Mapping Current and Projected Chilling Hours for Fruit Trees Using Different Scenarios under Different Locations in Egypt

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ABSTRACT

This study aims to quantify the actual (2022 and 2023) and anticipated (2020-2039, 2040-2059, 2060-2079 and 2080-2099) chilling hours estimated by the 7.2°C and 10°C thresholds for fifty stations in Egypt under five climate change scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5). The results are mapped using ARC GIS to demonstrate chilling hours for any point at a given scenario and time. Median temperatures for the actual and projected monthly and annual minimum temperatures are discussed. Winter minimum temperature increases from one scenario to the next and from one projection period to the next. The lowest winter average minimum temperature is projected to be 10.2 (9.6-10.8°C) under the SSP1-1.9 scenario for the first projection period, while the highest was 13.9 (12.6-15.3°C). Under SSP1-1.9 scenario, twelve locations receive >100 hours, three of them are in Sinai (Nueibaa; Catherine; Nekhel), which they receive 497, 361, and 276 hrs. below 7.2°C, respectively. Under the rest of the scenarios, no station receives more than 100 hrs. below 7.2°C. Similar trends with more details were found for chilling hours below 10.0°C. The results show that chilling hours less than 7.2°C in Nueibaa will receive 489, 407, 350, and 309 hrs. for the projection periods 2020-2039, 2040-2059, 2060-2079 and 2080-2099, respectively. Eight locations receive between 100-200 hrs. for the projection period ending 2039. These results emphasis the need for allocating currently cultivated fruit trees species and cultivars physiologically require chilling hours to examine appropriate adaptation measures for mitigating anticipated yield reduction.

Keywords: Chill hours- Adaptation-7.2°C - 10.0°C- Chilling maps.

INTRODUCTION

Egypt's climate poses unique challenges for the cultivation of deciduous fruit trees, which require a certain number of chilling hours to break dormancy and ensure proper flowering and fruiting. Chilling hours, defined as the cumulative number of hours below a specific temperature threshold during winter, are critical for the successful cultivation of deciduous fruit trees. In Egypt, where the climate is characterized by mild winters, accurately estimating chilling hours is essential for selecting suitable fruit tree varieties and optimizing orchard management (Salama et al., 2021 and Farag et al., 2010). Thus, it is important to find a strategy to calculate the chilling and heat requirements, and this may require experiments at a very large scale, which is impractical (El Yaacoubi et al., 2020).

A very close relationship between dormancy and chilling requirements, particularly under the conditions of climate change, has been reported generally (Hernandez et al., 2021, Campoy et al., 2019 nd Guo et al., 2014) but also at species level, e.g., apricot (Campoy et al., 2012), apple and almond (El Yaacoubi et al., 2016), sweet cherry (Kaufmann and Blanke 2017) and pomegranate (Nasrabadi et al., 2020).

Adequate chill is of great importance for successful production of deciduous fruit trees. However, temperate fruit trees grown under tropical and subtropical regions may face insufficient winter chill, which has a crucial role in dormancy and productivity (Salama et al., 2021).

The estimation of chill hours started by assuming hourly temperatures between 0 and 7.2° to be responsible for bud breaking (Weinberger, 1950). This method did not consider the temperature scenarios and was believed to be a poor indicator of the chill effectively accumulated by the buds (Melke, 2015).

Richardson et al. (1974), known as Utah Model, developed estimated chill accumulation occurs between 2.5 and 12.5 °C, while temperatures outside this range was considered nil or negative, which gave good results in cool climates. However, Linsley-Noakes et al. (1994) found that Utah Model gave negative chill values in tropical and sub-tropical climates and concluded that temperature above 12.5 °C and below 1.5°C should be zero. Other studies assumed that warm temperatures cannot destroy accumulated chill unites if reached certain quantities (Fishman et al., 1987; Erez et al., 1990). Another recent alternative to the previous models were developed for mild winter areas. These models also gave good results by nullifying the negative values generated by Utah model (Linkosalo, 2000, Hänninen, 199, Shaultout and Unrath, 1983 and Gilreath and Buchanan, 1981). Jacobs et al. (2002) explained that a wide range of chilling temperatures between 1°C and 13°C were equally effective in inducing dormancy release in apple trees.

Previous studies have indicated a decline in chilling hours in many parts of the world due to rising temperatures. In Egypt, research has shown variability in chilling hours across different regions and years, affecting the yield and quality of fruit crops such as grapes, apples, peaches, apricots, and pears (El-Khalifa et al., 2020). They also indicated the correlation between productivity and chill hours received and concluded that higher productivities of fruit trees in new lands resulted from lower temperatures.

A climate change impact on agricultural productivity has drawn the attention of researchers all over the world (Medany at al., 2024). With the increasing rate of climate change, improvements in some managing tools (e.g., discovering new, more effective dormancy breaking organic compounds; breeding new, climate-smart cultivars in order to solve problems associated with dormancy and chilling requirements; and improving dormancy and chilling forecasting models) have the potential to solve the challenges of dormancy and chilling requirements for temperate fruit tree production in warm winter fruit tree growing regions (Salama et al., 2021).

Winter chill should be studied like other weather dependent processes because the present trends in chill decline across locations significantly affect fruit culture in areas with mild winter (Melke, 2015).

Understanding and accurately estimating chilling hours is crucial for fruit growers in Egypt to select appropriate cultivars and optimize orchard management practices. With the ongoing impacts of climate change, traditional chilling hour models may no longer be reliable, necessitating updated and region-specific research. Therefore, identifying the problems related to lack of insufficient winter chilling would help in designing possible strategies for the changing scenarios and understanding the current physiological responses of the plant against these changes.

Nabil et al. (2021) reported that horticulture maps are absent in Egypt, despite the vital importance of horticulture crops as a main part of the agriculture economy.

This study aims to quantify the actual (2022 and 2023) and anticipated (2020-2039, 2040-2059, 2060-2079 and 2080-2099) chilling units estimated by the 7.2°C and 10°C thresholds, for fifty stations around the country, under five future different climate change scenarios according to the IPCC Sixth Assessment Report (SSP1 1.9, SSP1 2.6, SSP2 4.5, SSP3 7.0, and SSP5 8.5). The results are mapped using ARC GIS to demonstrate chilling units for any point for a given scenario and time, that will assist in producing a set of horticulture maps.

MATERIALS AND METHODS

The study utilizes hourly temperature data from multiple meteorological stations across Egypt for 2022 and 2023. Chilling hours are calculated using the standard 7.2°C and 10.0°C thresholds. The results are compared with historical averages of 1950-2014 to identify trends in relation to the anticipated projected minimum temperatures and chilling hours.

1. Methodology

The work investigated the projected chilling hours distribution compared to the actual hours in fifty different locations all over Egypt for both 2022 and 2023. The objective of this study is to quantify the actual (2022 and 2023) and anticipated (2020-2039, 2040-2059, 2060-2079 and 2080-2099) chilling hours estimated by the 7.2°C and 10°C thresholds, for fifty stations around the country, under five different future climate change scenarios according to the IPCC Sixth Assessment Report (SSP1 1.9, SSP1 2.6, SSP2 4.5, SSP3 7.0, and SSP5 8.5). The results are mapped using ARC GIS to demonstrate chilling units for any point for a given scenario and time, that will assist in producing a set of horticulture maps. This involved the examination of historical climate data covering the years 1995-2014, as a reference period, and projected data from 2020 up to 2099, considering minimum surface air temperatures, with the estimated hourly median, low and high. The actual hourly data for minimum hourly surface air temperatures covering the period from January 1st 2022 to December 31st, 2023, were obtained from fifty automatic weather stations of the Central Laboratory for Agricultural Climate. Projected data were downscaled to hourly data using Microsoft® Excel® (Version 2406) for the four projected time intervals, under the five scenarios. The five different climate scenarios used are: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 w/m^2 that were based on ensemble of different global general circulation models. The basic spatial datasets for current and future climate are implemented on a global scale using a resolution of 0.25° by 0.25° downloaded from the World Bank Knowledge Portal (World Bank, 2024). Chilling hours were estimated based on 7.2 and 10.0°C thresholds. The chilling hours are mapped using ARC GIS to demonstrate chilling units for any location at a given scenario and time.

2. Study area:

The investigation was carried out for 50 locations representing all agroecological zones of Egypt. The precise location was given a number from 1-50 in order to be used as a reference and facilitate the recognition of name, and Governorate (**Figure 1**).

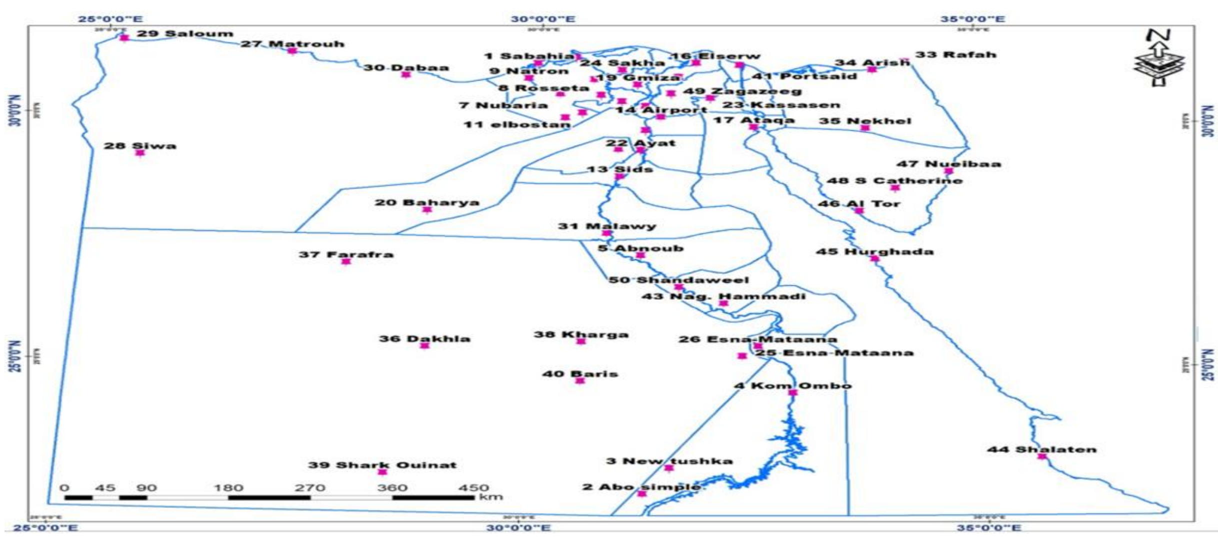

Figure (1): Geographic locations of the 50 weather stations in Egypt

3. Current air temperature:

Hourly air temperatures from 50 stations distributed around the country for the year 2022 and 2023 was obtained from the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research

Center, (**Figure 1**). The hourly average of both years was estimated to represent the current temperatures. Monthly minimum air temperature range (low, median and high) for 2022 and 2023 are illustrated in **Table (1)**. The World Bank Knowledge Portal (World Bank, 2024) was used to obtain monthly minimum air temperature range (low, median and high) in Egypt for the reference period 1950-2014 (**Table 1**). The "median" represented 50th Percentile of the Multi-Model Ensemble, the "low" is the single-day minimum value of the daily minimum temperatures over the aggregated data period, and the "high" is the single-day maximum value of the daily maximum temperatures over the aggregated data period (World Bank, 2024**)**.

4. Projected air temperatures:

Climate projections were previously based on those suggested in the Fifth Assessment Report (AR5) of the Intergovernmental Pannel for Climate Change (IPCC). The AR5 drew four main scenarios, known as Representative Concentration Pathways (RCPs: Meinshausen et al., 2011 and van Vuuren et al., 2011). The RCPs were identified by their radiative forcing reached at the year 2100, going from 2.6, 4.5, 6.0 to 8.5 W/m^2. The IPCC 6^{th} assessment report (IPCC AR6, 2021) presented model simulations from Coupled Model Intercomparison Project (CMIP) (Eyring et al. 2016). A new set of scenarios based on O'Neill et al. (2016). Climate projection data is modeled data from the World Climate Research Program. Data presented is CMIP6, derived from the Sixth phase of the CMIPs. The CMIPs form the data foundation of the IPCC Assessment Reports. CMIP6 supports the IPCC's Sixth Assessment Report. Data is presented at a 0.25º x 0.25º (25km x 25km) resolution.

In this study, five climate projection scenarios were identified to be used for climate change studies (O'Neill et al., 2016 and Allan et al., 2023): SSP1-1.9 (1.5° above 1850–1900 average), SSP1-2.6 for sustainable pathways (2°C above 1850–1900 average), SSP2-4.5 for middle-of-the-road, SSP3-7.0 for regional rivalry, and SSP5-8.5 for fossil fuel-rich development. A brief description of the nine scenarios is shown in IPCC AR6 (2021).

The projection data were downloaded from the World Bank Knowledge Portal (World Bank, 2024), with the following specifications:

- Egypt.
- Collection: cmip6-x0.25.
- Data type: climatology.
- Variables: Average Mean Surface Air Temperature, Average Maximum Surface Air Temperature, and Average Minimum Surface Air Temperature.
- Product: Anomaly.
- Aggregation: Monthly.
- Time Interval: 2020-2039, 2040-2059, 2060-2079, and 2080-2099.
- Percentile: Median or 50th Percentile of the Multi-Model Ensemble.
- Scenario: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.
- Model: Multi-Model Ensemble.
- Model Calculation: All.
- Download: Excel.

After downloading minimum air temperature data for the four time-projection intervals, and four scenarios, all data were downscaled to hourly data in reference to the actual hourly data for 2022 and 2023 using Microsoft® Excel® (Version 2406). Actual (2022 and 2023), historical (1995-2014) and projected (2020-2039, 2040-2059, 2060-2079, and 2080-2099 monthly) minimum average surface air temperature for Egypt, with the Median, Low and High statistical values, are shown in **Table (1)**.

Table (1). Actual (2022 and 2023), Historical (1995-2014) and projected (2020-2039, 2040-2059, 2060-2079, and 2080-2099 monthly) minimum average surface air temperature for Egypt. Median= 50th Percentile of the Multi-Model Ensemble; Low = the single-day minimum value, and High = is the single-day maximum value of the daily minimum temperatures over the aggregated data period.

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual 2022		Median	5.40	6.57	7.03	13.51	16.68	20.94	21.41	22.73	21.27	17.78	13.36	11.17
		Low	1.15	5.12	2.40	8.51	11.75	17.36	19.26	21.25	18.87	15.76	10.00	7.62
		High	8.35	9.76	12.26	18.94	21.08	24.84	23.65	25.14	22.84	22.27	16.32	13.58
Actual 2023		Median	8.27	6.38	10.82	13.35	16.98	21.39	22.74	23.05	22.31	19.27	15.29	11.59
		Low	5.80	3.41	6.97	8.64	11.69	18.42	20.49	20.66	19.82	16.96	9.96	8.35
		High	10.54	10.48	15.84	19.37	22.80	25.55	26.48	27.51	26.49	23.38	19.51	14.56
Historical 1995-2014		Median	7.60	8.90	12.00	16.30	20.00	22.80	24.00	24.10	22.00	18.70	13.50	9.10
		Low	7.12	8.28	11.43	15.74	19.53	22.35	23.61	23.73	21.62	18.14	13.02	8.60
		High	8.05	9.42	12.61	16.83	20.45	23.22	24.34	24.38	22.43	19.17	14.05	9.59
2020-2039	SSP1-1.9	Median	8.31	9.65	12.78	16.93	20.88	23.76	25.06	25.28	23.07	19.56	14.44	9.90
		Low	7.79	9.03	12.15	16.43	20.34	23.26	24.53	24.69	22.56	18.95	13.81	9.38
		High	8.87	10.27	13.47	17.49	21.42	24.26	25.48	25.84	23.68	20.31	15.32	10.62
	SSP1-2.6	Median	8.40	9.70	12.90	17.10	21.00	23.80	25.10	25.40	23.10	19.70	14.60	10.00
		Low	7.80	9.10	12.20	16.50	20.40	23.40	24.50	24.70	22.50	19.10	13.90	9.40
		High	8.90	10.40	13.80	17.50	21.50	24.30	25.50	25.90	23.70	20.40	15.50	10.80
	SSP2-4.5	Median	8.40	9.90	13.00	17.00	21.00	23.90	25.20	25.50	23.20	19.60	14.60	10.00
		Low	7.90	9.30	12.30	16.50	20.40	23.40	24.70	24.90	22.80	19.10	13.80	9.60
		High	9.00	10.30	13.70	17.70	21.60	24.40	25.60	26.00	23.90	20.40	15.50	10.70
	SSP3-7.0	Median	8.40	9.60	12.80	16.90	21.00	23.90	25.20	25.40	23.10	19.70	14.50	10.00
		Low	7.80	8.80	12.00	16.40	20.50	23.30	24.60	24.80	22.70	19.00	14.00	9.30
		High	9.10	10.50	13.50	17.60	21.60	24.40	25.70	26.10	23.80	20.40	15.30	10.60
	SSP5-8.5	Median	8.40	9.80	12.90	17.00	21.10	24.00	25.40	25.60	23.40	19.80	14.70	10.10
		Low	8.00	9.20	12.30	16.60	20.40	23.40	24.70	24.90	22.70	19.10	14.00	9.60
		High	9.10	10.40	13.50	17.70	21.70	24.60	25.80	26.30	24.20	20.70	15.80	11.00
2040-2059	SSP1-1.9	Median	8.54	9.82	12.96	17.19	21.10	24.06	25.40	25.55	23.41	19.90	14.64	10.14
		Low	7.98	9.24	12.31	16.69	20.46	23.48	24.81	24.97	22.82	19.20	13.99	9.53
		High	9.14	10.47	13.66	17.75	21.60	24.55	25.85	26.23	24.02	20.56	15.54	10.93
	SSP1-2.6	Median	8.80	10.10	13.10	17.40	21.30	24.30	25.60	25.80	23.70	20.20	14.80	10.40
		Low	8.10	9.30	12.30	16.60	20.60	23.50	25.00	25.10	22.90	19.40	13.80	9.70
		High	9.40	10.70	14.00	17.90	22.00	24.80	26.10	26.60	24.30	20.90	15.90	11.30
	SSP2-4.5	Median	8.90	10.30	13.50	17.60	21.70	24.60	26.10	26.20	24.00	20.40	15.10	10.70
		Low	8.20	9.60	12.60	17.10	20.80	23.90	25.30	25.40	23.40	19.70	14.40	9.90
		High	9.70	11.00	14.30	18.40	22.10	25.10	26.60	27.00	24.80	21.10	16.30	11.40
	SSP3-7.0	Median	9.20	10.40	13.40	17.70	21.80	25.00	26.30	26.50	24.30	20.60	15.40	10.80
		Low	8.40	9.80	12.60	17.30	20.90	24.20	25.60	25.70	23.50	19.60	14.50	10.00
		High	10.10	11.40	14.60	18.60	22.60	25.50	26.80	27.30	25.10	21.50	16.40	11.90
	SSP5-8.5	Median	9.30	10.70	13.90	18.20	22.10	25.30	26.80	27.10	24.70	21.10	15.80	11.10
		Low	8.80	9.90	12.90	17.30	21.40	24.40	25.80	26.30	23.90	20.20	15.00	10.30
		High	10.20	11.50	14.80	18.80	22.70	26.00	27.50	28.10	25.70	21.90	17.00	12.20
2060-2079	SSP1-1.9	Median	8.41	9.71	12.84	17.11	20.93	23.88	25.19	25.37	23.21	19.73	14.53	9.98
		Low	7.93	9.19	12.33	16.60	20.42	23.36	24.66	24.83	22.62	19.11	13.92	9.49
		High	8.93	10.33	13.44	17.61	21.40	24.42	25.69	26.04	23.82	20.41	15.33	10.81
	SSP1-2.6	Median	8.80	10.20	13.20	17.50	21.40	24.50	25.70	26.00	23.70	20.20	14.90	10.30
		Low	8.10	9.40	12.40	16.70	20.60	23.60	24.80	25.00	22.90	19.30	14.10	9.70
		High	9.40	10.90	14.00	18.30	22.10	25.20	26.40	26.80	24.60	21.10	16.10	11.60
	SSP2-4.5	Median	9.40	10.80	13.80	18.10	22.00	25.10	26.60	26.90	24.60	21.00	15.80	11.20
		Low	8.70	10.10	13.00	17.40	21.50	24.20	25.80	26.10	23.60	20.10	14.70	10.30
		High	10.20	11.70	14.90	19.00	22.70	25.80	27.30	28.00	25.40	21.80	16.80	12.30
	SSP3-7.0	Median	9.90	11.20	14.20	18.60	22.70	25.90	27.40	27.90	25.40	21.70	16.30	11.50
		Low	9.10	10.30	13.40	17.70	21.80	25.10	26.70	26.90	24.20	20.60	15.50	10.80
		High	11.10	12.40	15.70	19.30	23.30	26.90	28.40	29.00	26.50	22.80	17.50	13.20
	SSP5-8.5	Median	10.60	11.90	15.00	19.20	23.30	26.60	28.40	28.80	26.40	22.70	17.20	12.30
		Low	9.80	11.00	14.00	18.40	22.60	25.50	27.30	27.70	25.30	21.60	15.90	11.50
		High	11.60	12.70	16.10	20.00	24.30	27.50	29.40	30.40	27.70	23.50	18.70	13.60
2070-2099	SSP1-1.9	Median	8.26	9.60	12.73	16.99	20.81	23.67	25.01	25.19	23.04	19.55	14.37	9.87
		Low	7.82	9.07	12.28	16.57	20.29	23.22	24.53	24.64	22.47	18.92	13.80	9.35
		High	8.81	10.23	13.29	17.48	21.26	24.24	25.52	25.82	23.64	20.25	15.19	10.58
	SSP1-2.6	Median	8.50	10.20	13.20	17.30	21.30	24.10	25.60	25.90	23.60	19.90	14.70	10.20
		Low	8.00	9.30	12.50	16.80	20.40	23.40	24.70	24.90	22.70	19.00	13.70	9.50
		High	9.60	11.00	14.10	18.20	22.00	25.00	26.40	26.70	24.50	20.90	16.20	11.20
	SSP2-4.5	Median	9.70	11.00	14.20	18.60	22.40	25.50	27.00	27.40	25.10	21.50	16.10	11.50
		Low	9.00	10.30	13.40	17.70	21.80	24.70	26.30	26.50	23.90	20.40	15.20	10.40
		High	10.70	12.20	15.40	19.70	23.40	26.40	28.10	28.60	26.30	22.50	17.40	12.80
	SSP3-7.0	Median	10.90	12.10	15.10	19.60	23.70	26.90	28.80	29.30	26.70	23.00	17.40	12.80
		Low	10.00	10.90	14.00	18.60	22.80	25.80	27.90	28.00	25.40	21.40	16.30	11.80
		High	12.10	13.80	16.70	20.50	25.00	28.20	30.00	31.10	28.10	24.20	19.10	14.20
	SSP5-8.5	Median	11.90	13.20	16.40	20.50	25.00	28.30	30.30	30.90	28.30	24.30	19.00	14.10
		Low	10.70	12.10	15.10	19.60	23.60	26.60	28.70	28.80	26.30	22.50	17.40	12.60
		High	13.40	14.70	17.50	21.70	25.90	29.50	31.70	33.00	30.00	25.50	20.70	15.70

The projected monthly average minimum surface air temperature anomalies for Egypt (reference period 1950-2014), during four projection periods (2020-2039; 2040-2059; 2060-2079; and 2080-2099), for the four scenarios: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 (World Bank, 2024) are illustrated in **Figure (2)**.

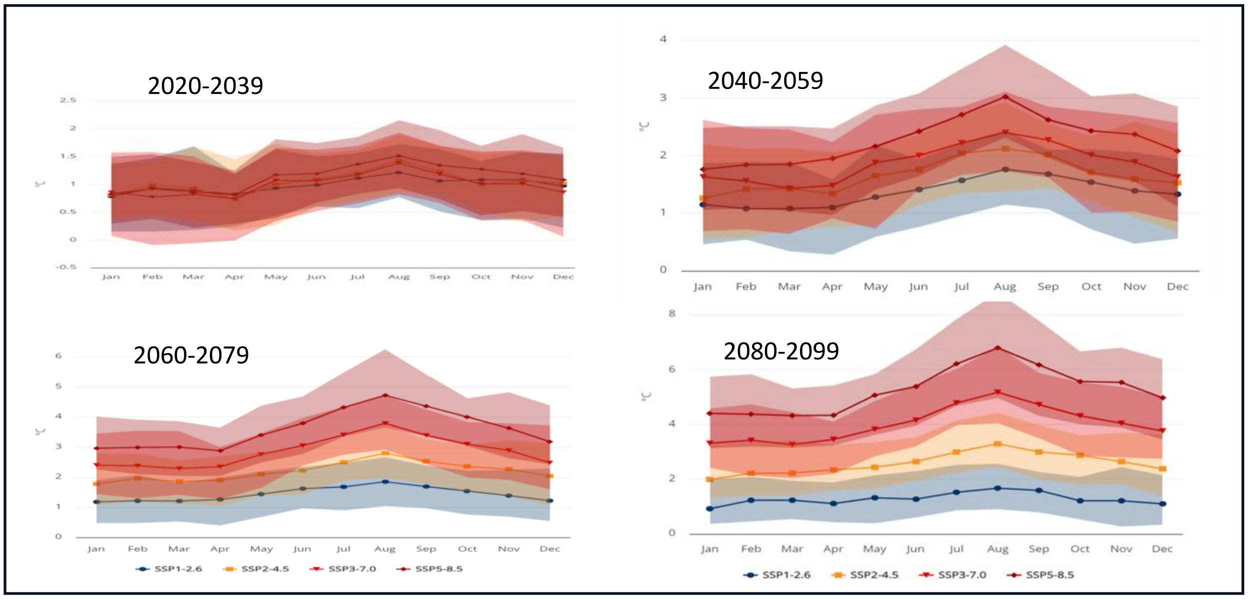

Figure (2). Projected monthly average minimum surface air temperature anomalies for Egypt (reference period 1950-2014), during four projection periods (2020-2039; 2040-2059; 2060-2079; and 2080-2099), for the four scenarios: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.

5. Spatial interpolation using Topo to Raster:

ArcGIS software, developed by Esri, was used for spatial analysis, data mapping, and geoprocessing. ArcGIS provides robust tools for handling geospatial data, from simple visualizations to complex spatial modeling. In this context, ArcGIS 10.8.2 was employed to perform spatial interpolation using the Spatial Analyst extension, which offers various interpolation methods, including the one used in this study: Topo to Raster. This method generates continuous surfaces from irregularly spaced data points, which is crucial for understanding spatial phenomena like temperature distribution, precipitation patterns, or in this case, chilling hours (ESRI, 2020).

There were three steps to Apply Topo to Raster: i. Input of chilling hours data for the 50 weather stations; ii. Processing of data using advanced interpolation techniques, considering topography and other factors; and iii. Raster maps are generated representing a continuous surface of chilling hours across Egypt, based on the input data.

The Topo to Raster method is based on several mathematical techniques, including linear interpolation, inverse distance weighting (IDW), and smoothing algorithms. Linear interpolation is used when values need to be estimated along specific linear features (such as contour lines or profiles). This method calculates the value between two known points based on their relative distances. Inverse Distance Weighting (IDW) is a commonly used interpolation technique that assumes that points closer to one another are more similar than those further apart. The value at an unsampled location is estimated using a weighted average of values from nearby sampled points, where the weights are inversely proportional to the squared distance between the sampled and unsampled points **(**Longley et al., 2015**).** The Topo to Raster tool was also applied for smoothing algorithms to ensure a smooth and continuous surface by minimizing the overall curvature of the surface (ESRI, 2020).

6. Statistical analysis:

The actual hourly average minimum surface air temperatures were the average of instant measures of minimum air temperature during each hour of the day for both years 2022 and 2023, starting from January 1st, till December 31st. Three daily minimum air temperatures each day were obtained: daily "Mean" minimum temperature, daily "High" minimum temperature and daily "Low" minimum temperature. Basic statistics were applied to obtain "Mean", "Low" and "High" for every month. Median was the mean value of the single day mean minimum temperature of the month. "Low" was the single-day minimum value, and "High" was the single-day maximum value of the daily minimum temperature of the month (Ott and Longnecker, 2010).

The monthly projected values were downloaded with their estimated statistical values. "Median"= 50th Percentile of the Multi-Model Ensemble; "Low" = the single-day minimum value, and "High" = is the single-day maximum value of the daily minimum temperatures over the aggregated data period (WORLD BANK, 2024).

RESULTS AND DISCUSSIONS

1. Historical and actual minimum air temperatures:

The annual average median, low and high temperatures for the reference period 1950-2014 were 16.6, 16.1, and 17.1°C, respectively. The annual average median temperature of 2023 was higher than 2022 (16.0 compared to 14.8). The annual average low and high temperature for 2023 were 20.2, and 12.6°C, while it was 18.3 and 11.6 °C in 2022 (**Table 1**). These values indicate clearly that the average median of minimum temperatures of both 2022 and 2023 was 15.4°C compared to 16.6°C for the reference period, or 1.2°C lower. The average low temperature for both years is even 4.0°C lower, while the average high was 2.2°C higher. These values illustrate the magnitude of changes in minimum air temperature patterns that require further attention to the details of minimum air temperatures, and consequently the way the chilling degrees is estimated (Salama at al., 2021, Campoy et al., 2019, Campoy et al., 2012, Erez et al., 1990 and Fishman et al., 1987).

Regarding minimum temperatures during winter months (December, January, February and March), average "median" and "low" minimum temperatures in 2020 were lower than 2023, while the opposite was obtained regarding average "high" minimum temperatures. Comparing the reference values to the averages of both 2022 and 2023 together, the results showed the average "median" and "low" minimum temperatures for winter of the reference period were higher than those of 2022 and 2023. Meanwhile, the average "high" minimum temperature was higher in the reference period than those of 2022 and 2023. These results are similar to those of the annual values for minimum air temperatures and reaffirm the importance of understanding the behavior of plant dormancy against hourly temperatures. The results agree with those obtained by El-Geziry (2021). Other weather parameters or growing conditions may contribute to productivity of deciduous fruit trees along with minimum surface air temperatures (Campoy et al., 2019 and Fadón, 2020).

2. Projected minimum air temperatures:

As could be extracted from **Table (1)**, the annual average for median values of minimum air temperatures regardless of projection period was 19.6, 19.0,18.5, 17.9, and 17.5°C for the five scenarios SSP5-8.5, SSP3-7.0, SSP2, 4.5, SSP1-2.6, and SSP1-1.9, respectively. Similarly, winter averages were 12.0, 11.4, 11.0, 10.5, and 10.2°C, respectively. “Low” and “High” values showed also the same trend, as the “Low” values ranged from 18.7 to 17.0°C for the annual averages and ranged from 11.1 to 9.7°C for the winter averages, while the “High” values ranged from 20.7 to 18.2°C for the annual averages and ranged from 13.0 to 10.9°C for the winter averages. This trend of scenario temperature projections agreed with the general implications that the set of scenarios represented show progressive warming from SSP1-1.9 towards SSP5-8.5 reported by Allan et al. (2023) and IPCC, AR6 (2021).

Regarding the change in minimum temperatures for the four projected periods 2020-2039; 2040-2059; 2060-2079; and 2080-2099, the annual “Median” average, regardless of scenario, were 10.2 (9.6-10.9); 10.8 (10.1-12.2); 11.3 (10.5-12.2); and 11.8 (10.9-12.9°C), respectively, while winter average were 17.6 (17.0-18.2); 18.2 (17.5-19.0); 18.8 (18.0-19.7); and 19.4 (18.4-20.5°C), respectively. For the combination, the lowest annual and winter average minimum temperature is projected to be 17.5 (16.9-18.1°C) and 10.2 (9.6-10.8°C) under the SSP1-1.9 scenario for the first projection period, while the highest values were 21.9 (20.3-23.3°C) and 13.9 (12.6-15.3°C), respectively.

These results bring the attention to the need for investigating all possible adaptation options for growing deciduous fruit trees successfully under the Egyptian Conditions, including switching species, cultivars, locations and agricultural practices (El-Khalifa, 2020, Campoy et al., 2019 and Campoy et al., 2012).

3. Actual chilling hours:

The actual chilling hours estimated under 7.2 and 10.0°C were performed for two successive years of 2022 and 2023, and the results are shown on the right of **Figures (3 and 4)**. The number of chill hours temperatures below 7.2°C in the 50 locations ranged between 0 to 628 hours, only 3 out of them received >400 hours (Nueibaa, S. Catherine, and Nekhel in Sinai), 5 locations <400 and >200 hours (Dakhla, Sewa, Baharya, Abnoub and Malawy), and 15 locations received <200 and >100 hours (Sids, Farafra, Future Natron, Kharga, Badrasheen, Cairo Airport, Ouinat, Nag. Hammad, Shandaweel, Ayat, Baris, Esna, Tamea, and Kassasen). The remaining 27 locations received less than 100 hours. As shown in **Figure (3)**, most of the agricultural areas below Asyut Governorate, the Northern coast and the Red Sea currently receiving the least chilling hours. The areas currently with the highest number of fruit trees are located west of Delta, Nubaria, Ismailia region, and Northern part of the Nile Valley till Asyut (CAPMAS, 2023). There are inconsistencies in the production of pears, plums, apricot, grapes, apples, and olives for various abiotic reasons accompanied by climate variabilities (INDEXBOX, 2024; INDEXBOX, 2024a; Martins et al. 2024). On the other hand, low temperatures below 7.2°C may cause damage to temperate trees such as mangoes and citrus (Bhattacharjee et al., 2022). Detailed research for the specific adaptation options and mapping of projected fruit tree’s location is highly required.

The number of chill hours temperatures below 10.0°C in the 50 locations ranged between 0 to 1280 hours (**Figure 4**). Three location showed chilling hours <10.0°C higher than 1000 hours, 15 locations received <1000 and >500 hours, 16 locations received <500 and >300 hours, and the remaining 16 locations received less than 300 hours. The location of stations on the actual chilling hours below 7.2°C map in Figure 3 is similar to those on the map of **Figure (4)**. The detailed map of hours below 10.0°C could be useful for mapping suitability of cultivation of fruit trees, whether to cold sensitive trees, or planting low chilling requirement trees (El-Khalifa, 2020 and Campoy et al. ,2019).

4. Projected chilling hours:

4.1. Chilling hours less than 7.2°C:

Nueibaa, Sant Catherine and Nekhel receive 389, 285, and 206 hrs., respectively, below 7.2°C as average for all scenarios and all projection periods (**Figure 3**). Compared to the actual years, those three locations will be 62, 62 and 51%, respectively, lower in the average projected period than the actual.

Regarding the scenarios, for the optimistic scenario SSP1-1.9, twelve locations receive >100 hours, three of them are the aforementioned locations which receive 497, 361, and 276 hrs., respectively. Those three locations will receive >200 hrs. under SSP1-2.6 scenario, and the only ones receive >100 hrs. under the rest of scenarios. Four more stations receive more than 100 hrs. under SSP1-2.6 scenario. Detailed locations of each scenario, with their interaction with the projection period, are illustrated on the vertical maps, which show clearly the need to allocate fruit tree species and cultivars in appropriate locations for future cultivations. These results agree with Farag et al. (2010) and El-Khalifa et al. (2020).

Regarding the projection period, the results show that chilling hours less than 7.2°C are decreasing with time. For example, Nueibaa location will receive 489, 407, 350, and 309 hrs. for the projection periods 2020-2039, 2040-2059, 2060-2079 and 2080-2099, respectively. Only eight locations receive >100 and <200 hrs. for the closest projection period ending 2039, namely: Siwa, Dakhla, Abnoub, Malawy, Future, Baharya, Farafra, and Sids. Those stations will receive less than 100 hours for the rest of the projection periods. No stations out of Sinai will receive >100 hrs. for the rest of projection periods (**Figure 3**). Detailed locations of each projection period, with their interaction with the projection scenarios are illustrated on the horizontal maps, which demonstrate the need for allocating currently cultivated species and cultivars of fruit trees physiologically require chilling hours in order to examine appropriate adaptation measures necessary for mitigating anticipated yield reduction (El-Khalifa, 2020 and Campoy et al., 2019).

4.2. Chilling hours less than 10.0°C:

Nueibaa, Sant Catherine and Nekhel receive 894, 720, and 693 hrs., respectively, below 10.0°C as average for all scenarios and all projection periods (**Figure 4**). Compared to the actual years, those three locations will be 70, 68 and 67%, respectively, lower in the average projected period than the actual.

Regarding the scenarios, for the optimistic scenario SSP1-1.9, the three aforementioned locations in Sinai receive 1073, 875, and 860 hrs., respectively; thirteen locations receive >400 and <700 hours; eight additional locations receive >300 hours, while the remaining 26 locations receive less than 100 hours below 10.0°C. Under the pessimistic scenario SSP5-8.5, Nueibaa, Sant Catherine, Nekhel, Siwa, and Baharya receive 712, 563, 525, 325, and 305 hrs., respectively. Eleven additional locations receive >200 hrs., 14 locations receive > 100 hrs., while the remaining 20 location receive <100 hrs. The other three scenarios range between SSP1-1.9 and SSP5-8.5. Detailed locations of each scenario are illustrated on the vertical maps, with their interaction with the projection period, which show clearly the need to allocate fruit tree species and cultivars in appropriate locations for future cultivations. These results agree with Farag et al. (2010) and El-Khalifa et al. (2020).

Regarding the projection period, the results show that chilling hours less than 10.0°C are decreasing with time. For example, Nueibaa location will receive 1051, 930, 834, and 761 hrs. for the projection periods 2020-2039, 2040-2059, 2060-2079 and 2080-2099, respectively. During the closest projection period till 2039, eight locations receive >500 hrs., namely Nueibaa, Sant Catherine, Nekhel, Siwa, Baharya, Dakhla, Farafra and Future Natron. Other eight locations receive >400 and <500 hrs. for the same period, namely: Malawy, Abnoub, Sids, Shark Ouinat, Kharga, Ayat, Cairo Airport, and Badrasheen. Additional eight stations receive >300 hrs., and eight different locations receive >200 hrs. the remaining 18 locations receive <200 hrs. below 10.0°C (**Figure 4**). Detailed locations of each projection period are illustrated on the horizontal maps, with their interaction with the scenarios, which demonstrate the need for allocating currently cultivated species and cultivars of fruit trees physiologically require chilling hours in order to examine appropriate adaptation measures necessary for mitigating anticipated yield reduction (El-Khalifa, 2020 and Campoy et al., 2019).

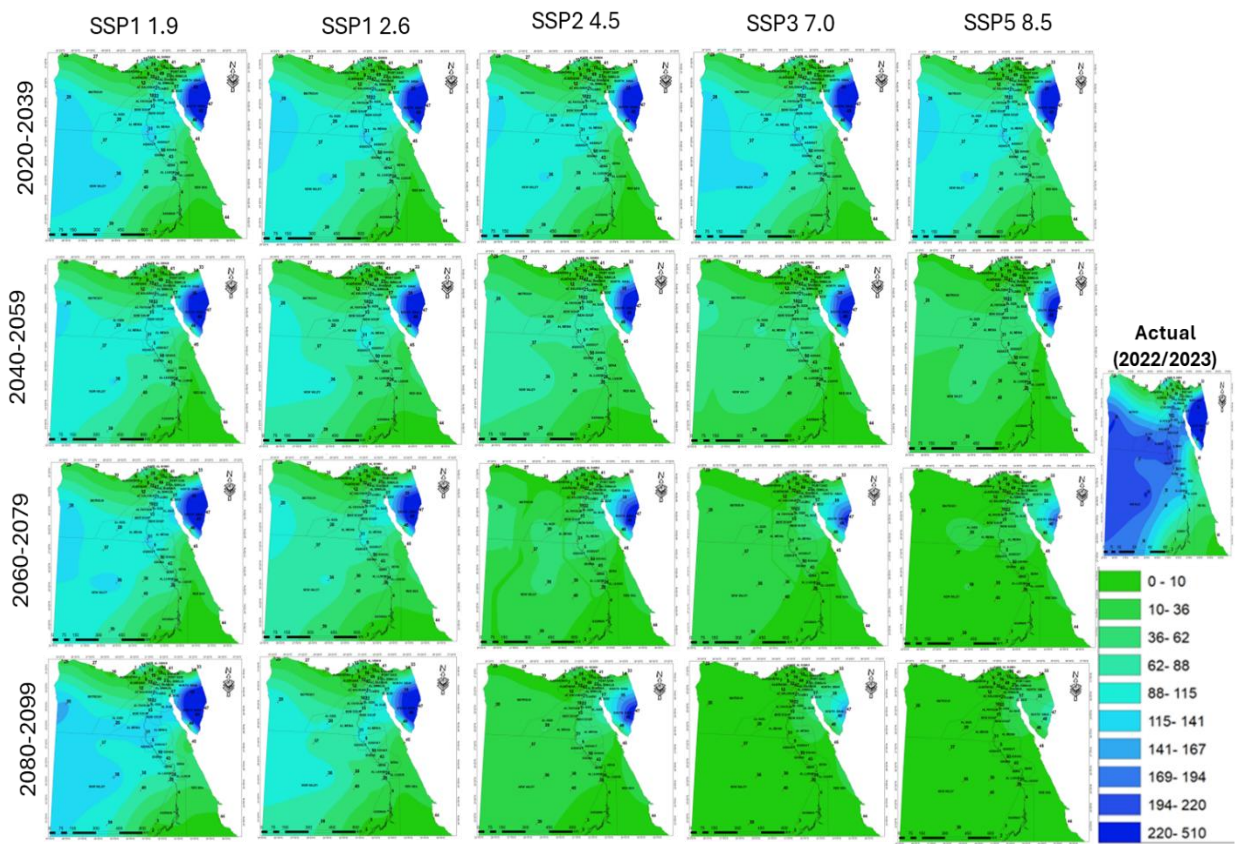

Figure (3). Chilling hours below 7.2 °C, under actual (2022/2023) hourly temperatures and five future scenarios (SSP1 1.9, SSP! 2.6, SSP2 4.5, SSP# 7.0, & SSP5 8.5) in 50 locations in Egypt for four projected periods (2020-2039, 2040-2059, 2060-2079 & 2080-2099).

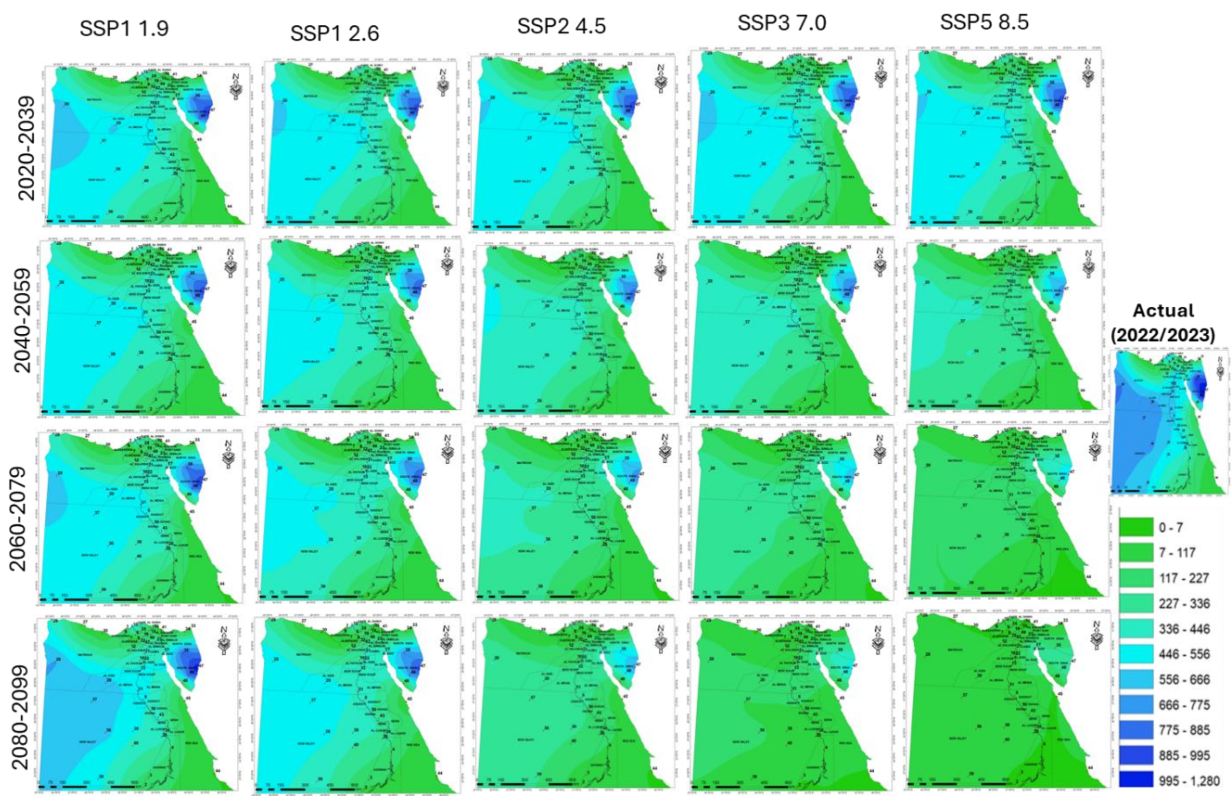

Figure (4). Chilling hours below 10.0 °C, under actual (2022/2023) hourly temperatures and five future scenarios (SSP1 1.9, SSP! 2.6, SSP2 4.5, SSP# 7.0, & SSP5 8.5) in 50 locations in Egypt for four projected periods (2020-2039, 2040-2059, 2060-2079 & 2080-2099).

CONCLUSION

Minimum temperatures were fluctuating from the year 2021 to 2022, and their average was higher than the average period 1950-2014 by 1.2°C. The chilling hours decreased from optimistic to pessimistic scenario, and also decreased along the projection periods 2020-2039, 2040-2059, 2060-2079, 2080-2099. The majority of countries receive less than 100 hours below 7.2°C by the end of the century. The results concluded that there is a need for allocating currently cultivated species and cultivars of fruit trees physiologically require chilling hours in order to examine appropriate adaptation measures necessary for mitigating anticipated yield reduction.

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الملخص العربى

رسم خرائط لساعات البرودة الحالية والمتوقعة لأشجار الفاكهة باستخدام سيناريوهات مختلفة في مواقع مختلفة في مصر

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تهدف هذه الدراسة إلى تحديد ساعات البرودة الفعلية (2022 و 2023) والمتوقعة (2020-2039، 2040-2059، 2060-2079، 2080-2099) أقل من 7.2 و10 درجات مئوية لخمسين محطة في مصر تحت خمسة سيناريوهات لتغير المناخ (SSP1-1.9، SSP1-2.6، SSP2-4.5، SSP3-7.0، وSSP5-8.5). تم وضع النتائج على خرائط باستخدام ARC GIS لإظهار ساعات البرودة لأي نقطة وأي سيناريو في أي سنة. تم مناقشة نتائج متوسط درجات الحرارة الدنيا الشهرية والسنوية الفعلية والمتوقعة. أظهرت النتائج ارتفاع درجة الحرارة الدنيا شتاءً من سيناريو إلى آخر، ومن فترةٍ توقع إلى أخرى. ومن المتوقع أن يبلغ أدنى متوسط لدرجة الحرارة الدنيا في فصل الشتاء 10.2 (9.6-) 10.8 درجة مئوية في إطار السيناريو الأول لفترة التوقع الأولى، في حين كانت أعلى القيم 13.9 (12.6-15.3) درجة مئوية. وفي ظل هذا السيناريو، يتلقى اثني عشر موقعًا أكثر من 100 ساعة، ثلاثة منها في سيناء (نويبع، سانت كاترين، ونخل)، حيث يحصلون على 497 و361 و276 ساعة أقل من 7.2 درجة مئوية، على التوالي. وفي بقية السيناريوهات، لا تستقبل أي محطة أكثر من 100 ساعة أقل من 7.2 درجة مئوية. نفس الاتجاه لساعات البرودة أقل من 10.0 درجة مئوية. أظهرت النتائج أن ساعات التبريد أقل من 7.2 درجة مئوية في نويبع، على سبيل المثال، ستحصل على 489، 407، 350، و 309 ساعة برودة لسنوات 2020-2039، 2040-2059، 2060-2079 و2080-2099، على التوالي، بينما تتلقى ثمانية مواقع فقط أكثر عدد ساعات بين 100 و200 ساعة أقرب الفترات التي تنتهي عام 2039. تؤكد هذه النتائج على الحاجة إلى تحديد مواقع أنواع وأصناف الفاكهة المنزرعة حاليًا والتي تتطلب فسيولوجيا ساعات برودة لتحديد تدابير التكيف المناسبة للتخفيف من الانخفاض المتوقع في الإنتاجية.