Spatial Distribution of Meteorological Factors During the Key Growth Periods of Apple Cultivation in Longdong Region of Gansu Province

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Abstract With the ongoing development of the apple industry in the Longdong region of Gansu, this sector has emerged as a key driver for the government's initiatives aimed at increasing stable income for local residents and promoting rural revitalization. The Longdong region boasts a favorable geographical location and a suitable climatic environment, making it an ideal area for apple cultivation. This paper analyzes meteorological data from the national meteorological observatory in Longdong over the past forty years, focusing on average temperature, precipitation, sunshine duration, and relative humidity during three critical growth periods of apples. The research reveals significant differences in the distribution of meteorological conditions across these key growth stages. Notably, the average temperature is higher in the central and northern parts of the region, while lower temperatures are observed in the southwestern areas. The average daily maximum temperature tends to be higher in the northwest and lower in the central and southwestern regions. Conversely, the average daily minimum temperature demonstrates a distinct pattern, being higher in the south and lower in the north. Additionally, precipitation is more abundant in the southeast and less so in the northwest. Sunshine hours are greater in the northern and central regions, while the southwestern and northeastern areas receive fewer hours of sunlight. Finally, relative humidity is higher in the south and lower in the north.

Key words Apple; Longdong region; Meteorological factor; Spatial distribution

DOI 10.19547/j.issn2152 - 3940.2024.05.001

The Longdong region of Gansu Province is situated in the Loess Plateau of northwest China, characterized primarily by fragmented hills and ridges, with a smaller portion consisting of plains. This area boasts a beautiful natural environment and abundant mineral resources. Agricultural specialty products such as apples, pumpkin seeds, and *Hemerocallis citrina* are cultivated here, gaining popularity both domestically and internationally[1]. Qingyang City features significant altitude variation, ranging from 885 to 2 089 m, resulting in considerable temperature differences between morning and evening. The soil is rich in trace elements, including potassium, calcium, magnesium, zinc, and selenium, making it an ideal region for apple cultivation[2]. By the end of 2020, a total of 81 333.33 hm^2 of apples had been planted across seven counties and one district in Qingyang City, yielding approximately 790 000 t annually with a value exceeding 3 billion yuan. Among the 146 townships in Qingyang City, 22 townships reported apple planting areas exceeding 0.1 hm^2 per person. Consequently, the apple industry has become a pivotal sector in Qingyang City, driving sustained and stable income growth for the population and supporting rural revitalization. The apples produced in the Longdong region are notable for their quality and size. The spatial distribution of meteorological factors significantly impacts apple cultivation. Based on local conditions, the key growth periods for apples are classified into three stages: sprouting and fruiting from March to May, fruit swelling from June to August, and coloring and ripening from September to October. This paper examines the spatial distribution patterns of meteorological conditions during these three critical stages.

1 Apple sprouting and young fruit stage

As shown in Fig. 1a - f, the average temperature across most areas ranged between 10 and 11 ℃. Regions such as Zhenyuan and the northeast of Qingcheng recorded an average temperature of 11 ℃, with a peak of 11.3 ℃ in Qingcheng. In contrast, lower temperature areas, primarily found in Huachi, Xifeng, and Zhengning, exhibited the lowest temperature of 10.0 ℃ in Huachi. The average daily maximum temperature generally exceeded 30 ℃, with the northwest region experiencing higher temperatures, reaching a maximum of 31.5 ℃ in Qingcheng. The southeastern area, including Xifeng and Zhengning, had lower temperatures, remaining below 30 ℃, with the minimum temperature in Xifeng being 28.4 ℃. The average daily minimum temperature varied between - 10 and 6 ℃, exhibiting a clear pattern of higher temperatures in the south and lower in the north. The highest minimum temperature was recorded at Zhenyuan (- 7.2 ℃), while the lowest occurred in Huachi (- 10.7 ℃). Rainfall generally ranged from 80 to 105 mm, with higher amounts in the southeast and lower amounts in the northwest. Areas receiving less than 80 mm of rainfall were primarily located in the northwest of Hua-

Received: August 9, 2024 Accepted: September 17, 2024

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chi and the northeast of Huanxian, while regions with over 105 mm of rainfall were mainly found in Ningxian and Zhengning County. Most sunshine hours ranged between 650 and 700 h, with greater sunshine in the central and northern regions and less in the southwestern and northeastern areas. The maximum sunshine was recorded at 695.9 h in Qingcheng, while the minimum was 629.6 h in Huachi. The average relative humidity in most areas ranged from 50% to 60%, with regions in the northeastern part of Huanxian experiencing humidity below 50%. Areas with relative humidity exceeding 60% were mainly found in the southwestern part of Ningxian, the southern part of Xifeng, and the eastern part of Zhengning.

During the sprouting and young fruit stages, meteorological conditions had two primary effects on apple growth: the influence on the growth period and the impact on yield. The average temperature in March and the sunshine hours in mid-March and early April significantly affected the apple growth period. Higher average temperatures and more abundant sunshine in March led to an earlier start of the reproductive period. In Longdong, the average temperature in March varied considerably, being highest in Zhenyuan and Qingcheng and lowest in Huachi and Zhengning. Consequently, apple growth in Zhenyuan and Qingcheng began earlier than in Huachi and Huanxian, which aligns with observed patterns. The average temperature in May significantly influenced apple yield, with yields increasing alongside rising temperatures. Qingcheng recorded the highest average temperature in May, followed by Zhenyuan and Huanxian, while Zhengning had the lowest, followed by Ningxian and Xifeng. Over the years, apple production in Qingcheng has been notably higher than in other production areas.

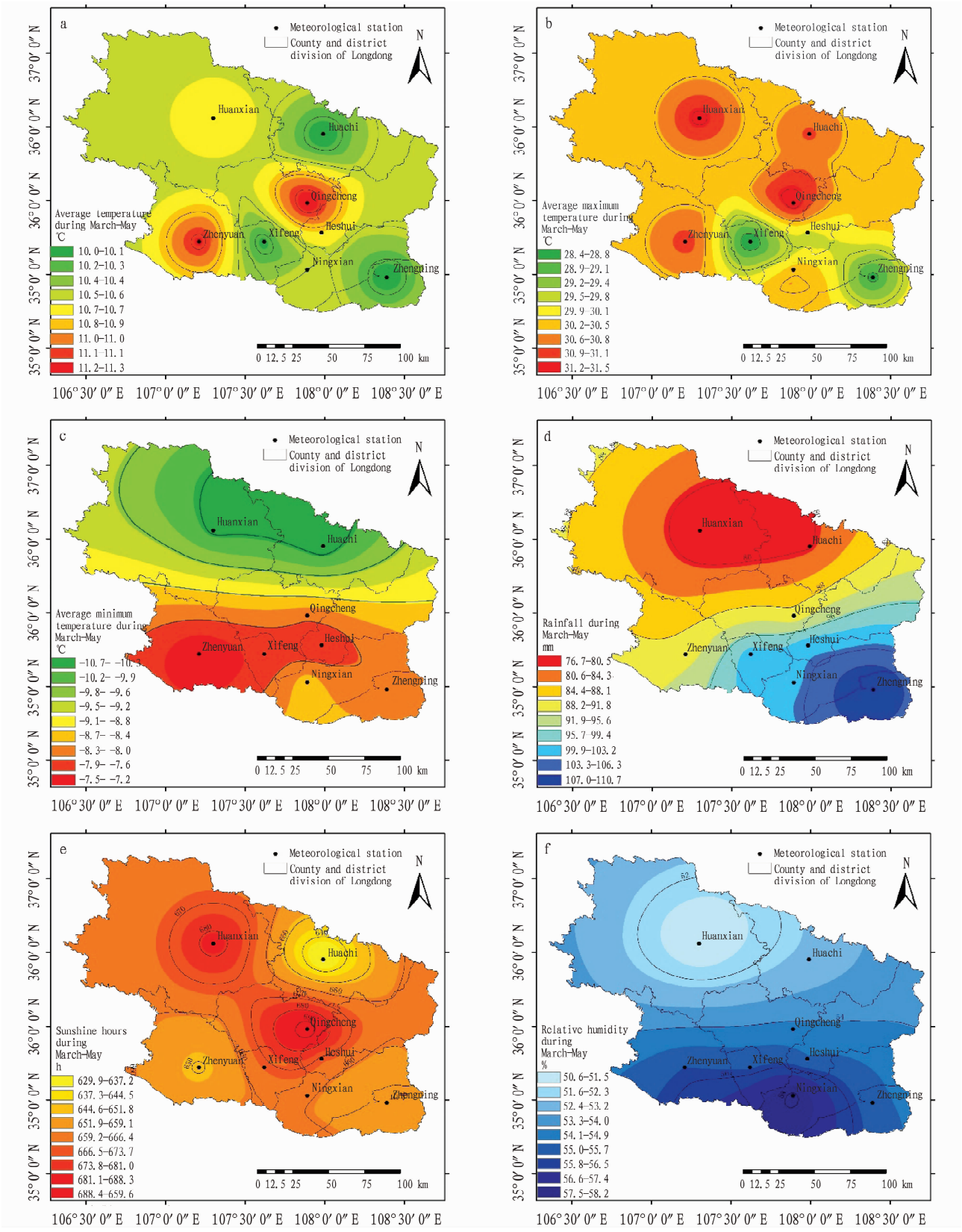
2 Apple fruit swelling stage

As shown in Fig. 2a – f, the average temperature during the apple fruit swelling period ranged between 20.5 and 21.5 ℃ in most areas, demonstrating a clear pattern of being higher in the northwest and lower in the southeast. Regions such as Huanxian, Huachi, Zhenyuan, and Qingcheng exhibited relatively high average temperatures, whereas Ningxian and Zhengning experienced lower averages. The average daily maximum temperature primarily ranged from 32 to 35 ℃, with the highest temperature recorded at 35.2 ℃ in Huanxian, while lower temperatures were noted in the southeast, with a minimum of 31.5 ℃ in Zhengning. The average daily minimum temperature typically ranged between 8.5 and 9.5 ℃, with lower values observed in the northern and southern regions and higher values in the central area. The highest minimum temperature was 9.9 ℃ in Xifeng, while the lowest was 7.2 ℃ in Ningxian. Rainfall during this period mainly ranged from 270 to 300 mm, with greater amounts found in the southeast and less amounts in the northwest. Areas receiving less than 270 mm of rainfall were primarily located in Huanxian and the northwest of Zhenyuan, while regions with rainfall exceeding 300 mm were mainly found in Zhengning and Ningxian. The average relative humidity across most areas ranged between 65% and 70%, with values below 65% observed in Huanxian. Regions with average relative humidity greater than 60% were primarily situated in the southwestern part of Ningxian and the eastern part of Zhengning. Sunshine hours typically ranged between 650 and 700 h, with more sunshine recorded in the central and northern regions and less in the southwestern and northeastern areas. The maximum sunshine was recorded at 711.3 h in Qingcheng, while the minimum was 625.9 h in Huachi.

During the fruit swelling and growth period, meteorological conditions exerted three primary effects on apples: first, the impact on fruit diameter; second, the influence on sugar content; and third, the effect on overall yield. Fruit growth is particularly pronounced from late June to early August. During this rapid growth phase, relative humidity, rainfall, and average temperature significantly influence fruit development, while sunshine hours are not a key meteorological factor affecting fruit swelling and growth. As illustrated in Fig. 2, Zhengning and Ningxian experienced relatively high rainfall and humidity but had lower average temperatures. Conversely, Zhenyuan and Qingcheng exhibited higher average temperatures, accompanied by lower relative humidity and rainfall. Consequently, these four counties displayed both favorable and unfavorable meteorological factors, which mutually constrained fruit development. Thus, the differences in apple fruit size among Zhenyuan, Qingcheng, Zhengning, and Ningxian were not statistically significant. Analysis of sugar content indicates that favorable meteorological conditions for apple sugar accumulation from June to August include high average temperatures, substantial daily temperature ranges, ample sunshine, and low rainfall. The spatial distribution of these meteorological conditions from June to August, as shown in Fig. 2, revealed that Qingcheng, Huanxian, and Zhenyuan met these favorable criteria. Measurements of sugar content from 2016 to 2017 indicated that apples from Qingcheng and Zhenyuan exhibited relatively stable and high sugar levels. The influence of meteorological conditions on yield primarily manifested as an increase in yield corresponding to rising average temperatures in June, July, and August. Fig. 2 showed that the average temperatures in Qingcheng, Zhenyuan, Huachi, and Huanxian were relatively high during these months. This indicated that the stable and elevated average temperatures from June to August were key meteorological factors contributing to high apple production in these regions.

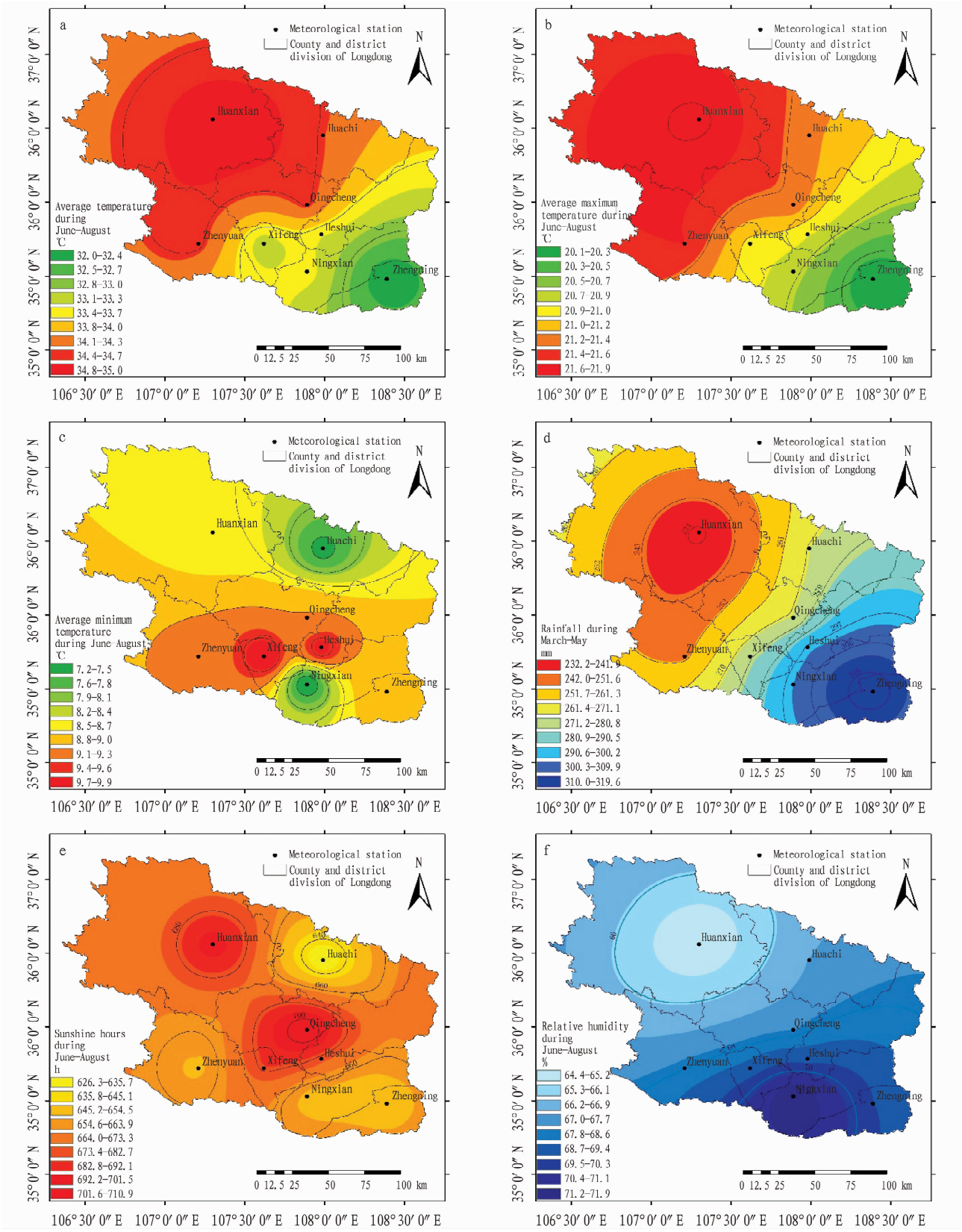
3 Apple coloring and maturity stage

As shown in Fig. 3a – f, the area with an average temperature ranging from 12.2 to 13.0 ℃ during the apple coloring and maturity stage was the most extensive. Higher average temperatures were observed in the northeast of Qingcheng, Zhenyuan, and the northwest of Heshui, with the maximum temperature recorded at 13.2 ℃ in Qingcheng. In contrast, the average temperatures in Huachi, Xifeng, Zhengning, and other locations were relatively low, with the minimum temperature occurring at 12.0 ℃ in Huachi.



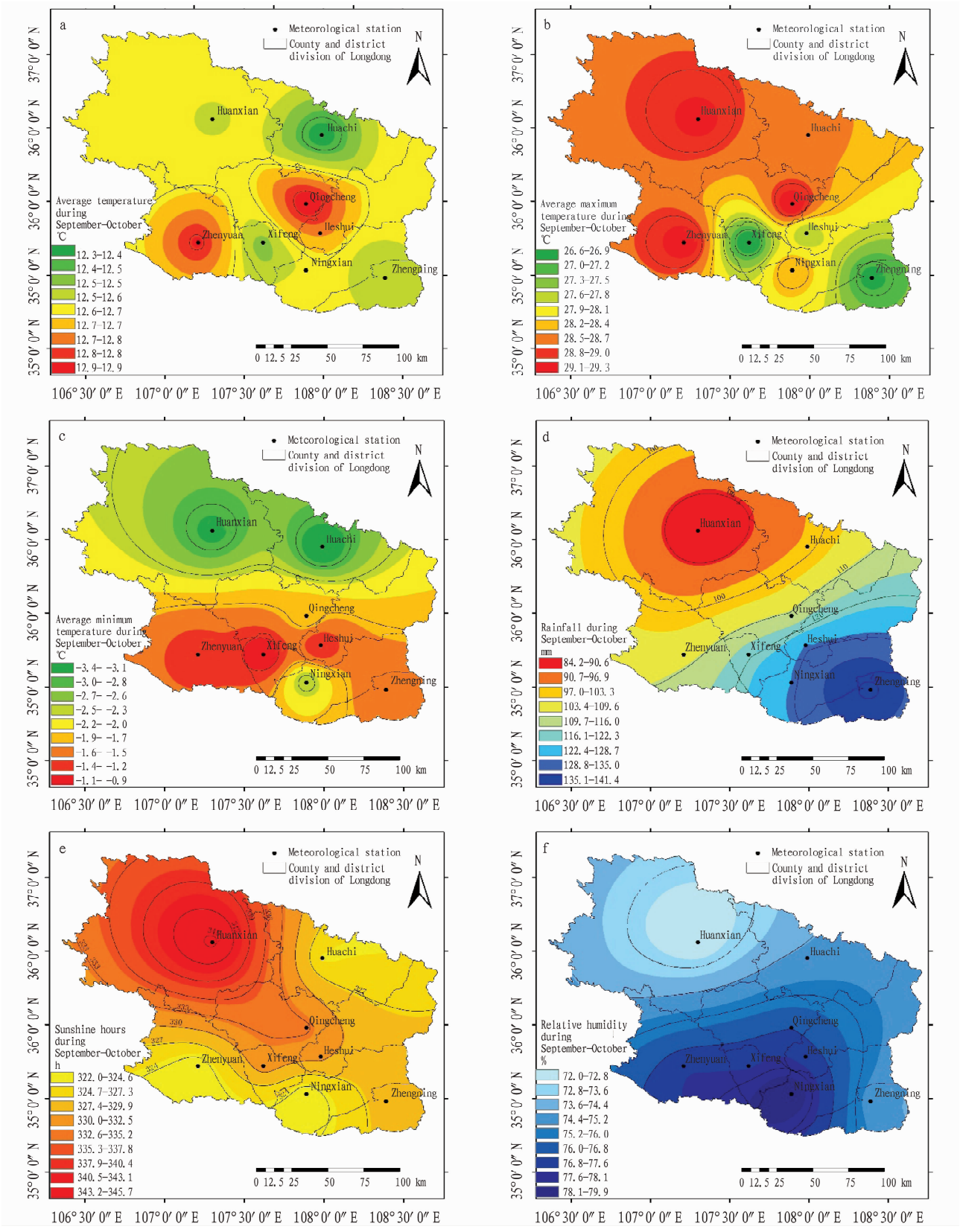
Note: a. Average temperature; b. Average daily maximum temperature; c. Average daily minimum temperature; d. Rainfall; e. Sunshine hours; f. Relative humidity.

Fig. 1 Spatial distribution of meteorological conditions during the sprouting and young fruit stage of apples from 1984 to 2020



Note: a. Average temperature; b. Average daily maximum temperature; c. Average daily minimum temperature; d. Rainfall; e. Sunshine hours; f. Relative humidity.

Fig. 2 Spatial distribution of meteorological conditions during apple fruit swelling period from 1984 to 2020



Note: a. Average temperature; b. Average daily maximum temperature; c. Average daily minimum temperature; d. Rainfall; e. Sunshine hours; f. Relative humidity.

Fig. 3 Spatial distribution of meteorological conditions during apple coloring and maturity period from 1984 to 2020

The average daily maximum temperature predominantly ranged from 28.0 to 29.0 ℃, with higher temperatures noted in the northwest, peaking at 29.3 ℃ in Qingcheng. In the southeast, areas such as Xifeng, Zhengning, and Heshui experienced lower temperatures, with the lowest recorded temperature being 26.6 ℃ in Xifeng. The average daily minimum temperature generally ranged from 8.5 to 9.5 ℃, exhibiting higher values in the southern regions and lower values in the northern areas. In regions like Xifeng, Zhenyuan, and Heshui, the daily minimum temperatures were higher, with the maximum being −0.9 ℃ in Xifeng. Conversely, the daily minimum temperatures in Huanxian and Huachi were lower, with the minimum recorded at −3.4 ℃ in Huanxian.

The rainfall during the apple coloring and maturity period generally ranged from 90 to 130 mm, with higher amounts in the southeast and lower amounts in the northwest. Areas receiving less than 90 mm of rainfall were mainly found in Huanxian and the northwest of Huachi, while those with rainfall exceeding 130 mm were primarily located in Zhengning and the southeast of Ningxian. The average relative humidity across most areas was favorable, ranging from 73% to 76%. Regions with average relative humidity below 73% were concentrated in Zhengning and Huanxian, whereas areas with humidity above 76% were primarily found in the southwest of Ningxian and the southeast of Zhenyuan. Most sunshine hours ranged between 325 and 340 h, with more sunshine observed in the central and northern regions, while the southwest and northeast received fewer hours. The maximum sunshine recorded was 354.6 h in Huanxian, while the minimum was 313.2 h in Ningxian.

During the apple coloring and maturity period, meteorological conditions had two primary effects on apples: the impact on fruit coloring and the effect on fruit yield. September and October are critical months for apple coloring, which is closely related to average temperature and sunshine hours. Although specific analyses of the impact of meteorological conditions on apple coloring are not detailed in this paper, the effects on yield during these months are analyzed. Correlation analysis of meteorological conditions affecting yield at eight weather stations in the Longdong region indicated that the most significant influencing factor on yield from May to August was average temperature. In contrast, the primary meteorological factors affecting yield from September to October were September rainfall, September sunshine, and October average temperature. The yield in Huanxian, Zhenyuan, Huachi, and Xifeng showed a significant positive correlation with the average temperature in October, while the yield in Qingcheng, Huachi, Xifeng, and Heshui had a significant negative correlation with September sunshine. Additionally, Qingcheng's yield was positively correlated with September rainfall, whereas Ningxian's yield exhibited a significant negative correlation with September rainfall. As shown in Fig. 3, the average temperature in October was higher in Xifeng and Zhonghuan and lower in Huachi, aligning with actual production results in Xifeng, Zhenyuan, and Huachi. The spatial distribution of sunshine hours in September across Qingcheng, Huachi, Xifeng, and Heshui was relatively uniform, exerting little impact on yield differences. In Qingcheng, September rainfall was moderate and had minimal effect on yield variation. Conversely, Ningxian experienced higher September rainfall, which was significantly negatively correlated with yield, resulting in lower production consistent with observed data.

4 Conclusions

In summary, the distribution characteristics of meteorological conditions during the three key growth periods were distinctly evident. The average temperature was higher in the central and northern parts of the region, while it was lower in the southwest. The average daily maximum temperature was elevated in the northwest but lower in the central and southwestern regions. The average daily minimum temperature exhibited a clear trend, being higher in the south and lower in the north. Rainfall was greater in the southeast and less in the northwest, while sunshine hours were higher in the northern and central regions and lower in the southwestern and northeastern areas. Relative humidity was also higher in the south and lower in the north. The impact of these meteorological factors varied across different regions, resulting in differences in apple quality and yield among various counties in the Longdong region.

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