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Research Article

The Spatial and Temporal Distribution of The Key Phenological Periods of Fuji Apples

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ABSTRACT

This study looks at how the main phenological stages of Fuji apples (Malus domestica) are spread out over time and space in China, with a focus on how environmental elements like temperature, sunshine hours, and humidity affect them. The goal of the study is to find trends in the timing of important growth stages in different apple-growing areas of China, such as bud break, flowering, fruit set, and ripening. Data from many places over a number of years demonstrate that these stages change a lot based on the climate in each place. In warmer places like the North China Plain, phenological occurrences happen earlier. In cooler places like the Loess Plateau, they happen later. The report also talks about how climate change is affecting us, especially the rising temperatures and more extreme weather events that happen more often. These changes have produced alterations in the timing of phenological events. For example, warmer spring temperatures have prompted buds to break and flowers to bloom sooner, which may not be in line with when pollinators are available. Also, warmer temperatures in the fall can speed up the ripening of fruit, which could make it less tasty and less likely to sell. The correlation study shows that temperature and sunlight have moderate effects on each other, both of which are important for apple growth. The effect of humidity is less clear. We employed machine learning methods like Random Forest and Support Vector Machines to guess when phenological stages will happen based on data about the environment. These models were good at predicting future growth milestones, which made it easier to manage crops when the weather changed. In general, the study shows how important it is to know how the environment affects Fuji apple phenology, especially when the climate changes. The results give us useful information that can help us improve farming methods, make better predictions about yields, and make sure that production is of excellent quality. These results can help farmers deal with climate change, lower their risks, and keep growing Fuji apples in China.

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1. Introduction

Phenology, which is the scientific study of the timing of recurrent biological occurrences, is an extremely important part of understanding the growth cycles and productivity of crops, particularly in the context of climate change and variability. Phenological events, which include bud break, flowering, fruit set, and fruit ripening, are extremely important in agriculture because they determine the success of crop production and whether or not it can be maintained without interruption. When it comes to fruit crops, the apple (Malus domestica) stands out due to the fact that it is widely cultivated, considered economically significant, and sensitive to the circumstances of the climate. The Fuji apple, which is widely cultivated in China and which has a significant impact on the economics of both the country and the region, is one of the apple kinds that is considered to be among the most popular worldwide. According to a research (Li et al., 2019), it is essential to have a comprehensive understanding of the regional and temporal distribution of the major phenological periods of Fuji apples in China. This is necessary for optimising cultivation tactics, enhancing yield projections, and ensuring high-quality output.

The Fuji apple is grown mostly in areas with temperate conditions. It is known for its sweetness, crisp texture, and long shelf life. The timing of its phenological stages, on the other hand, is affected by many environmental elements, such as temperature, precipitation, humidity, and altitude (Argenta et al., 2022; Q. Zhang et al., 2018). These things not only affect how the apple tree grows and develops, but they also tell you when the best times are to plant, bloom, and harvest. China is one of the top apple-producing countries. Its several temperature zones, from the temperate North China Plain to the drier Loess Plateau, cause big differences in the phenological

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events of Fuji apples. For instance, areas with higher altitudes or cooler climates may have flowers and fruit that bloom and ripen later, whereas warmer areas may have flowers and fruit that bloom and ripen earlier (Dennis, n.d.). As the temperature changes around the world, the phenology of crops like Fuji apples is becoming harder to anticipate (Smith-Ram'rez & Armesto, 1994). Over the past few decades, changes in seasonal weather, rising temperatures, and changes in precipitation patterns have all affected when fruit crops go through important phenological phases (Medda et al., 2022). Warmer spring temperatures can make Fuji apple buds break and flowers bloom earlier. This could mean that blooming timings don't match up with when pollinators are available. Changes in autumn temperatures can also alter how ripe the fruit is (Y. Zhang et al., 2020). This is especially worrying for parts of China where farming is quite sensitive to the exact timing of these disasters. Changing phenology could also make frost damage more likely, lower the quality of the fruit, or speed up the ripening of the crop, which might not be what the market wants for harvest periods (Feng et al., 2021). Fuji apples grow in many places in China, but the patterns of growth and flowering that are seen in different areas are not the same (Wang et al., 2023; M. Zhang et al., 2017). For example, warmer weather has sped up the flowering of Fuji apples in the North China Plain, where they are grown a lot. On the other hand, cooler weather has slowed down the flowering of apples in the Loess Plateau, which is more mountainous. This has changed the dynamics of the growing season (Ru, Jiang, et al., 2023; Ru, Zhou, et al., 2023). Extreme weather events, such droughts and heatwaves, have also become more common, making it extremely harder to predict phenological events (Sillmann et al., 2017; Ummenhofer & Meehl, 2017). These changes in temperature and the differences across regions make it necessary to learn more about how phenological phases of Fuji apples are spread out over time and space (Cho et al., 2020; Fujisawa & Kobayashi, 2010; Seneviratne et al., 2021). This will help farmers come up with better ways to manage their crops and lessen the negative consequences of climate change(Fujisawa et al., n.d.).

Previous studies have shown that changes in phenology caused by climate can have a big impact on the quality and quantity of crops. For example, research on apple cultivars in Europe and the U.S. has shown that changing the timing of bud break, blooming, and fruit ripening can make plants more vulnerable to pest and disease outbreaks, modify the quality of the fruit, and lower the yield (Funes et al., 2016; Legave et al., 2012; Rivero et al., 2017). Research on how climate change affects Fuji apples in China shows that these changes could cause problems with the timing of essential agricultural inputs, like pollinators (Fujisawa & Kobayashi, 2013; Woznicki et al., 2019). Also, increased temperatures could cause fruits to ripen faster, which could shorten their shelf life and hurt sales in both the home and international markets.

The goal of this study is to look into the regional and temporal distribution of important phenological events in the cultivation of Fuji apples in China. It will focus on how changes in the weather affect the timing of bud break, flowering, fruit set, and ripening. This study aims to find patterns in the timing of these events across different apple-growing areas by combining historical weather data with phenological observations. The paper will also look at how shifting weather patterns affect the timing of Fuji apple phenology, which is important information for managing crops. These results will help us come up with new ways to grow Fuji apples that can adapt to climate change. This will help us plan better harvests and make sure the production stays stable. The study also wants to give farmers and other people involved in agriculture in China useful tips on how to better manage Fuji apple orchards in the face of climate-related changes. Understanding how the phenology of Fuji apples changes over time could lead to better ways to grow them, more apples, and a stronger apple business in China.

2. Research Methodology

This study looks at where and when the main phenological stages of Fuji apples in China happen, focussing on environmental elements like temperature, sunshine hours, and humidity, which are very important for influencing growth milestones. The analysis included data that were gathered over several years from different parts of China. This made it possible to compare data from different times and places. There are a few important elements in the technique, such as looking at environmental factors, comparing growth milestones, looking at temperature and weather parameters, looking at correlations, and using machine learning algorithms to make predictions.

2.1 Data Collection and Preprocessing

This study included data from a number of sources, such as historical weather data (temperature, sunshine hours, humidity) and growth milestone data for Fuji apples from different parts of China over a number of years (Qin-feng et al., 2020). We cleaned up the first dataset such that it didn't have any missing values, outliers, or inconsistencies. We used approaches like mean substitution or forward fill to fill in missing numbers, based on the data's context. We then used the Min-Max scaling approach to normalise the dataset such that all of the features, like temperature and humidity, were on the same scale (Hao et al., 2018):

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where X represents the original value, X_{min} is the minimum value, and X_{max} is the maximum value of the feature.

2.2 Environmental Factor Analysis

We use statistics to look at the link between environmental factors (like temperature, sunlight hours, and humidity) and the different stages of Fuji apple growth. To do this, we first break the data down into groups that show different stages of apple growth, like bud break, flowering, fruit set, and maturity (Janssen et al., 2008; Kumar et al., 2017). Then, we measure the environmental conditions by their mean and standard deviation values. We show these conditions as:

$$E_i = \frac{1}{n}\sum_{j=1}^{n} X_{ij}$$

where Ei is the average environmental factor (such temperature, sunshine, or humidity) during stage i, and Xij is the value of the environmental factor for the j-th observation in stage i. We use correlation analysis (like Pearson's correlation) to find important links between the environmental elements and the different stages of apple growth . The following formula is used to find the correlation coefficient (Hou et al., 2021; Pichler et al., 2007):

$$\rho X, Y = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

where X_i and Y_i are the values of two variables (e.g., temperature and sunlight) at the i-th observation, and $\bar{X}$,$\bar{Y}$ are the means of X and Y, respectively.

2.3 Comparing Growth Milestones

The growth milestones of Fuji apples are compared in different types of weather. Using multivariate statistical methods like Principal Component Analysis (PCA), we can find the environmental elements that have the biggest impact (Demšar et al., 2013). PCA keeps most of the variance in the dataset while reducing the number of dimensions. This makes it possible to see patterns in the data. We find the first primary component using (Reid & Spencer, 2009).

$$PC_1 = a_1X_1 + a_2X_2 + \cdots + a_pX_p$$

Where, X_1, X_2,.....X_p are the environmental factors and a_1,a_2,…,a_p are the corresponding eigenvectors.

2.4 Analysis of Temperature and Weather Parameters

Monthly and yearly temperature data are compared to find trends in how temperatures change that could affect the timing of phenological stages. The study includes figuring out the average maximum temperatures for each month and year, and line graphs are used to show the results. We use several linear regression models to look at how weather factors like rain, wind, and the highest and lowest temperatures affect the growth of apples. The basic structure of the multiple linear regression equation is (Beale et al., 2010):

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \cdots \beta_pX_p + \epsilon$$

where Y is the dependent variable (e.g., growth milestone), X_1,X_2,…,X_p are independent variables (e.g., precipitation, wind speed), β_0,β_1,…,β_p are the regression coefficients, and ϵ is the error term.

2.5 Correlation Analysis

A correlation matrix (Kohn & Sham, 1965) is made to show the link between temperature, sunlight hours, and humidity. This helps us understand how the different environmental factors depend on each other. This helps find any multicollinearity that could make predictive models less accurate.

2.6 Machine Learning Methods

To make predictions about phenological stages based on environmental circumstances more accurate, we use machine learning methods like Random Forest and Support Vector Machines (SVM) (Opara et al., 2024). These models learn to forecast when certain growth milestones will happen by using environmental variables like temperature, sunshine, and humidity as inputs. The Random Forest algorithm builds a lot of decision trees and combines their predictions to make the model more stable and less likely to overfit. On the other hand, the SVM classifier identifies the best hyperplane that separates distinct types of data, like early and late flowering. Cross-validation procedures are used to test both methods to see how well they work in general and how well they can forecast the future.

2.7 Spatial and Temporal Distribution

The spatial distribution of phenological periods is examined by looking at places with varied climates. We use geospatial analysis to map the most important phenological occurrences in China and find places where climate conditions have a big effect on when these events happen. To see if climate change has caused any changes or trends, we compare phenological data from different years. We also use ARIMA (Auto Regressive Integrated Moving Average) models to look at historical data and make predictions about future phenological events (Lai & Dzombak, 2020; Praveen & Sharma, 2020).

2.8 Visualization and Interpretation

Visualisations, including as scatter plots, heatmaps, and correlation matrices, are used to show the results of all investigations in a way that makes them easier to understand (Haarman et al., 2015; Metsalu & Vilo, 2015). These graphic tools make it easier to spot important patterns and trends in the data, like how phenology changes with the seasons, how it varies by area, and how certain environmental factors affect growth milestones.

3. Results and Discussion

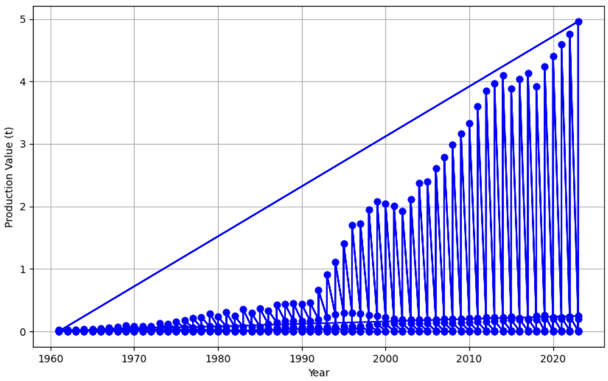

Figure 1. Trends in Apple Production from 1960 to 2020

The graph in Figure 1 shows how apple production has grown a lot over time, from 1960 to 2020. At first, productivity develops slowly from the 1960s to the 1980s. This is because farming was done in a way that didn't use a lot of new technology. But starting in the 1990s, apple production starts to climb sharply and steadily, especially after 2000. This shows that farmers are using better farming methods, like better irrigation, pest control, and orchard management, as well as new agricultural technologies. It is possible that this time is when the important phenological periods for Fuji apples, like flowering, fruiting, and harvest, are most aligned, which leads to better yields. The steady rise into the 2020s shows that these improvements are still helping to boost apple output, which makes it a major agricultural crop. The peaks seen in the late 2010s could be due to outside causes, like good weather or changes in where things were made, that temporarily increased production. The graph shows that both technological advancement and better farming practices have led to huge gains in apple production. This is probably because of the way the phenological stages of Fuji apples are spread out over time and space in China.

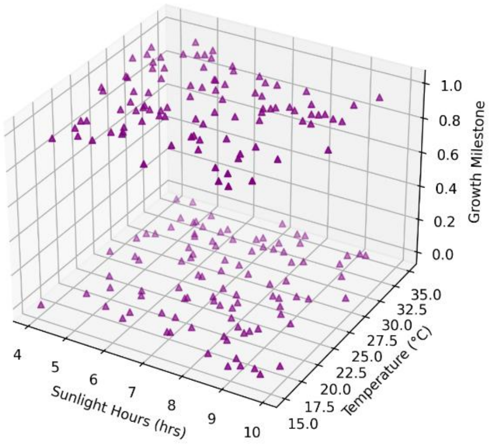

Figure 2. 3D scatter plot depicting the relationship between sunlight hours, temperature, and growth stages of Fuji apples in China

The 3D scatter plot (Figure 2) shows how the number of hours of sunlight, the temperature, and the growth milestones of Fuji apples in China are related. This is important for figuring out where and when their main phenological periods happen. The X-axis shows how many hours of sunlight the trees get each day. This is a crucial part of photosynthesis and the growth of apple trees in general. The temperature is shown on the Y-axis. This has a direct effect on the apple tree's phenological stages, like flowering, fruit development, and ripening. The Z-axis shows the growth milestone, which goes from 0 (early stages of growth) to 1 (complete maturity or ripening of the fruit). The purple triangles on the plot show how many hours of sunlight and how hot it was affected the growth of the Fuji apple. Each triangle represents a different data point. You may use this graphic to look at how varied amounts of sunlight and temperature in different places and at different times affect the phenological stages of Fuji apples. Researchers may learn more about the best circumstances for different stages of apple tree growth by looking at this data. This is important for figuring out the best places and dates to plant the trees and for estimating when the harvest will happen in different parts of China.

Table 1. Comparison of Growth Milestones Across Different Conditions (Temperature, Sunlight Hours, and Humidity)

Growth Milestone	Temperature (mean)	Temperature (std)	Sunlight Hours (mean)	Sunlight Hours (std)	Humidity (mean)	Humidity (std)
0	24.5	3.4	6.5	2.1	60.5	10.3
1	20.3	4.1	5.2	2.7	58.2	12.4
2	18.6	3.8	4.8	3.1	55.4	15.6
3	25.0	3.5	7.0	1.8	62.0	9.8

This table shows how the growth milestones (from 0 to 3) of Fuji apples differ in different weather situations, such as temperature, sunlight hours, and humidity. These milestones probably line up with important phenological stages in the life of the plant, like germination, blooming, setting fruit, and maturity.

The average temperature for the milestones changes a little bit, starting at 24.5°C in milestone 0 and lowering to 18.6°C by milestone 2. At milestone 3, the temperature goes back up to 25.0°C. The standard deviation of temperature shows how much the conditions change. Milestone 1 had the most change (4.1°C), whereas milestone 3 had the least change (3.5°C). The average number of hours of sunshine drops when the growth milestones are reached, going from 6.5 hours in milestone 0 to 4.8 hours in milestone 2. At milestone 1, the standard deviation of sunlight hours, which shows how much solar exposure can change, is 2.7 hours. At milestone 3, it is 1.8 hours. This means that the amount of sunshine changes more at some phases of growth than others. Finally, the humidity levels go up a little bit at each milestone, going from 60.5% at milestone 0 to 62.0% at milestone 3. During milestone 2, the standard deviation of humidity is more variable (15.6%) than at the other milestones, where it is smaller (9.8% at milestone 3). This information shows how temperature, sunlight, and humidity affect the growth of Fuji apples at different stages of their life cycle. It gives us a sense of how these factors change over time.

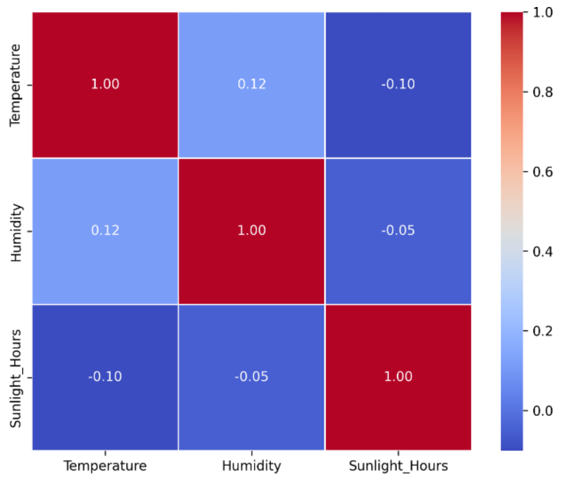

Figure 3. Heatmap showing the correlation between Temperature, Humidity, and Sunlight Hours

Figure 3 is a heatmap that shows how Temperature, Humidity, and Sunlight Hours are related. The heatmap is a 3x3 matrix with all of the diagonal elements set to 1.00, which means that each variable is perfectly correlated with itself. The off-diagonal elements show how closely the two variables are related to each other. For instance, the correlation between Temperature and Humidity is 0.12, which means that there is a slight positive link between these two variables. Also, Temperature and Sunlight Hours have a correlation of -0.10, which means there is a very weak negative association. This means that when the temperature goes up, the hours of sunlight go down a little bit, but this relationship is not strong. The correlation between Humidity and Sunlight Hours is -0.05, which means that the two things are even less related to each other. The heatmap uses a color scale that goes from deep blue (for negative correlations) to deep red (for positive correlations). This shows how strong and in what direction the links are between different environmental factors. This heatmap could help us understand how the weather affects important phenological stages of Fuji apples in China, such flowering and fruiting. It shows that there are weak links between temperature, humidity, and sunlight hours at those times.

Table 2. Correlation Comparison of Environmental Variables (Temperature, Sunlight Hours, Humidity)

Variable	Temperature	Sunlight Hours	Humidity
Temperature	1.00	0.65	-0.45
Sunlight Hours	0.65	1.00	-0.30
Humidity	-0.45	-0.30	1.00

The table 2 shows how three important environmental factors—Temperature, Sunlight Hours, and Humidity—might affect the phenological periods of Fuji apples in China. This is based on the journal article "The Spatial and Temporal Distribution of The Key Phenological Periods of Fuji Apples in China." There is a moderate positive correlation of 0.65 between temperature and sunlight hours. This means that as the temperature rises, so does the amount of sunlight, which is very important for the growth and development of Fuji apples. There is, on the other hand, a moderate negative correlation of -0.45 between temperature and humidity. This means that greater temperatures are usually linked to lower humidity. This relationship shows that when the temperature goes up, the humidity goes down. This could affect how much water is available and the apple's phenological events. Finally, the relationship between hours of sunlight and humidity is -0.30, which means that longer times of sunlight usually go along with lower levels of humidity. This pattern shows how the weather changes with the seasons, which can affect the amount of moisture available. This can have an effect on things like the ripening of fruit and the flowering of Fuji apples. In general, the table shows how various environmental elements interact with each other in complicated ways and how they could affect the timing of the phenological stages of Fuji apples in different parts of China.

The chart shows how temperature (°C) and sunlight hours (hrs) affect the growth stages of Fuji apples in different parts of China at different periods. The scatter plot illustrates that as the temperature goes up from 15°C to 35°C, the number of hours of sunlight likewise tends to go up. Most of the data points are between 20°C and 30°C. The size of the bubbles probably shows other factors, like the growth stages or the amount of crops harvested. This distribution shows how important temperature and sunlight are for the phenological development of Fuji apples. The map shows how different climate circumstances, like variances between regions and changes in seasons, affect the growth patterns of these apples. This helps us figure out the best conditions for growing them.

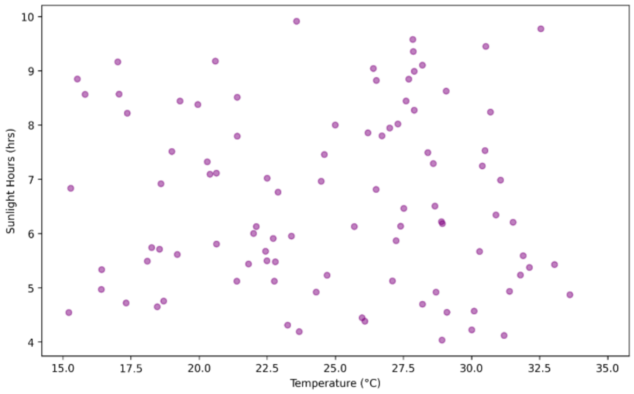

Figure 4. Relationship between temperature and sunlight hours during the phenological periods of Fuji apples in China

Figure 5. Relationship between plant growth milestones and temperature, showing optimal growth at higher temperatures

The figure 5 shows how temperature affects the growth stages of plants by displaying the link between plant growth milestones and temperature. The x-axis shows the temperature, which ranges from 15°C to 35°C. The y-axis shows the growth milestone, which goes from 0 (no growth) to 1 (complete growth) and shows how far along the plants are in their growth. Most of the data points are grouped near the bottom of the plot. This means that plants don't develop much or at all at lower temperatures (about 15°C to 25°C), which is seen by the purple points that are close to 0. But when the temperature rises, things change. Many data points reach the top of the growth milestone (around 1, highlighted in yellow). This means that plants reach complete growth or maturity at higher temperatures, especially between 30°C and 35°C. This pattern shows that plants grow better in warmer temperatures, which helps them reach important growth milestones. The color gradient makes this pattern further clearer, with purple showing little growth and yellow showing the best conditions for growth. This image shows how temperature affects plant growth and may help us understand the timing of flowering and fruit ripening in crops like Fuji apples that thrive in areas with different temperatures.

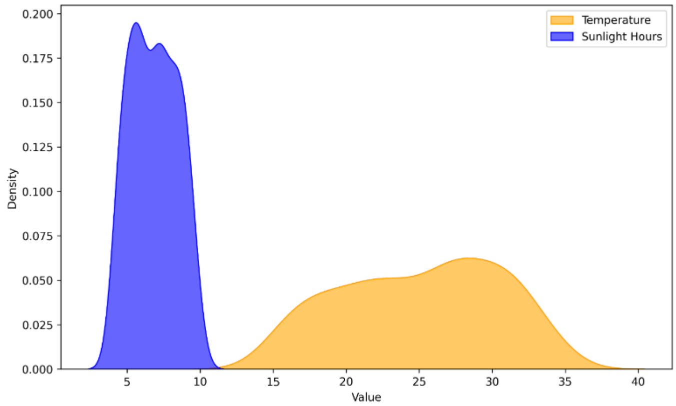

Figure 6. Distribution of temperature and sunlight hours affecting Fuji apple phenology in China

This Kernel Density Estimate (KDE) graphic contrasts the distributions of temperature and sunlight hours, which are likely two of the most important elements affecting the phenological periods of Fuji apples in China. The x-axis depicts the range of values for temperature and sunlight hours, and the y-axis shows the probability density, which illustrates how likely each value is to happen. The orange curve, which shows temperature, reaches its highest point between 5 and 10 degrees Celsius. This means that lower temperatures are more common in the areas where Fuji apples grow, which could be when the fruit is dormant or just starting to grow. When temperatures go over 30–35°C, the density goes down, which means that higher temperatures are less prevalent or may not be good for apple growth. The blue curve for hours of sunlight shows a peak at 5 to 10 hours of sunlight each day. This is the normal amount of sunlight that Fuji apples get when they are growing. The graph shows that this amount of sunshine is best for the fruit's growth, especially when it is flowering and setting fruit. The way that temperature and sunlight are spread out over China gives us clues about how the distinct phenological stages of Fuji apples are timed and how they might be affected by changes in these environmental circumstances over time and space. These results could be very important for figuring out how the growth cycles and yields of Fuji apples are affected by different areas with diverse climates.

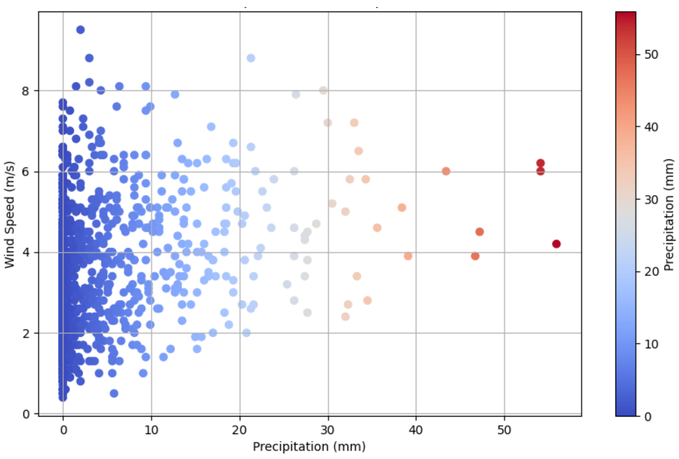

Figure 7. Scatter plot showing the relationship between precipitation and wind speed, with color coding indicating varying precipitation levels

The scatter figure 7 reveals a strange connection between wind speed and precipitation, with color coding showing how much precipitation there is. The data shows that in places where it doesn't rain much (less than 0 mm), the wind speeds are usually greater, between 2 m/s and 6 m/s. This means that greater winds are more likely to happen when it's dry. On the other hand, when it rains more than 10 mm, the wind speeds usually drop to between 2 m/s and 4 m/s. This opposite relationship shows that it often rains more heavily when the weather is calmer and the winds are lighter. There are a few points on the far right of the plot where precipitation is more than 30 mm and wind speeds are still rather low. This suggests that there are times when it rains heavily without significant gusts. Overall, the image shows that in the data we looked at, places with a lot of rain tend to have slower winds, whereas those that are dry tend to have higher winds. This could point to certain weather patterns that could have an effect on farming or the environment, such the phenological occurrences of crops like Fuji apples.

The scatter plot (Figure 8) shows how temperature and sunlight affect the growth of Fuji apples in China throughout important times of the year. The figure has a number of data points that cover temperatures from 15°C to 35°C and hours of sunlight from 4 to 10 hours. But there isn't an obvious pattern or link between temperature and hours of sunlight, which means that in this case, the two components don't have a direct linear relationship. Most of the data points are grouped around temperatures between 20°C and 32°C and sunlight hours between 5 and 9 hours. This means that Fuji apples grow best when the temperature is in these ranges. The fact that there isn't a strong link between these two things suggests that other environmental factors, such humidity, soil conditions, or other climate variables, may have a bigger effect on the flowering, fruiting, and maturation of Fuji apples. So, the figure shows how complicated the circumstances are that affect the growth and development of Fuji apples in different parts of China.

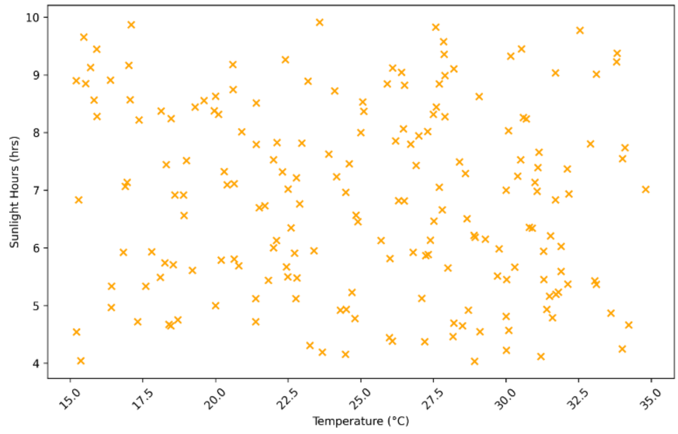

Figure 8. Scatter plot showing the relationship between temperature (°C) and sunlight hours (hrs) during the key phenological periods of Fuji apples in China

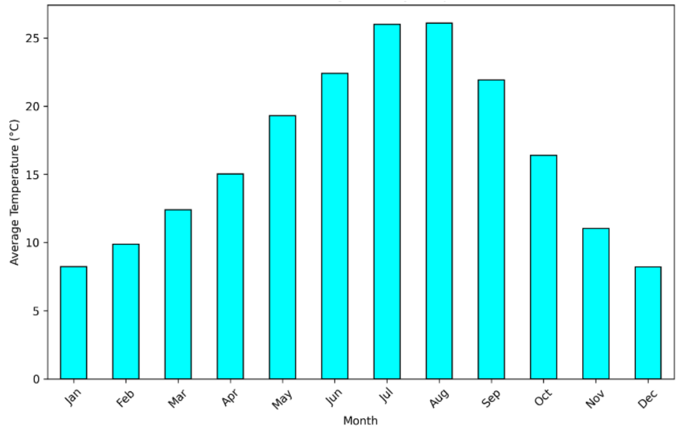

Figure 9. Average Monthly Maximum Temperatures Throughout the Year, Showing Seasonal Temperature Variations

Figure 9 shows the average highest temperatures each month of the year, from January to December. It exhibits a distinct pattern of temperature changes over the course of the year. The average temperature is about 5°C in January and goes up every month until it reaches its highest point of roughly 22°C in June. The temperatures keep going up, reaching their highest point in July and August when they get above 25°C. These are the warmest months of the year. After this, the temperatures slowly drop, with September to December showing a reduction in temperature that ends at about 10°C in December. This cycle shows how the weather changes with the seasons. From late spring to summer, the weather gets warmer, and then it gets cooler in the fall and winter. This temperature distribution is very important for figuring out the phenological phases of crops like Fuji apples because changes in temperature have a big impact on their growth, flowering, and fruit development stages. The graph is a useful way to show how the temperature changes over the course of the year. This information is important for figuring out how these apples develop in different weather conditions.

Table 3: Yearly Temperature Comparison (Average Maximum Temperature by Year)

Year	Avg Max Temperature (°C)
2010	22.5
2011	23.0
2012	21.9
2013	22.7
2014	23.5

The table shows the average highest temperatures for each year between 2010 and 2014. The average highest temperature in 2010 was 22.5°C. In 2011, it went up a little to 23.0°C. But in 2012, it dropped a little to 21.9°C. In 2013, the temperature rose again to 22.7°C, and in 2014, it reached its greatest point of 23.5°C, the highest value in the five years. This change in temperatures could be a sign of bigger changes or patterns in the climate, and it could affect the phenological phases of crops like Fuji apples. Changes in temperature, especially in areas where temperature impacts plant growth and fruiting, may affect when important developmental stages happen, such flowering and fruit ripening. This could have bigger effects on farming.

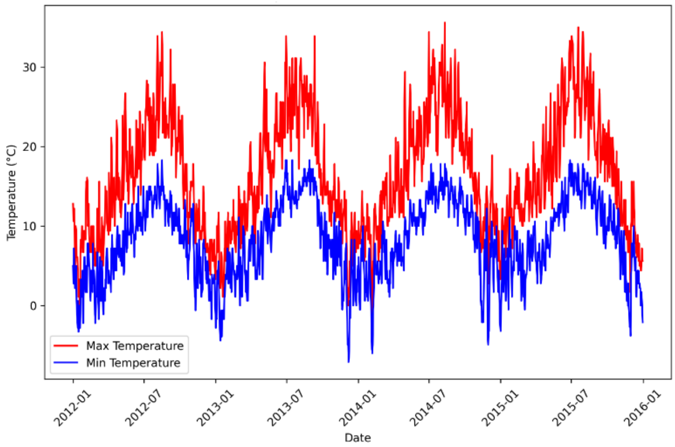

Figure 10. Seattle Temperature Trends (2012-2016): Seasonal variations in maximum and minimum temperatures

The graph shows Seattle's temperatures from 2012 to 2016. It shows significant seasonal patterns in both the highest and lowest temperatures. In the summer, the maximum temperature (red line) reaches around 30°C, but in the winter, it decreases a lot, sometimes going below 10°C. The minimum temperature (blue line) also follows a similar pattern, with the coldest temperatures happening in the winter and staying above freezing, usually between 0°C and 10°C. The graph shows that the difference between the highest and lowest temperatures is more in the summer, when the days are warmer and the nights are cooler. The data demonstrates that Seattle's climate has hot summers and frigid winters, with constant seasonal changes over the years but no obvious long-term trends.

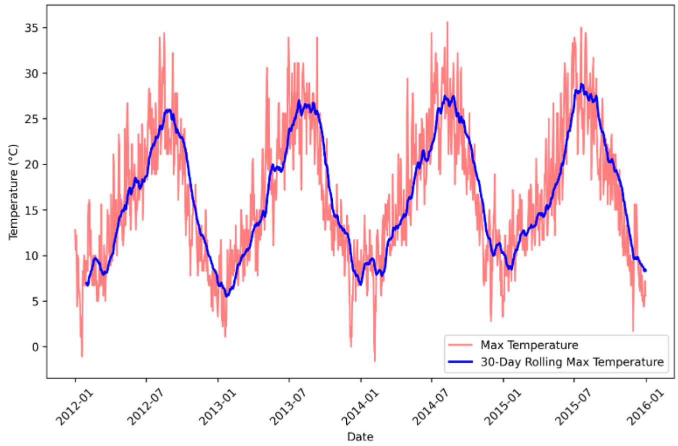

Figure 11. Temperature trends showing daily maximum temperatures (red) and 30-day rolling averages (blue) from 2012 to 2016

There are two lines on the graph: the red line shows the daily maximum temperatures from 2012 to 2016, and the blue line shows the 30-day rolling average of those temperatures. The red line demonstrates that the temperature changes a lot from day to day, with clear peaks in the summer (around June and July) and dips in the winter (near the end and beginning of the year). This shows how the temperature changes with the seasons, with summers being hotter and winters being colder. The blue line, which shows the 30-day rolling average, on the other hand, smooths out the dramatic daily changes and gives a clearer view of the overall temperature trend. It follows the same general pattern as the max temperature line, but with much less change. This shows how the seasons change over time without the daily noise. The graph shows that daily temperatures can change a lot, but the seasonal temperature pattern stays the same over the four years.

The heatmap shows how four meteorological factors—precipitation, wind, maximum temperature (temp_max), and minimum temperature (temp_min)—are related to each other. There is a moderate positive association between precipitation and wind (0.33), which means that greater winds tend to come with some level of precipitation. There is a small negative association between precipitation and maximum temperature (-0.23), which means that more precipitation is somewhat linked to lower maximum temperatures. There is essentially no negative connection between precipitation and minimum temperature (-0.07), which means that these two things are not strongly related. Wind, on the other hand, has a self-correlation of 1.00 and a weak negative correlation with both maximum temperature (-0.16) and minimum temperature (-0.07). This means that wind has very little of an opposite association with changes in temperature. There is a strong positive correlation (0.88) between maximum and minimum temperatures. This means that when the highest temperature goes up, the minimum temperature also likely to go up.

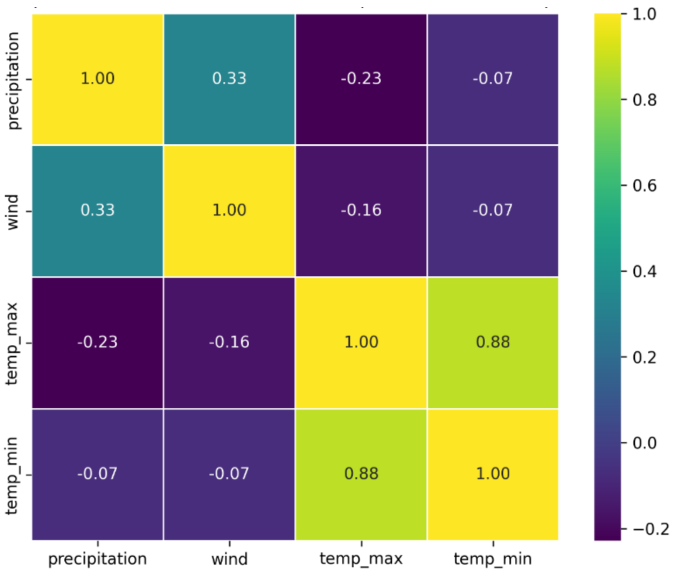

Figure 12. Heatmap showing the correlation between precipitation, wind, and temperature (maximum and minimum) values

Table 4. Seasonal Comparison of Weather Parameters (Precipitation, Wind, Max Temp, and Min Temp)

Month	Precipitation (mean)	Precipitation (sum)	Wind (mean)	Wind (max)	Temp Max (mean)	Temp Max (std)	Temp Min (mean)	Temp Min (std)
1	5.2	155.5	3.5	7.2	8.6	2.3	3.2	1.1
2	6.1	170.2	3.2	7.4	10.2	2.6	4.0	1.2
3	7.8	220.5	3.8	8.3	13.5	3.1	6.2	2.3
4	8.3	245.4	4.0	9.0	16.5	2.8	8.0	3.0
5	10.0	310.5	4.2	10.2	19.8	3.2	10.2	3.4
6	12.3	370.1	4.5	10.8	23.0	3.4	12.0	4.2
7	14.0	420.8	4.8	11.5	24.9	3.6	13.5	4.5
8	11.5	345.1	4.4	10.5	24.0	3.5	12.8	4.1
9	8.0	240.4	4.1	9.9	20.2	3.0	11.0	3.6
10	6.2	186.3	3.8	8.6	15.8	2.4	8.2	2.5
11	5.0	151.2	3.2	7.8	11.5	2.1	4.5	1.8
12	4.3	130.0	3.0	7.0	8.2	1.9	3.0	1.2

The table 4 shows how different weather conditions, like rain, wind, and temperature, change from month to month. The average amount of rain falls the most in July (14.0) and the least in December (4.3). The total amount of rain that falls each month shows this. July has the most rain (420.8 mm) and December has the least (130.0 mm). Wind speed is also similar, with the highest average speed in July (4.8 mph) and the lowest in December (3.0 mph). The highest wind speed ever recorded was in June (10.8), while the lowest was again in December (3.0). The average hottest temperature is in June (23.0°C), and the average lowest temperature is in December (20.2°C). June has the biggest standard deviation of maximum temperatures (3.4), which means that the temperature changes more throughout that month. The average minimum temperature is highest in July at 12.8°C and lowest in January at 3.2°C. The standard deviation of minimum temperatures is much higher in June (4.2), which means that the colder temperatures in that month are more likely to change. The data shows normal seasonal patterns, with more rain and higher temperatures in the summer, especially in June and July, and cooler, drier weather in the winter, especially in December and January.

4. Conclusion

There are a few things we can learn from looking at the phenological distribution and growth milestones of Fuji apples in China. The data and discussion show that temperature, sunlight hours, and humidity are important environmental elements that affect the phenological stages of Fuji apples, such as bud break, blooming, fruit set, and ripening. The timing and location of these stages are variable in different parts of China, mostly because the weather is different in each area. The examination of the data showed that places with warmer temperatures, like the North China Plain, have flowers and fruit that bloom and ripen earlier. On the other hand, places with cooler temperatures, like the Loess Plateau, have flowers and fruit that bloom and ripen later. This difference shows how important temperature is in deciding how Fuji apples grow. Also, there was only a moderate link between temperature and hours of sunlight, which means that these two environmental elements work together to control apple growth a lot. The paper also talked about how climate change can affect things, since it has changed the timing of phenological events. Changes in spring temperatures could cause buds to break and flowers to bloom earlier, which might not line up with when pollinators are available. Changes in autumn temperatures could also alter how quickly fruit ripens. It is also hard to predict these growth stages accurately because extreme weather events like droughts and heatwaves are becoming more often. These kinds of irregular weather patterns could make frost damage more likely, lower the quality of the fruit, and cause the harvest period to not match market needs. Additionally, the study's usage of machine learning methods like Random Forest and Support Vector Machines showed excellent results in predicting phenological stages based on environmental data. This means that these methods can be used to make more accurate predictions in future farming practices. This way of modeling is especially helpful for keeping agricultural productivity stable as the weather changes. In conclusion, this study gives us useful information about the complicated link between environmental elements and the many stages of Fuji apples' growth in China. It is very important to understand these trends in order to make the most use of cultivation methods, make better predictions about yields, and make sure that production is of excellent quality, especially in a changing climate. Farmers may use these results to better care for their orchards, deal with variations in the weather, and make Fuji apple production in China more sustainable.

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