).

The reproductive stage is the most sensitive time in a crop's life cycle, and this sensitivity causes a considerable reduction in seed set and crop output (Hein *et al*, 2021). It is reported that the seedling and reproductive phases of rice can be negatively impacted by temperatures above 35°C. It have been shown to have a negative impact on various aspects of reproductive development in a variety of species including meiosis in both male and female gametes, pollen germination and pollen tube growth, pollen/pistil interactions, ovule viability, pollen grain number, formation of endosperm and embryo development, fertilization and post-fertilization processes. According tovanader Merwe *et al*., 2015, the sunflower seeds and the oil constituents are significantly impacted by high temperature during grain filling stage.It is also observed that the high temperature (33°C) decreases anther dehiscence and pollen fertility rate; it results in a reduction in the amount of pollen on the stigma, which in turn causes decreased fertilization,

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spikelet fertility, and sterile seed in rice (Hurkman *et al*., 2009).Pollen viability is lost as a result of high-temperature stress due to changes in membrane integrity, protein, carbohydrate and lipid mechanisms and phospholipid profiles(Djanaguiramana *et al.,* 2018).

High temperatures also have an influence on photosynthetic membranes, grana stack growth, ion leakage and aberrant stacking. High temperature affects the activities of carbon metabolic enzymes, starch accumulation, and sucrose synthesis through down regulating certain genes involved in carbohydrate metabolism. Abscisic acid, ethylene, and salicylic acid are the key phytohormones that are increased by high temperatures, whereas gibberellic acid, cytokinin and auxin are reduced. Reactive oxygen species are also produced as a result of high temperatures (Bita and Gerats, 2013) resultsoxidative stress (Potters., 2007).Increased generation of ROS, including lipid peroxidation, superoxide free radicals, and hydrogen peroxide (H_2O_2), results in increased cell membrane damage (Narayanan *et al.,* 2016).High temperature reduces the net assimilation rate and the denaturation of proteins occurs, it induces programmed cell death in some cells or tissues. This results in decreased ion flux, leakage of electrolytes, changes in relative water content, the production of toxic compounds, and disruption of homeostasis, all of which reduce cell viability.Due to lower Rubisco activation, many plant species experience a drop in stomatal conductance (gs) and net photosynthetic rate when exposed to moderate heat stress.

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Extreme temperatures have a significant impact on photosynthesis in leaves. Temperature has an impact on the mechanisms involved in photosynthetic metabolism (Asthir, 2015). High temperatures have a significant impact on chloroplast throughout the photosynthesis process, including grana stack enlargement and aberrant stacking (Wahid *et al*., 2005). The influence of high temperature stress on chlorophyll production in plastids plays a significant role in light harvesting. The chlorophyll pigments in plastids are also harmed and degraded by the high-temperature stress. By eliminating the enzymes involved in the process of chlorophyll production, high temperature stress-related inhibition of chlorophyll biosynthesis was achieved. Under high-temperature stress, 5-aminolevulinate dehydratase (ALAD), the initial enzyme of pyrrole biosynthesis, showed reduced enzymatic activity (Ashraf *et al.,* 2013).

So, the high-temperature stress is one of the main abiotic variables that negatively impacts crop output. Through its impact on the physiological system, high-temperature stress poses a danger at various development phases and eventually lowers output (Wahid *et al.,* 2007).

CONCLUSION

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Climate change will cause temperatures to rise in the next years, which will have a significant impact on agricultural productivity. Despite the fact that many research efforts focus on biotic and abiotic stresses to shield plants from harmful circumstances. The plants need to be given the best circumstances for growth at each stage. Germination, vegetative stage, reproductive stage, and the yield are all impacted by high temperature stress and it is critically necessary to find innovative ways to adapt crops to these changes. From the seedling stage up to the harvest stage, the crop has to be improved.

	2013		2014		2015		2016		2017	
	Max Temp (℃)	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**
January	30.3	22.0	30.6	21.5	30.6	21.6	32.3	22.6	32.6	22.8
February	31.4	22.1	31.3	22.3	31.6	22.3	32.9	23.2	32.5	21.5
March	32.3	24.0	32.4	22.9	32.4	23.7	34.5	24.7	33.4	24.5
April	33.1	25.4	32.4	24.5	32.7	24.5	35.3	26.4	34.2	25.9
May	32.1	25.0	31.9	24.8	32.1	25.3	33.8	24.8	33.7	25.5
June	29.0	23.0	30.8	25.2	31.4	24.5	31.5	24.4	31.4	25.5
July	29.1	22.7	30.0	24.3	31.3	24.6	31.6	24.7	31.6	24.7
August	29.2	23.7	29.5	23.7	31.7	24.6	31.8	24.8	31.2	24.6
September	29.2	23.9	30.2	24.2	31.4	24.4	31.8	24.5	31.5	24.5
October	30.8	23.2	30.5	23.8	31.3	24.0	31.7	24.3	31.1	24.9
November	30.6	23.5	30.2	23.4	31.6	23.8	32.0	24.0	30.8	24.2
December	30.8	21.9	30.2	24.0	31.5	23.3	32.3	23.6	31.8	23.4

Table 1.Weather data- The monthly average temperature (Maximum and Minimum temperature) at College of Agriculture, Vellayani from 2013-2017.The data collected from Department of Agricultural Meteorology, College of Agriculture, Vellayani.

*Max Temp (℃) – Maximum temperature in ℃

*Min Temp (℃) – Minimum temperature in ℃

	2018		2019		2020		2021		2022	
	Max Temp(℃)	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**	**Max Temp (℃)**	**Min Temp (℃)**
January	31.7	21.7	32.0	21.1	32.3	22.9	31.8	23.5	32.4	22.9
February	32.4	23.6	33.6	23.6	33.0	23.3	33.2	22.3	32.4	21.5
March	33.3	24.7	34.6	24.8	33.5	24.6	34	23.3	33.4	24.4
April	33.9	25.9	35.0	25.8	34.2	25.6	33.8	25.9	33.1	22.5
May	32.8	25.3	34.1	26.3	32.6	25.6	32.1	24.9	32.2	23.5
June	31.1	24.7	31.9	25.4	31.5	24.8	32.3	25.6	31.6	23.4
July	30.7	23.8	30.8	24.8	31.7	24.7	31.3	24.9	30.4	22.7
August	30.3	23.6	30.8	24.2	31.7	26.3	30.9	23.9	30.5	22.5
September	32.4	24.3	30.9	24.4	31.1	24.6	31.1	23.5	30.9	23.2
October	31.4	24.3	30.7	24.1	31.3	24.8	31.1	22.3	31.2	23.6
November	31.6	24	31.9	24.5	32.4	25.1	30.1	22.5	30.9	22.5
December	32.0	23.5	31.7	23.8	32.5	24.1	32.1	23.4	31.2	21.1

Table 2.Weather data- The monthly average temperature (Maximum and Minimum temperature) at College of Agriculture, Vellayani from 2018-2022.The data collected from Department of Agricultural Meteorology, College of Agriculture, Vellayani.

*Max Temp (℃) – Maximum temperature in ℃

*Min Temp (℃) – Minimum temperature in ℃

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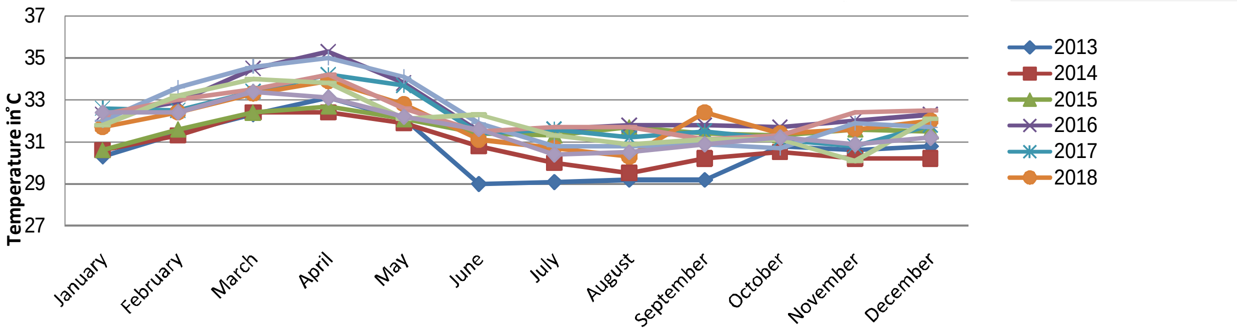

Figure 1. The graph depicting the month-by-month average maximum temperature from 2013-22

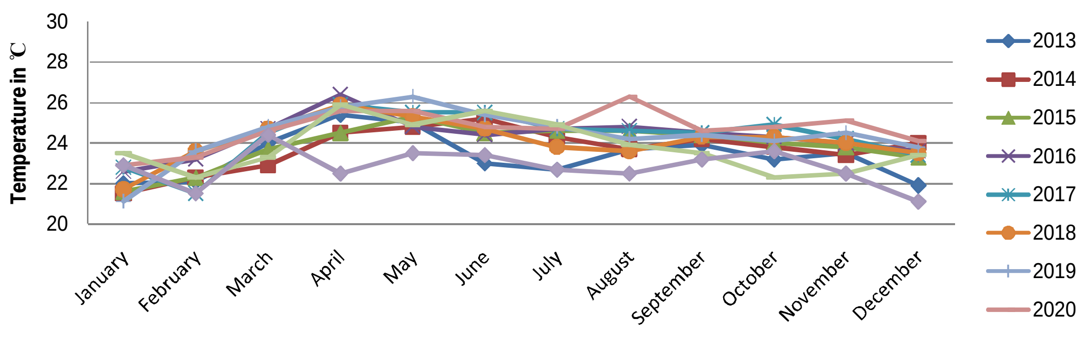

Figure 2. The graph depicting the month-by-month average minimum temperature from 2013-22

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

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