



## Response of Pomegranate trees to Climate Changes and Geographical Distribution in Halabja Governorate, Iraq .

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### ABSTRACT

This study conducted in the poultry fields of the Department of Animal Production/College of Agriculture/ University of Kirkuk, for the period from 2024/7/4 to 2024/8/8, to know the effect of adding clove bud powder and vitamin C as a heat stress reliever and its effect on the productive performance of broilers. 240 one-day-old ROSS 308 Unsexed broiler chicks were used and the average initial weight was (39. 09) g. The chicks were randomly distributed into eight treatments with 3 replicates of 10 birds per replicate. The following experimental treatments :(T0) Control treatment,(T1) Vitamin C 250g/ Ton,(T2) clove bud powder 250g/ Ton Feed,(T3) clove bud powder 500g/ Ton Feed, (T4) clove bud powder 1000g/ Ton Feed ,(T5) clove bud powder 250g + 250g vitamin C Ton /Feed ,(T6) clove bud powder 500g + 250g vitamin C Ton /Feed ,(T7) clove bud powder 1000g + 250g vitamin C Ton / Feed. The results showed significant differences between the supplementation treatments and the control treatment in the average live body weight, the average weight gain, and the feed conversion ratio, and most of the weight increases occurred in the second treatment in all weeks. As for feed intake , a significant decrease was observed in favor of the sixth treatment.

**Keywords:** Silver Cloves, Vitamin C, Heat Stress, Production Traits.

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### Introduction

Pomegranate (*Punica granatum* L.) is widely recognized for its health-beneficial metabolites with a substantial demand for its fruit in global markets [1]. There are many cultivars of pomegranates trees in Halabja Governorate as There are many cultivars of pomegranates trees in Halabja Governorate as include Salaxani, Kawa Hanar, Katose Sorahanar, Malase, and Sweet Pomegranate. These varieties bloom in the spring, typically around early May, and are harvested toward the end of September, coinciding with the hottest months of the year. Notably, the initial stage of fruit expansion, involving cell division, occurs during heat waves with extreme temperatures (>34°C). Suboptimal climate conditions during fruit development can result in physiological skin disorders, such as cracking and rusting. Following the brief period of cell division, fruit growth primarily involves the enlargement of fruit cells [2].

Agriculture in Halabja governorate is not limited to pomegranates; other crops such as grapes, peaches, apricots, figs, olives, pears, and grains—including wheat, barley, and sunflower—are also cultivated. The number of pomegranate farms in Halabja governorate exceeds 1,880 encompassing approximately 1,000,000 pomegranate trees that collectively yield around 35,000 tons of fruit annually [3], Pomegranate trees in Halabja begin fruiting early with some varieties producing fruit by the third year of planting. Peak yields occur between the ages of 6 and 9 years and the trees can live up to 50 years. The yield of each tree ranges from 25 to 30 kg of fruit annually, with fruits typically ripening in August and continuing until the end of September depending on the variety. However, the productivity of pomegranate trees is expected to decline in the future due to climate change. Modeling studies are an effective tool for predicting the potential impacts of climate change on crop production. Climate change has already been evident in the Sulaimaniyah governorate, located approximately 90 km west of Halabja. by [4]. which analyzed temperature data from 1973 to 2019, clearly demonstrates the effects of climate change in the region. The collected data indicated an increase in the average annual temperature by approximately 1.3°C. Moreover, rainfall data for the same period revealed an increase in mean precipitation, with an average of 679 mm annually sufficient for agricultural irrigation needs, especially for crops like wheat, which require about 450 mm of rainfall for optimal production. Sunshine hours were lowest in December, with a total annual average of 184.4 hours for the period 1985-2022. The lowest recorded sunshine hours were in 1996, with only 2.3 hours, followed by 2018 with 3.3 hours. Over the decades, wheat growing seasons have shifted, with planting often advancing to November. In the most recent decade (2011-2020),

some farmers have resorted to planting in December to ensure sufficient rainfall [5, 6]. Wind speed records also indicate significant variability. The highest wind speeds recorded in the past 34 years occurred in January and February 2017, reaching 8 and 9 m/s, respectively, whereas lower wind speeds were observed in April, May, June, and September (0.1 m/s). The highest average wind speeds occurred in 1985 and 1992, with values of 3.1 and 2.2 m/s, respectively. In contrast, the lowest wind speed recorded was 1 m/s in 1991. Over the 34-year period, the average change in wind speed was 0.04 m/s. Results from climate change data spanning a decade indicate that wind patterns, along with vapor pressure, are influenced by seasonality, timing, variability, and magnitude, all of which may be altered under future climate scenarios [7, 8].

## Methods

Halabja governorate is located Coordinates: 35°11'11"N 45°58'26"E in Kurdistan region 90km east of Sulaimaniyah governorate and 714km northeast of Baghdad with elevation 900m this area is one of the most fertile areas in all Iraq. The city lies at the base of what is often referred to as the greater [Hawraman](#) region stretching across the [Iran–Iraq](#) border. Halabja is surrounded by Hawraman and Shnrwe range in the northeast, Balambo range in the south and [Sirwan river](#) in the west. Pomegranate orchards were selected in cooperation with the Halabja Agriculture Directorate during a survey of areas documented in 2008 and 2014 in addition to the survey we conducted in 2023, where the number of orchards in each area was calculated. Meteorological data was documented from the Meteorological and Seismic Monitoring Directorate in Halabja Governorate [3].

Table1. Location study and the number of pomegranate orchards and the popular varieties in each location

| Locations | Villages         | GPS Coordinate            | Numbers of Orchards | Popular Varieties               |
|-----------|------------------|---------------------------|---------------------|---------------------------------|
| L1        | Ahmed Awa        | 35°17'53.9"N 46°03'44.5"E | 134                 | Kawa Hanar, Katose Sorahanar    |
| L2        | Dea koan         | 35°16'34.7"N 46°02'08.0"E | 87                  | Salaxani, Kawa Hanar            |
| L3        | DaraShysh Saroo  | 35°12'55.8"N 46°02'44.9"E | 64                  | Sweet Pomegranate, Salaxani     |
| L4        | Tapa Kora        | 35°15'21.4"N 45°59'33.3"E | 228                 | Salaxani, Sweet, Kawa Hanar     |
| L5        | Anab             | 35°12'36.4"N 46°00'55.1"E | 199                 | Katose Sorahanar, Salaxani      |
| L6        | Zamaky Saro      | 35°12'06.6"N 45°58'00.9"E | 134                 | Sweet, Salaxani, Kawa Hanar     |
| L7        | Bawa Kochak      | 35°08'55.8"N 45°58'28.8"E | 335                 | Katose Sorahanar, Sweet po.     |
| L8        | Jalyla           | 35°11'52.5"N 45°57'57.2"E | 162                 | Salaxani, Sweet Pomegranate     |
| L9        | Biawaelia        | 35°13'52.8"N 46°00'19.1"E | 118                 | Katose Sorahanar, Salaxani      |
| L10       | Bamoak           | 35°09'41.7"N 45°59'44.1"E | 228                 | Sweet Po., Kawa Hanar           |
| L11       | Qeshlaxa Roota   | 35°14'38.8"N 45°59'02.4"E | 180                 | Katose Sorahanar, Sweet Po.     |
| L12       | Preacy Saro      | 35°11'48.0"N 45°56'14.6"E | 115                 | Salaxani, Katose Sorahanar      |
| L13       | Tapa Goliawe     | 35°16'51.0"N 45°56'47.7"E | 124                 | Salaxani , Katose Sorahanar,    |
| L14       | Basharati khwaru | 35°15'56.8"N 45°57'04.0"E | 390                 | Salaxani, Sweet Po.,            |
| L15       | 12 Emamy Saro    | 35°13'29.4"N 45°52'40.8"E | 202                 | Kawa Hanar, Salaxani, Sweet Po. |
| L16       | Ababayle         | 35°10'20.6"N 46°02'00.6"E | 126                 | Katose Sorahanar, Salaxani      |
| L17       | Daliyen          | 35°13'51.7"N 45°57'04.0"E | 94                  | Katose Sorahanar, Salaxani      |
| L18       | Halibja          | 35°12'33.4"N 45°57'58.4"E | 628                 | Kawa Hanar, Katose Sorahanar    |
| L19       | Kela spy         | 35°09'41.8"N 45°58'24.1"E | 254                 | Katose Sorahanar, Kawa Hanar    |

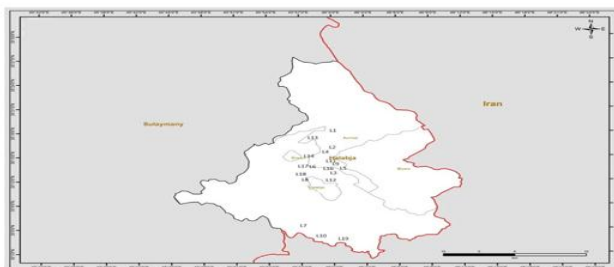


Figure1. Study sites in Halabja Governorate map



figure 2. Katose Sorachnar



Figure3. Sweet pomegranate and Kawa Hanar fruit



Figure4. Salaxani and Malese fruit

## Results and Discussions

### Pomegranate Survey in 2008, 2014 and 2023

Some villages show significant increases in values over the years, while others exhibit declines or fluctuations. 2008–2014: This period appears to exhibit growth for most villages, particularly "Bawa Kochak," "Basharty khwaru," and "Ababayle." 2014–2023: While some villages maintain their growth, others like "DaraShysh Saroo" and "Bamoak" decline notably. Villages with Consistent Growth: "Halibja" and "Bawa Kochak" display steady increases across all periods. Fluctuations: Some villages, like "Dea koan" and "Zamaky Saro," show marked variability across the years. Growth is apparent between 2014 (40) and 2023 (134), suggesting improvements in flowering-related yields in recent years, likely due to stable environmental factors or enhanced agricultural practices. Dea koan: Experienced a significant surge in 2014 (435) [9]

Table 2. Annual increases in pomegranate orchards numbers at the village level.

| Villages         | Increasing years                    |                                      |
|------------------|-------------------------------------|--------------------------------------|
| Ahmed Awa        | 2008 to 2014: Decrease (49 → 40),   | 2014 to 2023: Increase (40 → 134)    |
| Dea koan         | 2008 to 2014: Increase (33 → 435),  | 2014 to 2023: Decrease (435 → 120)   |
| DaraShysh Saroo  | 2008 to 2014: Increase (10 → 324),  | 2014 to 2023: Decrease (324 → 64)    |
| Tapa Kora        | 2008 to 2014: Increase (31 → 210),  | 2014 to 2023: Increase (210 → 228)   |
| Anab             | 2008 to 2014: Increase (79 → 201),  | 2014 to 2023: Decrease (201 → 198.5) |
| Zamaky Saro      | 2008 to 2014: Increase (9 → 222),   | 2014 to 2023: Decrease (222 → 68)    |
| Bawa Kochak      | 2008 to 2014: Increase (63 → 525),  | 2014 to 2023: Decrease (525 → 335)   |
| Jalya            | 2008 to 2014: Increase (60 → 165),  | 2014 to 2023: Decrease (165 → 161.5) |
| Biawaelia        | 2008 to 2014: Decrease (79 → 160),  | 2014 to 2023: Decrease (160 → 118)   |
| Bamoak           | 2008 to 2014: Increase (117 → 317), | 2014 to 2023: Decrease (317 → 226)   |
| Qeshlaxa Roota   | 2008 to 2014: Increase (25 → 103),  | 2014 to 2023: Increase (103 → 180)   |
| Preacy Saro      | 2008 to 2014: Increase (28 → 222),  | 2014 to 2023: Decrease (222 → 115)   |
| Tapa Goliawe     | 2008 to 2014: Increase (28 → 112),  | 2014 to 2023: Increase (112 → 124)   |
| Basharati khwaru | 2008 to 2014: Increase (28 → 112),  | 2014 to 2023: Increase (112 → 124)   |
| 12 Emamy Saro    | 2008 to 2014: Increase (7 → 222),   | 2014 to 2023: Decrease (222 → 82)    |
| Ababayle         | 2008 to 2014: Increase (23 → 222),  | 2014 to 2023: Decrease (222 → 82)    |
| Daliyen          | 2008 to 2014: Increase (14 → 93),   | 2014 to 2023: Decrease (93 → 92)     |
| Halibja          | 2008 to 2014: Increase (376 → 444), | 2014 to 2023: Decrease (444 → 628)   |
| Kela spy         | 2008 to 2014: Increase (394 → 525), | 2014 to 2023: Decrease (525 → 335)   |

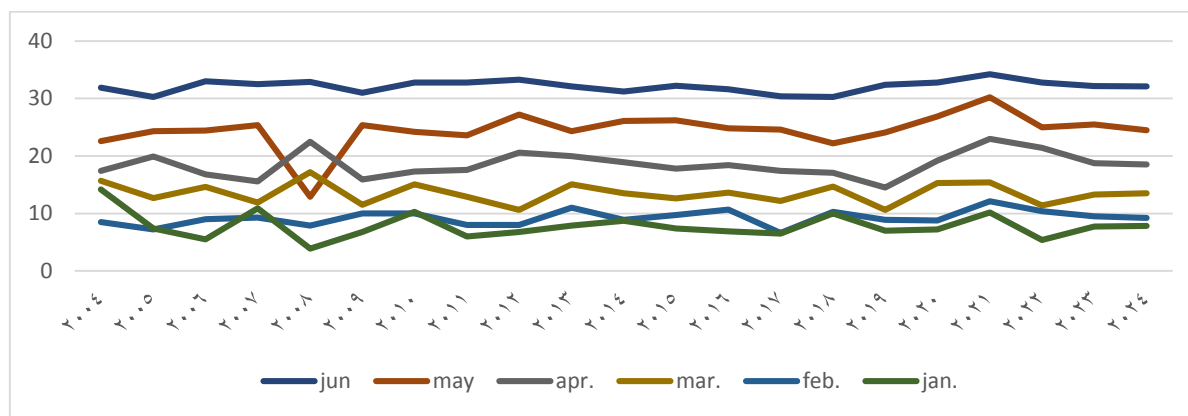


Figure5. Jan., May, Apr., Mar., Feb. and Jan. Annual Avengers Temperature for years 2004- 2024

In January 2004–2009: Temperatures ranged between 6.8°C and 14.2°C, with a trend toward moderate temperatures. 2010–2014: Temperatures were somewhat consistent, fluctuating between 6°C and 12.1°C, with a slight increase after 2010. In 2015–2024: The temperatures were generally higher, ranging from 7.4°C to 12.1°C, showing a gradual upward trend, particularly after 2017.

In February 2004–2009: Temperatures fluctuated between 6.8°C and 17.2°C, with some warmer years (like 2008 and 2009). And 2010–2014: Temperatures ranged from 7.4°C to 16.8°C, remaining fairly stable. In 2015–2024: A general increase, with values ranging from 7.7°C to 17.6°C, especially in 2021.

In March 2004–2009: Temperatures ranged from 5.5°C to 12.7°C, with moderate variation across the years. From 2010–2014: The temperature increased slightly, ranging from 7.4°C to 12.6°C. In 2015–2024: Temperatures ranged from 7.2°C to 13.5°C, with some fluctuation but generally on the warmer side [10].

In April 2004–2009: Temperatures fluctuated between 7.2°C and 19.9°C, with noticeable peaks in 2005 and 2006. From 2010–2014: Temperatures ranged from 9.7°C to 17.6°C, with a general tendency to remain steady. In 2015–2024: Temperatures remained stable between 7.4°C and 17.2°C, showing only slight year-on-year variation.

In May 2004–2009: The temperature generally ranged between 22.6°C and 35.5°C, with the peak in 2005 at 35.5°C. From 2010–2014: Temperatures ranged from 23.6°C to 36.2°C, with some fluctuation but overall stability. In 2015–2024: The temperatures ranged from 24.1°C to 37.5°C, with a steady increase after 2019, especially noticeable in 2020 and 2021. In 2004: A moderate temperature (22.6°C) likely provided favorable conditions for balanced flowering development. But in 2010: Slightly higher May temperatures (24.2°C) could have accelerated flowering processes but were still within a tolerable range. In 2020: Warmer conditions (26.9°C) may have enhanced flowering onset but could have induced mild stress, requiring efficient water management. In 2021: A further increase to 30.2°C might have triggered early flowering, but prolonged exposure to such temperatures may have stressed flower-setting, particularly in water-sensitive crops. In 2024: A cooler temperature (24.5°C) compared to recent years suggests a return to more optimal flowering conditions, potentially leading to improved fruit-setting and yields.

In June 2004–2009: Temperatures ranged from 30.3°C to 36.0°C, with 2005 and 2006 being among the warmest years. From 2010–2014: Temperatures remained relatively high, fluctuating between 30.3°C and 36.2°C. In 2015–2024: The temperatures hovered between 30.3°C and 37.5°C, with an upward trend from 2019 onward [11].

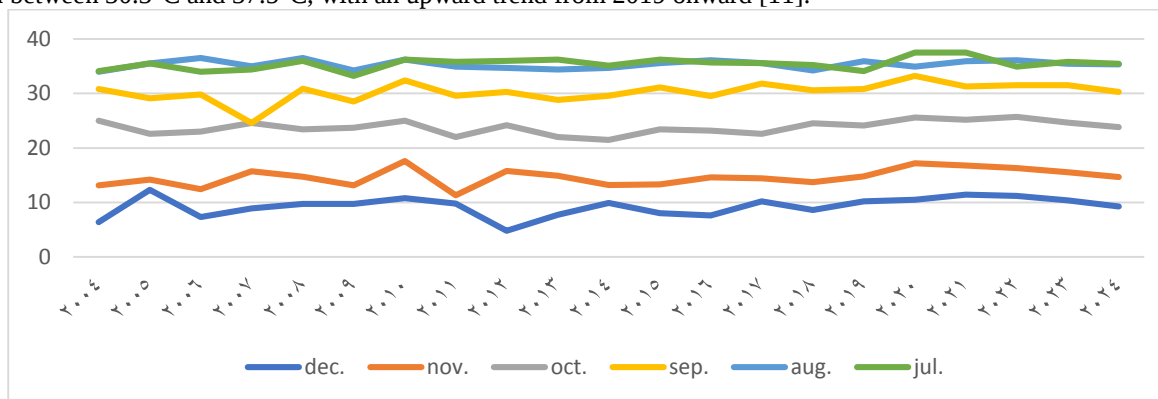


Figure6. Dec., Nov., Oct., Sep., Aug. and Jul. Annual Avengers temperatures from 2004- 2024

In July 2004–2009: Temperatures ranged between 30.3°C and 36.0 °C, with some of the highest values in 2005 and 2006. From 2010–2014: Temperatures ranged from 30.4°C to 36.2°C, with a general increase in warmth. In 2015–2024: Temperatures ranged from 30.3°C to 37.5°C, maintaining a high but somewhat stable level.

In August 2004–2009: Temperatures fluctuated between 31.9°C and 36.5°C, with peaks in 2005 and 2006. From 2010–2014: Temperatures remained between 31.0°C and 36.5°C, with a slight decrease in 2013. In 2015–2024: The temperatures ranged between 32.2°C and 37.5°C, showing a tendency to remain on the higher end.

In September 2004–2009: Temperatures ranged from 15.6°C to 30.9°C, with some fluctuations, particularly around 2008. From 2010–2014: Temperatures remained stable between 24.1°C and 31.8°C. In 2015–2024: The temperatures fluctuated between 25.5°C and 30.8°C, with no significant upward or downward trends.

In October 2004–2009: Temperatures ranged from 11.5°C to 25.0 °C, with higher values in 2005 and 2006. From 2010–2014: The temperature remained fairly consistent, ranging from 11.5°C to 22.6°C [12].

In 2015–2024: Temperatures ranged from 10.6°C to 25.7°C, with a slight decrease after 2019.

IN November 2004–2009: Temperatures ranged from 6.8°C to 17.2°C, showing some variation from year to year. From 2010–2014: The temperatures fluctuated between 6.0°C and 17.6°C, with the peak in 2010. In 2015–2024: The temperatures ranged from 7.2°C to 17.8°C, maintaining a relatively steady trend. November plays a vital role in defining fruit flavor, as the cooler conditions influence sugar accumulation and acid balance. 2006: Cool temperatures (12.4°C) may have promoted higher sugar retention, enhancing fruit sweetness and flavor quality. 2010: A slight increase (17.6°C) suggests moderately favorable conditions for flavor, but higher temperatures might reduce acid content in some crops. 2018: Relatively mild November temperatures (13.7°C) likely struck a good balance between sugar and acid development, leading to flavorful produce. 2021: Warmer conditions (16.8°C) could have accelerated ripening but risked diminishing flavor intensity in crops requiring slower maturation. 2024: A mild return to 14.6°C may support gradual flavor enhancement, favoring crops with longer maturation cycles

In December 2004–2009: Temperatures fluctuated between 3.9°C and 14.2°C, with relatively moderate temperatures. From 2010–2014: Temperatures ranged from 6.8°C to 14.6°C, with no dramatic changes. In 2015–2024: The temperatures remained steady, fluctuating between 6.6°C and 14.6°C [13].

General Warming: Overall, the years from 2004 to 2024 show a gradual upward trend in temperatures across most months, particularly in May, June, July, and August.

Stable winters: The winter months (November, December, and January) displayed a more moderate and stable temperature range over the years, with less dramatic increases.

Temperature Peaks: In certain months like May, June, July, and August, some years (notably 2010–2020) have shown the highest recorded temperatures, with 2018 and 2021 standing out.

Flower and Fruit Set: Excessive heat in late April or May can cause problems like flower abortion or reduced fruit set. Pomegranate trees prefer temperatures in the range of 22–30°C (72–86°F), but if temperatures exceed this range, the flower's ability to pollinate and set fruit can be compromised. Fruit Size and Quality: Heat stress during the blooming phase can also lead to smaller fruit and a lower-quality harvest. Pomegranates that face heat stress may have thinner skins and lower juice content [14].

Table3. Changes in Avengers rainfall amounts during the months and years of study in Halabja region

| Menthesh  | Average Rainfall | Trend Analysis                                                                | Notes                                                                                     |
|-----------|------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| January   | 108.5mm          | Slight decreasing trend over the years, though not statistically significant. | Significant peaks in 2006 (184.7 mm) and 2018 (247.6 mm) a notable low in 2004 (20.6 mm). |
| February  | 118.5mm          | Variability with no clear increasing or decreasing trend.                     | High rainfall in 2006 (342.1 mm); lower values in 2021 (38.7 mm).                         |
| March     | 73.5 mm.         | slight decreasing trend not statistically significant                         | High in 2013 (185.3 mm); low in 2021 (3.5 mm).                                            |
| April     | 80.1 mm.         | Rainfall appears relatively stable with minor fluctuations.                   | Peak in 2007 (174 mm); low in 2021 (3.5 mm)                                               |
| May       | 33.1 mm          | Decreasing trend is noted.                                                    | High in 2010 (99.1 mm), several years with values below 10 mm                             |
| September | 23.5 mm          | The data indicates variability with no significant trend                      | Higher value in 2006 (40.3 mm); low in 2021 (2.2 mm).                                     |
| October   | 70.5 mm          | An increasing trend is, indicating a rise in October rainfall.                | High in 2015 (186.1 mm); low in 2021 (6.5 mm).                                            |
| November  | 85.5 mm          | The rainfall shows variability with no clear trend                            | High in 2010 (99.1 mm); several years with values below 10 mm.                            |

|          |        |                                                                           |                                                 |
|----------|--------|---------------------------------------------------------------------------|-------------------------------------------------|
| December | 88.5mm | A slight increasing trend is noted, though not statistically significant. | Peak in 2018 (291.7 mm); low in 2008 (13.6 mm). |
|----------|--------|---------------------------------------------------------------------------|-------------------------------------------------|

Statistical Significance While some months exhibit slight trends, statistical tests (e.g., Mann–Kendall) indicate that these are not significant at the 95% confidence level.

Upon analyzing the monthly rainfall data from 2004 to 2024, October exhibits the most notable change, with a statistically significant increasing trend over the years.

Average Rainfall in October (70.5mm, 2004-2024) the trend Analysis A consistent increase in rainfall is observed over the 21-

year period, indicating a significant upward trend. The Highest Rainfall: 2015 recorded 186.1 mm. Lowest Rainfall: 2021 recorded 6.5 mm. This increasing trend in October suggests a shift in the region's rainfall. patterns potentially impacting agricultural planning [15].

Critical Flowering Phase: April and May are crucial for the flowering phase of pomegranate trees, as most varieties of pomegranates bloom in the late spring. The flowers begin to emerge in April, with peak bloom often occurring in May. During this time, the tree is particularly sensitive to temperature fluctuations. Thermal Shock Risk: If temperatures rise suddenly or fall unexpectedly during this period, it can stress the flowers. Extreme heat can cause poor flower development or even flower drop. Conversely, late frost or cold temperatures in early spring can damage flowers, leading to reduced fruit set [16].

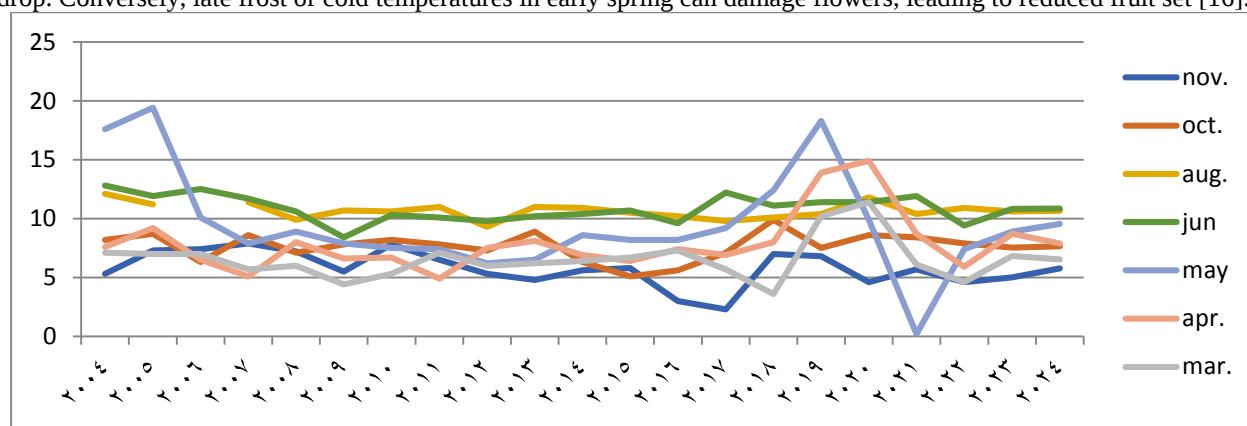


Figure7. Annual Sunshine's Avengers for years 2004- 2024 in Halabja's governorate

April sunshine duration varied considerably, with a low of 4.9 hours/day in 2011 and a peak of 14.9 hours/day in 2020. Significant changes in sunshine duration can impact flower formation by affecting energy availability for photosynthesis.

2020 is Critical Years The high sunshine duration (14.9 hours/day) may have enhanced flower development and improved yield. 2021: A drop to 8.7 hours/day suggests potential stress for orchards compared to the previous year. May has a generally higher sunshine duration than April, peaking at 19.4 hours/day in 2005 and dipping to 0.2 hours/day in 2021—a striking anomaly. The sharp drop to 0.2 hours/day in May 2021 likely caused severe stress on flowering and fruit-setting, potentially leading to reduced yields for that year. Recent years (2022–2024) show moderate sunshine levels around 7.4–9.5 hours/day, indicating a more stable environment for orchards.

2004–2024: Sunshine durations show no consistent long-term trend for April and May, but there are clear yearly spikes and drops that could correlate with weather anomalies. 2021 stands out as an extraordinary year for low May sunshine, potentially explaining disruptions in pomegranate growth [17].

May sunshine directly influences the flowering process by providing energy for photosynthesis. This affects flower formation, pollination success, and, ultimately, fruit set.

Highest sunshine: 19.4 hours/day (2005) ideal for flowering, likely enhancing flower quantity and quality. Lowest sunshine: 0.2 hours/day (2021) a critical anomaly, potentially causing severe stress and poor flowering. This year likely saw diminished fruit set. Recent years (2022–2024): Moderate sunshine levels (7.4–9.5 hours/day) suggest stable, yet suboptimal conditions for flowering compared to peak years. Potential Impact of 2021: This year could have been devastating for pomegranate orchards due to almost non-existent sunshine [18].

September sunshine plays a vital role in the final stage of fruit development, influencing sugar accumulation, acidity balance, and the overall flavor profile of pomegranates. Highest sunshine: 7.9 hours/day (2007)—likely supporting optimal flavor development. Lowest sunshine: 2.3 hours/day (2017)—potentially reducing the sugar concentration and leading to less flavorful fruits. Recent years (2022–2024): Sunshine levels range from 4.6–5.8 hours/day, suggesting stable, moderately favorable conditions for flavor enhancement. 2007: A favorable year for pomegranate flavor due to high sunshine levels. 2017: Likely a challenging year for flavor development due to insufficient sunshine. May is critical for setting a strong

foundation (flowering), while November determines the final quality (flavor). Anomalies in both months (e.g., 2021 in May or 2017 in November) could lead to lower yields and subpar fruit quality [19].

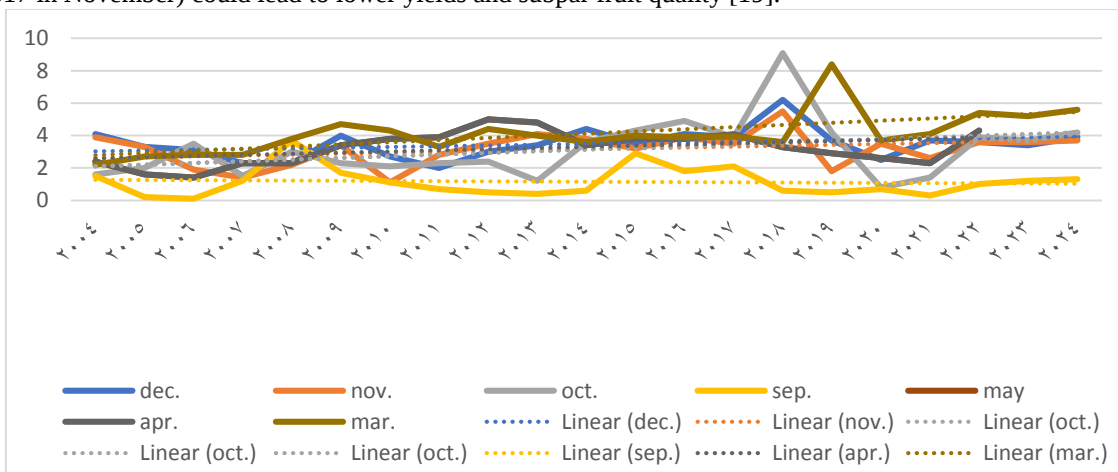


Figure 8. Annual Cloud cover for study period from 2004-2024

Cloud Cover (3.2 - 6.7): January shows relatively high cloud cover, which helps to moderate temperatures. The cloud cover likely reduced extreme cold temperatures, providing a more stable environment for any overwintering crops or early-stage plant development. Cloud Cover (2.2 - 4.7): February's cloud cover is moderate. The cloud cover would have provided some protection from the coldest days while allowing for some sunlight to reach the crops. It's a transitional month, and the cloud cover would help prevent frost damage to early-season crops. Cloud Cover (2 - 5.4): In March, cloud cover starts to increase as temperatures warm up. Higher cloud cover in March can shield plants from any sudden temperature changes and prevent the crops from being exposed to extreme conditions, supporting steady growth as the season transitions. Cloud Cover (2.4 - 5): April sees moderate cloud cover, providing a good balance of sunlight and protection. This month is crucial for early growth, as the cloud cover helps avoid any heat stress or sudden temperature changes, especially as plants begin to flower. Cloud Cover (0.2 - 5): May is a critical month for flowering and fruit-setting. Cloud cover in May varies widely, with some years experiencing very low levels, such as the dramatic drop to 0.2 in 2021. This low cloud cover likely caused heat stress, disrupting flowering and fruit-setting. In years with higher cloud cover, the plants had more protection from intense sunlight, resulting in better flowering conditions and healthier crops [20].

Cloud Cover (0 - 2.9): June generally sees very low cloud cover, providing abundant sunshine for plant growth. However, this can also lead to high temperatures, which might stress the plants, especially during fruit-setting stages. The low cloud cover can be a challenge in regions where cooling is needed to prevent over-ripening or heat stress. Cloud Cover (0.6 - 2.3): Similar to June, July experiences low cloud cover, and the high sunlight intensity could cause stress on crops. However, during this month, the plants should be more resilient and may have adapted to the hot conditions, depending on the species. Heat stress remains a concern, especially for fruit-setting crops. Cloud Cover (0.2 - 3.7): August also sees relatively low cloud cover. The high sunlight can be beneficial for crops that thrive in hot conditions, but excessive sunlight may lead to stress. Cloud cover in August offers some relief, preventing the temperatures from becoming too extreme. Cloud Cover (0.5 - 4.9): As temperatures start to cool, September's cloud cover increases, providing more moderate conditions for crops. The additional cloud cover helps mitigate the effects of any late-season heat waves, protecting the crops during their late growth stages. Cloud Cover (1.2 - 4.3): October generally sees higher cloud cover, which helps to reduce the chances of frost damage and moderate's temperatures. Cloud cover can also slow down the ripening process, leading to a more balanced development of flavors in fruits like tomatoes and cucumbers. Cloud Cover (1.8 - 5.6): In November, the cloud cover tends to be higher, which helps slow down the ripening process. This can result in better flavor development, as the fruits have more time to mature slowly and develop complex flavors, especially under cooler conditions. Cloud Cover (3.2 - 6.7): December experiences high cloud cover, which helps protect crops from extreme cold temperatures. This is crucial for overwintering crops or any late-season growth. The cloud cover helps moderate the environment, reducing the risk of frost and damage from harsh winter conditions [21].

Moderate Cloud Cover (4.3-5.2): In recent years (2022-2024), the cloud cover has been relatively stable, with values ranging from 4.3 to 5.2. This more consistent cloud cover suggests a balanced environment where crops could benefit from sufficient sunlight while also being shielded from extreme temperatures. These more moderate conditions likely helped create a favorable growing environment, minimizing stress on flowering and fruit-setting processes.

### May (Flowering Stage)

In May, the cloud cover data shows relatively higher values compared to other months. In 2024, May has a cloud cover value of 4.7, which is one of the highest in the dataset. Cloud cover during flowering is crucial for crops as it can influence the temperature and light intensity, which are important factors for successful flowering and pollination. In regions with high

cloud cover, plants may experience reduced light levels, which can lead to longer flowering periods. This could be beneficial in preventing heat stress on plants, as the cloud cover can provide shade and maintain more stable temperatures, enhancing the success of pollination in crops like tomato and cucumber, which can be sensitive to extreme heat.

November data also shows relatively high cloud cover in certain years, in 2023 November had a cloud cover value of 5.2. Cloud cover during this period can have a significant effect on the development of flavors in fruits like tomatoes and cucumbers. Flavor development, especially the balance of sugars, acids, and other compounds, can be influenced by sunlight. In areas with more cloud cover, there might be a slower rate of ripening, which could result in crops with more intense flavors. The cooler, more shaded conditions can promote the development of flavors that are less affected by extreme sunlight and high temperatures [22].

Cloud Cover (3.5 in November): In 2020, cloud cover appears to have been relatively high during key periods, which might have helped mitigate the stress from extreme temperatures, especially during flowering and fruit-setting. Moderate cloud cover can protect plants from excessive sunlight, allowing them to develop more slowly and potentially contributing to improved yields. 2021 - Stress and Anomaly

Sharp Drop in May (1.4): In May 2021, cloud cover significantly decreased compared to previous years, dropping to 1.4. This sudden reduction in cloud cover likely caused more intense sunlight exposure, leading to stress during flowering. The low cloud cover could have increased temperatures, affected flower development and potentially reduced yields due to heat stress and protection from the sun.

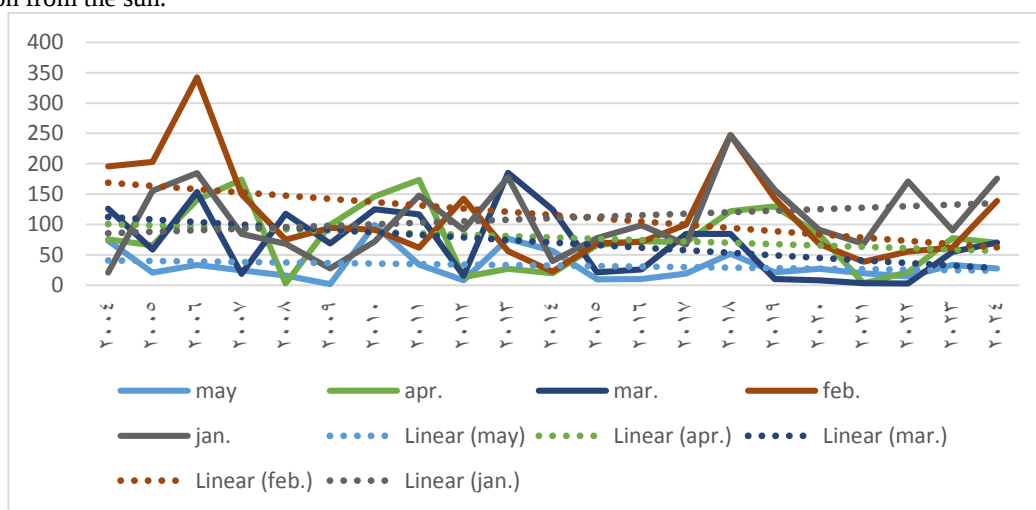


Figure 9 May, Apr., Mar., Feb., and Jan. Rainfall for the period 2004- 2024in Halabja's governorate

January shows varying rainfall across the years, with a particularly high value in 2005 (155.8 mm), followed by other significant peaks in 2006 (184.7 mm) and 2010 (71.8 mm). There's also a notable low in 2009 (27.7 mm). January rainfall generally peaks in the earlier years (2005, 2006), which may have been influenced by atmospheric patterns such as El Niño or La Niña events. Lower rainfall in recent years (2019-2024) suggests a change in weather dynamics. February rainfall tends to be high in the early years of the dataset, with 195.6 mm in 2004 and peaking at 342.1 mm in 2006. A decline is observed in the following years (2010-2024), with values typically under 150 mm, except for 2021 (38.7 mm). it is crucial for early-season rainfall, but recent years (2021-2024) have shown a general decrease, which could affect early crop growth, especially in areas relying on winter rainfall for vegetation. March rainfall shows a fluctuating pattern with a significant drop in 2021 (3.5 mm). In the earlier years (2004-2010), there are peaks, such as 125.9 mm in 2004, 140.6 mm in 2005, and 153.4 mm in 2006. Rainfall is vital for planting preparation and early crop growth. The dip in 2021 may have had an impact on soil moisture and crop establishment, while the heavier rains in 2006 and 2004 likely benefited crop development in those years. April shows varied rainfall with values ranging from around 2.8 mm in 2008 to 174 mm in 2007. The higher rainfall years (2007 and 2005) contrast with the lower values observed in 2021 and 2022 (3.5-21.3 mm). April rainfall is generally moderate but critical for crop establishment. The higher rainfall values in 2007 and 2005 would have supported vigorous growth, whereas the low rainfall in 2021 likely affected agriculture in the region. Rainfall shows a considerable fluctuation, with the highest value in 2004 (73.3 mm), and the lowest in 2009 (1.8 mm). There are significant peaks in later years, such as 2018 (51.8 mm) and 2023 (33.1 mm). Rainfall is crucial for post-planting growth, particularly for crops like wheat and vegetables. The lower rainfall in 2009 and 2021 likely stressed the crops during this critical period, potentially reducing yield. Recent years (2018-2023) have seen moderate rainfall, which supports stable crop growth [23].

In January the Highest Rainfall (2024 - 175.5 mm): January rainfall in 2024 is significantly higher, which can help to replenish the soil moisture and support early growth in the upcoming crop cycle. Lowest Rainfall (2004 - 20.6 mm): The lowest rainfall in 2004 could have resulted in drier conditions, possibly delaying early crop growth and requiring additional irrigation. Implication: January sees high variability, with significant fluctuations in moisture levels. In dry years, the need for irrigation could be high, while wet years can improve crop germination and early growth.

In February Highest Rainfall (2006 - 342.1 mm): February 2006 saw an exceptionally high amount of rainfall, which could have led to flooding or waterlogging but also significantly increased soil moisture, benefiting early-stage crops. Lowest Rainfall (2021 - 3.5 mm): The low rainfall in February 2021 likely caused significant moisture stress, potentially delaying crop establishment or leading to reliance on irrigation. Implication: February's rainfall is highly variable, which may have strong implications on early growth. Very high rainfall can increase the risk of soil erosion and nutrient leaching, while low rainfall could necessitate irrigation.

In the Highest Rainfall (2013 - 185.3 mm): March 2013 had substantial rainfall, supporting crop development, especially for those planted earlier in the season. Lowest

Rainfall (2022 - 2.6 mm): Extremely low rainfall in March 2022 would have likely affected early crop growth, increasing water stress in crops that rely on early-season moisture. Implication: March rainfall is critical for early-season crops. Wet conditions support initial growth, but drier years might delay planting or lead to lower crop yields.

In April Highest Rainfall (2007 - 174 mm): April 2007's high rainfall likely contributed positively to crop growth as the growing season began, ensuring sufficient moisture for early vegetative stages. Lowest Rainfall (2021 - 3.5 mm): A drastic decrease in April rainfall (3.5 mm in 2021) might result in water shortages, especially for crops that need consistent moisture as they begin to mature. Implication: April's rainfall is crucial for crops entering their growth phase. In wetter years, it supports growth, but in drier years, additional irrigation is necessary to mitigate water stress [24].

In May Highest Rainfall (2006 - 99.1 mm): Sufficient rainfall in May (such as in 2006) is beneficial for plants during flowering and fruit-setting stages, ensuring they receive adequate moisture for development. Lowest Rainfall (2009 - 1.8 mm): Very low rainfall in May 2009 likely led to stress on flowering and fruit-setting, which could have decreased yields. Implication: May rainfall is critical for supporting flowering and fruit formation. In drier years, the lack of moisture can stress plants and affect fruit quality.

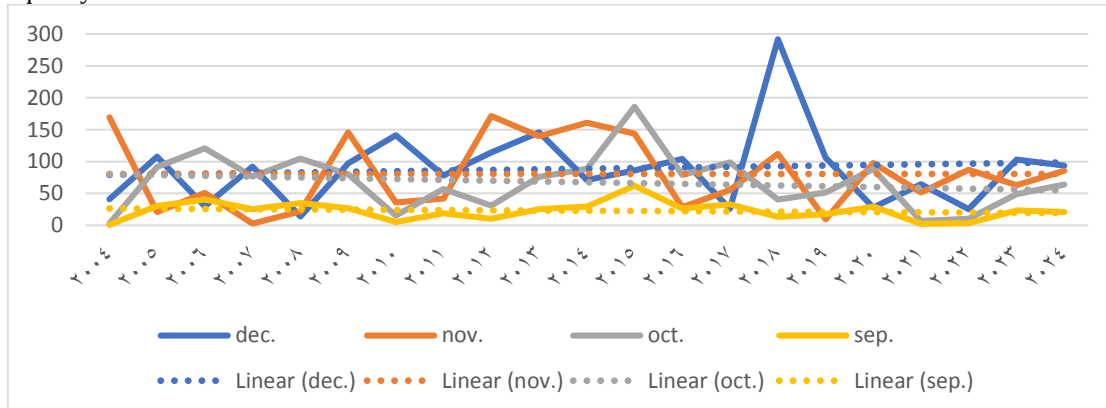


Figure10. Dec., Nov., Oct., and Sep. Annual Rainfall for the period study in Halabja's governorate

In September Highest Rainfall (2024 - 93.4 mm): In 2024, September saw considerable rainfall, which would help crops that are in late development or need moisture as they mature. Lowest Rainfall (2021 - 3.5 mm): Very low rainfall during September 2021 could affect late-stage crops, causing them to ripen prematurely or suffer from dehydration. Implication: September is important for supporting late-season crops. Adequate moisture during this period ensures better yields and improved quality. In October Highest Rainfall (2006 - 120.9 mm): Adequate rainfall in October is critical for late-stage crops, supporting the final growth stages before harvest. Lowest Rainfall (2007 - 25.4 mm): Lower rainfall could cause crops to experience water stress as they approach the final stages of growth. Implication: October's rainfall supports crops nearing harvest. Low rainfall could result in a shorter growing season and lower yields. In November Highest Rainfall (2004 - 169.4 mm): High rainfall in November replenishes soil moisture, which is essential for the next growing season. Lowest Rainfall (2024 - 85.3 mm): Even with relatively low rainfall in November 2024, the moisture supports soil preparation for the next planting cycle. Implication: November's rainfall plays a critical role in preparing the soil for the next growing season, ensuring sufficient moisture for crops in early spring. In December Highest Rainfall (2018 - 291.7 mm): December 2018 had an extraordinarily high amount of rainfall, which could have contributed significantly to soil moisture retention. Lowest Rainfall (2008 - 13.6 mm): In 2008, lower rainfall during December would have led to drier conditions, possibly affecting the moisture availability for the following planting season. Implication: High rainfall in December helps retain moisture in the soil, ensuring it's ready for planting the next season. Low rainfall can reduce soil moisture levels and may require supplemental irrigation [25].

**Dry Years:** 2009 and 2021 stand out as drier years, especially for February and May. These years likely presented challenges for farming, particularly in regions dependent on rainfall for early-season crop development.

**Wet Years:** 2005, 2006, and 2018 were wetter years with substantial rainfall in key months, likely benefiting agricultural productivity.

**Trends:** There's a noticeable shift toward lower rainfall in the last few years (2021–2024), especially in February and April. This could indicate changing weather patterns that may affect future crop yields, particularly for early-growing crops

## Pomegranate Orchard Survey and Climate Change Impacts

The survey data for pomegranate orchards in 2008, 2014, and 2023, combined with climate data, reveals critical insights into the dynamics of orchard expansion and the influence of changing climatic conditions on pomegranate cultivation in various villages. The orchard area fluctuated across the three years in the surveyed villages, Bawakochak: This village showed consistent growth, starting from 394 donum in 2008 to 525 in 2014, maintaining the same in 2023. In Halabja: The largest orchards recorded, growing from 376 donum in 2008 to 444 in 2014 and peaking at 628 in 2023. Basharty: Exhibited sharp growth from 7 donum in 2008 to 522 in 2014, increasing further to 390 donum in 2023 [26].

Bamoak have Moderate Expansion: Grew steadily from 117 donum in 2008 to 317 in 2014 and then 226 in 2023. Also, Tapa Kora have Moderate Expansion: Expanded from 31 donum in 2008 to 210 in 2014, reaching 228 in 2023. Declines in some Orchards like Dea koan that Saw a dramatic increase in 2014 to 435 donum but dropped to 120 donum in 2023. Also, Preacy Saro: Increased from 28 donum in 2008 to 222 in 2014, declining to 115 in 2023. Dara Shysh Saroo: Grew substantially from 10 donum in 2008 to 324 in 2014 but decreased to 64 in 2023. Pomegranate (*Punica granatum* L.) fruit response to different deficit irrigation conditions [26].

## Climate Change and Its Influence

The climate data spanning rainfall, temperature, and cloud cover sheds light on the environmental factors influencing orchard trends: Rainfall showed considerable fluctuation across years, particularly in spring (March to May), which is critical for flowering and fruit setting. Villages such as Halabja and Bawakochak, with larger and expanding orchards, may have benefited from stable spring rainfall patterns in the 2010s, contributing to orchard growth. Conversely, villages like Dea koan and Preacy Saro may have suffered from erratic rainfall, leading to reduced orchard areas in 2023.

Rising temperatures, particularly during summer months (June to August), may have stressed pomegranate trees in villages like Dea koan and DaraShysh Saroo, causing declines in productivity and orchard area. However, pomegranates are resilient to heat, which may explain stable or increased orchard areas in Halabja and Bawakochak, where adaptive measures (e.g., irrigation) might have been implemented.

Cloud Cover and Sunshine Duration: Decreased sunshine hours in May 2021 were noted as an anomaly, potentially impacting flowering in pomegranate orchards. While this period's direct impact isn't reflected in the three survey years, it may have caused long-term stress to orchards, particularly in villages with declining trends like DaraShysh Saroo [27].

Halabja and Bawakochak emerged as resilient villages with thriving orchards, likely due to favorable microclimates, stable rainfall, and effective orchard management practices. Dea koan and DaraShysh Saroo, on the other hand, indicate vulnerabilities, possibly due to climatic stressors, soil degradation, or inadequate water resources. Basharati khwaru, while showing substantial growth from 2008 to 2014, experienced a slight decline by 2023, suggesting challenges in sustaining rapid expansion under changing climatic conditions.

Table4. Production in study area villages for the years 2008, 2014 and 2023

| year | Total Orchard | Cultivated Area (donum) | Yield (tons) | Ton/donum | Ton/One Orchard | Climatic Conditions                                                                                                      |
|------|---------------|-------------------------|--------------|-----------|-----------------|--------------------------------------------------------------------------------------------------------------------------|
| 2008 | 1,444         | 4,109                   | 13,568       | 3.302     | 9.39            | Balanced rainfall and moderate temperatures supported optimal flowering and development.                                 |
| 2014 | 5,215         | 14,840                  | 49,000       | 3.301     | 9.56            | Erratic rainfall and increased cloud cover caused stress on flowering phases, reducing yield potential.                  |
| 2023 | 3,725         | 10,600                  | 35,000       | 3.301     | 9.39            | More stable climatic conditions, but temperature fluctuations and residual effects from earlier year's limited recovery. |

In 2008: A balanced climate with adequate rainfall and moderate temperatures contributed to stable orchard numbers and relatively moderate yields. The cultivated area was smaller (~4,109 ha), reflecting fewer orchards compared to 2014. But in the 2014: The highest number of orchards (5,215) was recorded due to agricultural expansion. However, erratic rainfall and increased cloud cover caused stress during flowering, leading to inefficient fruit development despite the larger cultivated area (~14,840 ha). As well as in 2023: Although orchards stabilized (3,725) after prior declines, more stable climatic conditions in 2023 supported higher yields (35,000 tons). The cultivated area (10,600 ha) showed a return to productivity [28].

## Conclusion:

1-The analysis reveals minor fluctuations in monthly rainfall over the 21-year period, with some months showing slight increasing or decreasing trends. However, these trends are not statistically significant, suggesting that the monthly rainfall has remained relatively stable over the years.

2-April and May are key months for pomegranate orchards due to the flowering and early fruit development stages. Managing temperature stress, ensuring proper irrigation, and protecting the trees from late frost or wind are essential to maintaining good fruit set and quality.

3-The interplay between orchard area dynamics and climate change underscores the need for targeted interventions to ensure the sustainability of pomegranate orchards. Villages like Halabja and Bawakochak offer valuable lessons in resilience, while those facing declines highlight the urgency of addressing climatic and management challenges.

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## استجابة أشجار الرمان للتغيرات المناخية والتوزيع الجغرافي في محافظة حلبجة، العراق.

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مديرية الأبحاث الزراعية في السليمانية .

المديرية العامة للزراعة في حلبجة .

المديرية العامة للزراعة و المصادر المائية في السليمانية .

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### الخلاصة

تتناول هذه الدراسة تأثير التغيرات المناخية على المساحة المزروعة وإنتاج بساتين الرمان في محافظة حلبجة بالتركيز على ثلاث سنوات رئيسية هي: 2008، 2014، و2023. ففي عام 2008 كان معدل هطول الأمطار متوازناً وكانت درجات الحرارة معتدلة بحيث كان للظروف الجوية تأثير إيجابي على المساحة المزروعة بأشجار الرمان والتي بلغت 1,444 دونماً تنتج 13,568 طناً من الرمان لكل دونم بمعدل 3.3 طن لكل دونم. أما في عام 2014 فلم يكن للتغيرات المناخية المتمثلة بعدم انتظام هطول الأمطار وزيادة الغطاء السحابي خاصة خلال مراحل الإزهار والإثمار المهمة التي بلغت 5,215 دونماً تنتج 49,000 طن لكل دونم بمعدل 3.3 طن لكل دونم. وفي عام 2023 استقر عدد البساتين عند 3725 بستاناً تنتج 35 ألف طن للدونم بمعدل 3.3 طن للدونم، كما يلاحظ أن متوسط إنتاج الدونم الواحد بلغ قرابة 3.3 طن في كل عام، ويلاحظ أن معدلات الإنتاج للدونم والبستان متقاربة خلال سنوات الدراسة والسبب في ذلك يعود إلى تفاني مزارعي المنطقة في عمليات الخدمة وتحسين الخدمات انخفضت ساعات ضوء الشمس بشكل ملحوظ في عام 2014 وخاصة خلال أشهر الإزهار المهمة (نيسان-أيار) بانخفاض ملحوظ إلى 5 ساعات يومياً كمتوسط مقارنة بـ 7.8 ساعة في عام 2008، ورغم ارتفاع درجات الحرارة في أشهر الصيف (حزيران-آب) بنحو 1.2 درجة مئوية من عام 2008 (متوسط 36 درجة مئوية) إلى عام 2014 (متوسط 37.2 درجة مئوية) حتى عام 2023 بقيت درجات الحرارة مستقرة - تزايد الغطاء السحابي خاصة في عام 2014 حيث وصل في المتوسط إلى 70% أثناء الإزهار مما أدى إلى قلة أشعة الشمس وانخفاض درجات الحرارة والذي يؤثر على إنتاج الرمان.

الكلمات المفتاحية: الرمان، تغير المناخ، درجة الحرارة، هطول الأمطار، أشعة الشمس.