Climate regionalization of various wine grape varieties in Hexi Corridor, China

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Abstract. Hexi Corridor is one of the most important wine grape cultivation areas in China and local wine industry is developing rapidly. The detailed study on regionalization of wine grape varieties may provide the scientific basis for the selection of wine grape varieties. In the study, according to the climatic characteristics in Hexi Corridor, with the two regionalization indicators of the frost-free period and active cumulative temperature, the areas with the frost-free period longer than 150 days and the active cumulative temperature higher than 2500 °C were classified as the suitable cultivation areas of wine grape. With the average meteorological data of 46 meteorological stations surrounding Hexi Corridor from 1980 to 2010 and the 90-m DEM data of Hexi Corridor, the models of the frost-free period and the cumulative temperature were established according to the multivariate stepwise regression method. In addition, the regionalization diagram of the wine grape varieties in Hexi Corridor was plotted with the residual interpolation method. In the diagram, the optimum wine grape cultivation region was divided in six areas according to active cumulative temperature and suitable wine grape varieties and proper cultivation elevation ranges were proposed for corresponding areas. The existing data of the grape quality in different wine grape cultivation areas in Hexi Corridor supported the regionalization results. The study results provided a theoretical basis for the selection of wine grape varieties in Hexi Corridor.

1. Introduction

Hexi Corridor is composed of a series of narrow and long plains among the mountains in the northwest of Gansu Province in China. Hexi Corridor is wide in west and narrow in east. In Hexi Corridor, the distance from east to west is about 1200 km and the distance from north to south is 100 to 200 km. Along the north of Qilian Mountains, three oasis basins (Wuwei, Zhangye, and Jiuquan) are naturally formed due to the impact of iceberg, snow and water and Gobi Desert is distributed in the northern edge of the basins. Hexi Corridor is one of China’s top ten wine grape production areas. Hexi Corridor is a part of the Silk Road and an important trade channel between the ancient China, Central Asia, and Europe. Wine grape cultivation and wine making has started in Hexi Corridor two thousand
years ago. In 1980s, the wine grape industry and wine making industry have entered the rapid development stage.

Hexi Corridor is characterized by long sunshine duration, the relatively large diurnal temperature range, loose soil, and dry climate. The droughty climate, barren soil, and the specific geographical location surrounding the Gebi Desert in Hexi Corridor largely restrict local traditional agriculture. Wine grape cultivation requires less water and less tillage operation and has the function of wind prevention and dune fixation. Local wine grapes have the good fruit quality and show significant advantages over other crops. Therefore, local wind cultivation area increases quickly. The cultivation area of wine grape in Gansu Province has increased from only 1000 hm² in 1985 to 20180 hm² in 2014. More than 95% of the cultivation area and several large wine companies are distributed around Hexi Corridor, Gansu. The main wine grape cultivar is **Cabernet Sauvignon**, which accounts for 45% of the total cultivation area of wine grape. The unreasonable composition of wine grape varieties leads to the local unreasonable composition of wine products. More than 80% of local wine products are dry red wines. Various wine production areas show no significant characteristics, thus leading to the poor product style and low market competitiveness.

In recent years, the regionalization of wine grape varieties in Hexi Corridor has been extensively explored [1-4]. With the analysis method of sliding analogy deviation to ecoclimatic demarcation, Chen Lei et al. [1] divided Hexi Corridor into 4 types: the most suitable cultivation area, suitable cultivation area, cultivable area, and non-cultivable area. This regionalization results were basically consistent with the heat requirement of late grape varieties, but the difference in the heat requirements among different wine grape varieties were not considered. Liu Mingshun [2] selected three indicators (the effective cumulative temperature above 10 °C, the average temperature in the hottest month (July), and the diurnal temperature range in the maturity stage (August–September)) as climate regionalization indicators of dry red and dry white grapes in Heixi, then correlated the three indicators with the geographical factors to establish the stepwise regression equation, divided Hexi Corridor into five climate areas with Citystar software platform in the geographic information system, and proposed the applicable wine grape varieties and elevation ranges for the 5 areas. The regionalization results were basically consistent with the actual cultivation areas, but the northern mountainous area, which was not applicable for wine growth due to the shorter frost-free period, was classified as the most suitable grape cultivation area. According to the stepwise regression method, Zhao Dongxu et al. [4] established the mathematical model of small-grid patterns, plotted the fine-grid layer for each area, and drew the ecoclimatic zoning map of wine grape varieties in Hexi Corridor based on the analysis results of sliding analogy deviation to ecoclimatic demarcation. In the regionalization results, the results of the eastern areas were highly consistent with the actual cultivation situation. However, the metrological data from only several metrological stations were utilized and the error of the established model was relatively large. Therefore, there were some significant errors in the northern mountainous area. Li Hua et al. [3] compared the grape climate zoning indicators adopted at home and abroad, selected the frost-free period as the first-level indicator, and the dryness as the second-level indicator, and performed the climate regionalization of the wine grape in Gansu Province. This study also considered the heat and moisture indicators, and yielded the basically consistent regionalization results compared to actual cultivation areas. However, the elevation in the region was high and the distribution of local metrological stations was sparse. Therefore, the zoning map directly obtained with the interpolation method had the low resolution and could be used to guide the selection of wine grape varieties.

In the study, based on the basic meteorological data of 46 metrological stations in the Hexi Corridor and its surrounding areas in the 30 years from 1981 to 2010, the average frost-free period and the dryness and the cumulative temperature of the grape growth season (April to September) were calculated. Combined with the 90-m DEM data of Hexi Corridor, the multivariate stepwise regression model of the frost-free period and active cumulative temperature was established. Moreover, the residual interpolation correction was carried out for all the indicators to improve the simulation accuracy of each meteorological factor and reduce the simulation error. In the study, the areas with the
cumulative temperature above 2500 °C and the number of frost-free days above 150 were determined as the suitable grape cultivation areas in Hexi Corridor. With active cumulative temperature as the regionalization indicator of wine grape varieties, we plotted the fine regionalization map of Hexi Corridor. Moreover, with the models of the frost-free period and cumulative temperature as well as the residuals, the elevation ranges were calculated for suitable grape cultivation areas in Hexi Corridor. Finally, opinions on wine grape cultivation were put forward for different areas according to the characteristics of various areas in Hexi Corridor. This study provides the guidance for the development and policy formulation of wine grape industry and wine making industry in Hexi Corridor.

2. Materials and methods

2.1. Data sources and data processing
Hexi Corridor involves five cities (Wuwei, Jinchang, Zhangye, Jiuquan, and Jiayuguan) in Gansu Province (36°29′~ 42°57′N, 92°13′~104°16′E), as shown in Fig. 1. The data utilized in this study included the metrological data of 19 meteorological stations in Hexi Corridor provided by Gansu Meteorological Bureau and the data of 27 typical meteorological stations in the geographic range (93°~105°10′N, 35°20′~43°50′E) of other provinces and autonomous regions provided by the Meteorological Information Center of China National Meteorological Administration. The data of the 46 meteorological stations in 30 years from 1981 to 2010 include the daily data of various meteorological elements. Average frost-free days and active cumulative temperature in 30 years were calculated in Excel software. DEM (Digital Elevation Model) data were from the geospatial data cloud (http://www.gscloud.cn) with a resolution of 3″ (90 m).

2.2. Indicator Selection
In grape climate regionalization, the mainly used indicators can be divided into three types: heat, precipitation, and light. Hexi Corridor has enough sunshine hours and light is generally not a limiting factor in local viticulture. Due to dry climate, irrigation conditions may restrict wine grape growth. If irrigation conditions are qualified, the heat is the only limiting factor of viticulture. In the selection of grape variety, the heat demand is mainly considered. Growth days and required heat conditions of grape vary with grape variety. Different varieties of wine grape require different growth days and heat conditions and are quite different in the adaptation capability to the environment. In northern China, air temperature is high in summer and the heat is enough for grape growth in many areas. However,
due to the shorter frost-free period, grape cultivation is not applicable in many areas. In northern China, the frost-free period is the key limitation factor of grape cultivation [5]. In grape climate regionalization, it is necessary to exclude the areas with the shorter frost-free period [3,6]. Active cumulative temperature and sunshine hours are applicable in grape climate regionalization in northern China [3,7-8]. Active cumulative temperature had been extensively explored and applied in variety regionalization and the data of active cumulative temperature are generally recorded in the data of the meteorological stations in China [9]. Relevant data are easily available for calculation. Therefore, in the study, the frost-free period and active cumulative temperature are selected as the regionalization indicator of grape varieties in Hexi Corridor.

In this study, the unsuitable cultivation area of grape was firstly excluded based on the indicator of the frost-free period. Then, in the suitable areas, regionalization of the wine grape varieties was performed with the cumulative temperature (the sum of daily average temperature above 10 °C). In the study, the cumulative temperature of 2800 °C was used as the minimum limit of viticulture [10-11]. Considering enough sunshine hours, large diurnal temperature difference and the phenomenon of the increasing cumulative temperature in Hexi Corridor, according to local practices of grape cultivation and the experiences of adjacent regions [12], the regions with the frost-free period longer than 150 days and the active cumulative temperature higher than 2500 °C were classified as the suitable cultivation areas of wine grape.

2.3. Research Methods

With the multivariate stepwise regression analysis method, the estimation models of the frost-free period and the cumulative temperature were respectively established. Then, the estimated values and the residuals compared to actual data of various stations were calculated for spatial interpolation. The simulated value of active cumulative temperature of each grid was calculated with the grid calculator in the surface analysis module of ArcGIS. Then the simulated grid layer was overlaid with the residual grid layer to obtain the active cumulative temperature grid layer. In this method, the influences of the terrain on the meteorological data as well as the errors caused by different locations were fully considered and the simulation results of the spatial distribution data of the thermal indicator were more accurate.

In the ArcGIS spatial analysis module, the geographic data of stations were converted into the data with the grid center point as the vector and then the vector data were used to calculate the spatial longitude and latitude. Finally, the longitude and latitude of the vector were transformed as the raster data. Based on the spatial analysis function of GIS, the gradient, aspect, and elevation information of the observation stations were extracted from the DEM data and added into the data of the meteorological stations. In the aspect data, both 0 degree and 360 degrees represents the positive north direction, so the data of the aspect should be pre-processed firstly. In the study, the degrees were firstly converted into the radian and then the cosine was calculated. After the data preprocessing, the obtained data of eastern and western slopes were basically the same, whereas the obtained data of northern and southern slopes are respectively positive and negative values [13], which were consistent with the warming effect related to the aspect.

2.4. Modeling

Meteorological data simulation values can be decomposed into the trend component and residual component. The trend component reflects the overall climate characteristics of the area and is affected by systemic macro factors in a wide range, such as longitude, latitude, elevation, and other factors as well as local small terrain factor [14-15]. The residual component reflects local climate change and is affected by some random factors.

The spatial distribution of the active cumulative temperature can be expressed as:

$$\Sigma T = \phi(\varphi, \lambda, h, \alpha, \beta, \varepsilon)$$

where \(\varphi\) and \(\lambda\) are respectively latitude and longitude; \(h\) is the terrain elevation; \(\alpha\) and \(\beta\) are respectively the gradient and aspect; \(\varepsilon\) indicates other factors in regression analysis. Combined with
climate characteristics in Gansu Province [16], geographic, and terrain factors, the active cumulative temperature estimation model is expressed as:

\[
\Sigma T = a_0 + a_1 \phi + a_2 \lambda + a_3 h + a_4 \varphi + a_5 \beta + a_6 k + \varepsilon
\]

where \(a_0\) is a constant term; \(a_1 \sim a_6\) are the coefficients of each term. The horizontal resolution of each meteorological index is estimated to be 3", which is the same to the resolution of the terrain elevation. When only the trend term is considered, the above equation can be expressed as:

\[
\Sigma T = a_0 + a_1 \phi + a_2 \lambda + a_3 h + a_4 \varphi + a_5 \beta + a_6 k
\]

Finally, multiple stepwise regression analysis was performed with the observation data in SPSS software to establish the active cumulative temperature model. The model of the frost-free period was established according to the same method (Table 1).

| Division target | Regression equation | R     | F value | P Value |
|-----------------|---------------------|-------|---------|---------|
| Accumulated temperature (\(\Sigma T\)) | \(\Sigma T=14301.31915-113.20476016\phi - 45.83410792\lambda - 1.4300286493h\) | 0.9602 | 178.3903 | 0.0001 |
| Frost-free period (FRD) | FRD=876.497580-10.927987775\varphi - 1.9234438043\beta - 0.05706644963h | 0.9111 | 74.3272 | 0.0001 |

Notes: \(\varphi, \lambda, \text{and} \ h\) respectively indicate the latitude, longitude, and elevation.

2.5. Residual Correction
The predicted value of cumulative temperature can be calculated with the above-mentioned prediction model and the geographical and topographic data of each metrological station. With the difference between the actual cumulative temperature and the predicted value of each station as the residual values (\(\varepsilon = \Sigma T_{\text{actual}} - \Sigma T_{\text{predicted}}\)), the spatial interpolation was performed according to the Kriging interpolation method [17] to obtain the raster layer of the \(\varepsilon\) value. Based on the 90-m DEM grid data of Hexi Corridor, the active cumulative temperature of each grid was calculated with the grid calculator under the surface analysis module in ArcGIS. The simulated raster layer was overlaid with the residual raster layer to obtain the raster layer of the corrected active cumulative temperature. The raster layer of the frost-free period was generated according to the same method.

2.6. Calculation of Suitable Elevation Range
The models of active cumulative temperature and the frost-free period can be respectively rewritten as:

\[
H = a_1 \Sigma T + b_0 \phi + c_0 + d_0 \lambda + e_0 \beta + f_0 k + \varepsilon
\]

\[
H = a_1 \text{FRD} + b_1 \phi + c_1 + d_1 \lambda + e_1 \beta + f_1 k + \varepsilon_1
\]

The latitude and longitude of each station was substituted into the above equations to calculate the above maximum elevation in the suitable cultivation area near each station. Finally, the elevation ranges of the suitable cultivation areas of various grape varieties were estimated with the geographical location of each station.

3. Results
Grape varieties of with different maturation periods have different heat energy demands in the growth period. Combined with heat energy demands of common grape varieties [6, 10-11] and cultivation conditions of different grape varieties in the producing areas and adjacent producing areas [1, 6], the ranges of active cumulative temperature for grape varieties of with different maturation periods are summarized. The suitable cultivation areas of grape was divided into the cultivation areas of extra-early maturing variety, early maturing variety, medium maturing variety, late maturing variety and extra-late maturing variety as well as the overheating area according to the cumulative temperature (Table 2). The layer of active cumulative temperature was overlaid with the layer of the frost-free period. According to the obtained overlaid layer, the areas with the frost-free period longer than 150 days and the active cumulative temperature higher than 2500 °C were classified as the suitable cultivation areas of wine grape.
Table 2. Preliminary regionalization program of wine grape varieties in Hexi Corridor

| Accumulated temperature ($\Sigma T$) | Partition | Optimum                        | Suitable                                  |
|-------------------------------------|-----------|--------------------------------|-------------------------------------------|
| 2500-2800                           | extremely early-maturation variety | Miller                          | Pinot Noir, Chardonnay, Pinot Gris, Riesling Silvaner, Gewurztraminer |
| 2800-3000                           | early-maturation variety         | Pinot Noir, Chardonnay, Riesling | Sauvignon Blanc, Pinot Gris, Syrah, Pinot Blanc, Riesling Silvaner, Gewurztraminer |
| 3000-3200                           | mid-maturation variety           | Riesling, Chardonnay, Merlot     | Cabernet Sauvignon, Pinot Noir, Italian Riesling Sauvignon Blanc, Colombard, Syrah, French Blue, Sangiovese |
| 3200-3400                           | late-maturation variety          | Cabernet Sauvignon, Cabernet Franc, Italian Riesling Grenach, Chardonnay, Merlot, Serong pearl, Semillon, Chenin Blanc, Ugni Blanc, Baiyu, Syrah |
| 3400-3600                           | extremely late-maturation variety | Grenache, Cabernet Sauvignon, Italian Riesling Canepabn, Cabernet Franc, Carignan, Zinfandel, Gamay, Ugni Blanc, Chenin Blanc, Cinsault, Syrah |
| >3600                               | overheated zone                  | Table Grape                     | Cabernet Sauvignon, Cabernet Franc, Grenache, Canepabn |

According to the active cumulative temperature range corresponding to each area in Table 2, the regionalization results of the suitable cultivation areas of grape varieties were further plotted in Fig. 2. In partial areas with the frost-free period of 150~160 days and the cumulative temperature above 2800 °C, due to the short growth period and frequent late frost, grape varieties with the longer growth period were not suitable. Therefore, the above areas were still classified into the cultivation area of extra-early maturing variety.

Figure 2. Regionalization diagram of wine grape varieties in Hexi Corridor
As shown in Fig 2, the suitable cultivation area of grape in Hexi Corridor is mainly distributed in the narrow and long basins between the Qilian Mountains and the northern mountain. All the grape varieties with different maturation periods have their corresponding suitable distribution areas depending on the elevation. The cultivation areas of the extra-early maturing variety are mainly distributed in the Qilian Mountains and the edge of the northern mountain, with low active cumulative temperature, the shorter frost-free period and the frequent frost and other hazards. The cultivation areas of the early maturing variety are mainly distributed in the middle of Wuwei City and the eastern part of Zhangye City with the 160-day frost-free period and relatively slight frost hazard. The cultivation areas of the medium maturing variety are widely distributed in Hexi Corridor and includes Liangzhou District and some towns of Shandan County in Wuwei City, Yumen, Suzhou, Jiayuguan, Ganzhou, Linze, Minqin and other counties. The cultivation areas of the late maturing variety are mainly distributed in Minqin, Gaotai, Dingxin, Yumen, Guazhou and other counties. The cultivation areas of the extra-late maturing variety are distributed in Dingxin, Yumen, and Guazhou. The overheating areas are mainly distributed in Dunhuang, where summer temperature is too high and grapes mature too fast, thus decreasing the acidity of wine grapes. In the overheating areas, eating grape varieties or grape varieties for dried products are more suitable.

In Wuwei City, except that Minqin County belongs to the cultivation areas of the late maturing variety, other counties are classified as the cultivation areas of early and medium maturing varieties. Zhangye City is classified as the cultivation areas of medium and late maturing varieties. Jiuquan and Jiayuguan are characterized by the high heat energy. Except that strip-shaped cultivation areas of early maturing variety are distributed in Qilian Mountains and the foot of the northern mountain, a large area of late and extra-late maturing varieties are distributed in Jiuquan and Jiayuguan. A large overheating area is distributed in Dunhuang and suitable for eating grape varieties. In the eastern part of Hexi Corridor, the highest elevation for the extra-early maturing grape varieties is about 1750 m; the highest elevation for the early and medium maturing grape varieties is about 1600 m; the highest elevation for the late maturing grape varieties is about 1450 m. In the middle part of Hexi Corridor, the highest elevation for the extra-early maturing grape varieties is about 1650 m; the highest elevation for the early and medium maturing grape varieties is about 1550 m; the highest elevation for the late maturing grape varieties is about 1400 m. In the eastern part of Hexi Corridor, the highest elevation for grape varieties is about 1450 m and the areas with the elevation lower than 1450 m are suitable for early, medium, and late maturing varieties. However, in the eastern part of Hexi Corridor, the frost-free period is short, so it is recommended to plant the early maturing varieties in the areas near to the highest elevation. In the Malushan District in northern Hexi, the highest elevation for planting wine grapes is only about 1,200 m. In some areas, due to special terrain conditions, the elevation shows significant differences and the highest elevation for planting wine grapes can reach about 2000 m. Therefore, in the areas with high elevation, it is necessary to carry out pilot cultivation tests for garden site selection.

When the active cumulative temperature of the area is consistent with the heat energy demands of local grape variety, the optimal grape quality is obtained. Although early and medium maturing grape varieties can grow mature in the late maturing area, due to faster maturation, the quality of grapes is worse than that in the slow maturation areas. Some widely distributed varieties, such as Cabernet Sauvignon and Chardonnay, are suitable for a wide area and can yield the good quality under various climate conditions. According to the report by Yan’s study [19], Pinot Noir in the producing base in Wuwei City contained the higher contents of total phenols, tannin, and anthocyanin than other varieties, displaying the optimal comprehensive quality; Merlot in the producing base in Gaotai County contained the higher contents of total sugar, total phenols, tannin, and total anthocyanin than those of Merlot planted in Wuwei and Minqin Counties, displaying the best comprehensive quality. Cabernet Sauvignon from various producing areas including Minqin, Wuwei and Zhangye Cities showed no significant difference in the sugar content, but the contents of total phenols, tannin and anthocyanin in Cabernet Sauvignon in the producing base in Zhangye City were much higher than those in Cabernet Sauvignon from Wuwei and Minqin Cities. Cabernet Sauvignon showed its best
fruit comprehensive traits in Zhangye Cities. The three producing bases [19] were respectively located in the boundary between the early maturing area and the medium maturing area, the boundary between the medium maturing area and the late maturing area, and the suitable cultivation area of later maturing varieties (Fig. 2). In the three producing bases, the grape varieties with the optimal quality were respectively Pinot Noir, Merlot, and Cabernet Sauvignon [19]. The results were consistent with the regionalization results of wine grape varieties in Hexi Corridor in this study.

The comparison between the regionalization diagram of wine grape varieties in Hexi Corridor (Fig. 2) and the actual distribution of the cultivation areas of various wine grape varieties (Fig. 3) indicated that the protection areas of geographical indication products in Hexi Corridor were basically in their suitable cultivation areas. Moreover, the suitable cultivation areas were larger than the actual cultivation areas. More than 20 grape varieties were planted in Hexi Corridor, including 8 dominant varieties displaying the better comprehensive quality. Wine grape varieties were basically distributed in the medium and late maturing areas and the early and late maturing varieties were the dominant varieties in Hexi Corridor. Early and extra-late maturing varieties showed significant potential in Hexi Corridor. According to the regionalization results, proper varieties can be selected in order to promote the economic development of various producing areas.

![Regionalization results of wine grape varieties and protection areas of geographical indication products in Hexi Corridor](image)

**Figure. 3** Regionalization results of wine grape varieties and protection areas of geographical indication products in Hexi Corridor

### 4. Discussion

Hexi Corridor is one of the major wine production areas in China. In recent years, the wine industry has increased rapidly in China. Definite regionalization results of grape varieties can provide the scientific basis for the development of local wine making industry. Hexi Corridor is located in the mid-latitude region with the higher elevation. In Hexi Corridor, the crop growth season is characterized by the high air temperature and the large diurnal temperature difference, which are conducive to the accumulation of fruit sugar. More grape varieties, including early, medium, and late maturing varieties, are suitable in Hexi Corridor. The grape cultivation areas in Hexi Corridor are distributed in boundary between basin and desert. The soils are dominated by sandy soil and gravel soil and characterized by the loose structure and the large porosity, which are beneficial to the growth
of grape roots. The soils are characterized by rich minerals, high heat exchange rate, and large diurnal temperature difference, which are conducive to fruit coloring and maturation. Hexi Corridor is characterized by dry climate, less precipitation, high transparency, rare pests and diseases and pesticides are seldom applied [18]. The precipitation is rich in summer in Qilian Mountains and generates the Heihe River, Shiyang River, and Shule River [20], which provide abundant resources for local agriculture in the oasis irrigation areas in Hexi Corridor. These rivers guarantee the development of the wine industry in this region. Due to the long sunshine hours and the large diurnal temperature difference, and much ultraviolet radiation and scattered light compared to the eastern part of China, the accumulation of sugar in wine grape in Hexi Corridor is higher than that in the eastern part of China. Local wine grapes have moderate sugar and acidity and can yield the better wine quality.

In this study, the frost-free period and active cumulative temperature were selected as the indicators of grape climate regionalization in Hexi Corridor. Firstly, the areas with the short frost-free period and the frequent late frost were excluded. The active cumulative temperature was selected as the indicator to exclude the areas without enough heat energy. In the suitable cultivation areas of wine grape, active cumulative temperature was used as the regionalization indicator to further divide the cultivation areas for different varieties. In Hexi Corridor, there are 19 metrological stations. The distribution of metrological stations is scarce and shows the east-west trend. The latitude differences among 16 stations are no more than 3 degrees. Heat energy differences caused by different latitudes can easily be covered by other indicators. Therefore, if only the data of metrological stations are used to establish the models, the weight of the latitude is relatively low. Liu Mingchun [2] and Zhao Dongxu [4] mistakenly classified the northern mountainous area as grape suitable cultivation area. In addition to the 19 meteorological stations in Hexi Corridor, 27 meteorological stations in the surrounding area were also introduced for modeling in this study. The latitude differences among all the stations exceeded 8 degrees, thus reducing the modeling error and excluding the unsuitable cultivation areas in the northwest of Hexi Corridor. In the study, 90-m DEM data were used and the estimation models of the frost-free period and active cumulative temperature were established by multivariate stepwise regression analysis. The estimation model was corrected with the spatial residuals and the accuracy of the spatial simulation data of heat index was improved. Moreover, based on the heat energy indicator model for Hexi Corridor, the elevation ranges of suitable cultivation areas were proposed for grape varieties with different maturation periods. In Hexi Corridor, different grape varieties had different suitable elevation ranges.

Hexi Corridor has more than 20 kinds of soils. The main soils in the western and middle Hexi Corridor are brown desert soil and gray-brown desert soil. In the eastern Hexi Corridor, the main soils are gray desert soil, light brown soil, and sierozem. The brown desert soil is mainly distributed in the Piedmont alluvial belt in front of the northern mountain [21-22]. The belt is characterized by the large area, suitable climate, and the fewer vineyards. Due to the fewer rivers and insufficient experiences in upgrading and utilizing such soil, the grape cultivation area is small. The experiences for exploiting brown desert soil in Turpan producing areas may be utilized in the Piedmont alluvial belt. In Hexi Corridor, the extreme minimum temperature in suitable cultivation areas of wine grape in the past 30 years is generally lower than -20 °C, so wine grape plants should be buried to prevent freezing disasters [7, 23]. Frost disasters frequently occur in April and early May in producing areas of grape. It is necessary to adopt anti-frost measures. In the middle and western areas of Hexi Corridor, in the selection of grape variety, it is necessary to select the grape varieties with the late germination period. However, in Wuwei City the frost-free period is longer and grape varieties with the early germination period and poor frost resistance are recommended, such as Pinot Noir and Chardonnay. Due to the serious shortage of precipitation in Hexi Corridor, good irrigation conditions are the prerequisite for the cultivation of wine grapes. Local climate in Hexi Corridor belongs to the warm and cool climate. Considering the global warming trend, the area suitable for the cultivation of grapes in Hexi Corridor and the required elevation will be increased [24]. Therefore, the influences of climate change on the regionalization of grape varieties in Hexi Corridor should be further explored.
5. Conclusion
In this study, the optimum wine grape cultivation region was divided in six areas according to active cumulative temperature and suitable wine grape varieties and proper cultivation elevation ranges were proposed for corresponding areas. The existing data of the grape quality in different wine grape cultivation areas in Hexi Corridor supported the regionalization results. The study results provided a theoretical basis for the selection of wine grape varieties in Hexi Corridor.

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