GIS-Based Climate Suitability Zoning for Taiwan Green Jujube Introduction and Expansion in Fujian

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Abstract

To rationally utilize Fujian' s climate resources and optimize the planting layout of Taiwan jujube in Fujian, climate suitability zoning for the introduction and expansion of Taiwan jujube cultivation in Fujian was conducted based on GIS. According to the growth meteorological indices, life cycle, and production management characteristics of Taiwan jujube, five meteorological factors were selected as zoning indices: annual active accumulated temperature 10 ℃ (ΣT 10 ℃), annual mean temperature (Tavg), annual extreme minimum temperature at 90% guarantee rate (T90%JDW), annual precipitation (R), and annual sunshine hours (S), to construct a climate suitability zoning index system for Taiwan jujube. The expert scoring method and Analytic Hierarchy Process were employed to conduct weight analysis of the zoning indices and establish a climate suitability index algorithm. Based on meteorological element values, longitude, latitude, and altitude, fine-grid estimation models for the five zoning indices were developed through linear regression. Combining the fine-grid estimation models and the climate suitability index algorithm, climate suitability zoning for the introduction and expansion of Taiwan jujube cultivation in Fujian was carried out. The reliability of the zoning results was verified using previous research findings and the current status of jujube cultivation. The results indicate that the suitable cultivation areas for Taiwan jujube are mainly distributed in coastal counties and cities south of Quanzhou' s municipal district and some inland counties and cities in Zhangzhou; the sub-suitable areas are primarily located in the central coastal region of Fujian and parts of Yongding and Shanghang townships in southern Longyan, where jujube cultivation may suffer from cold and freezing damage, necessitating attention to low temperature protection; the remaining counties and cities are unsuitable cultivation areas. The zoning results are consistent with previous research findings and the current status of jujube cultivation. The research findings can provide references for the introduction, expansion, and planting structure adjustment of

Taiwan jujube in Fujian.

Full Text

Preamble

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Climate Suitability Regionalization for Taiwan Green Jujube Introduction and Expansion in Fujian Province Using GIS

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Abstract: To rationally utilize Fujian' s climatic resources and optimize the planting layout of Taiwan green jujube (*Zizyphus mauritiana*), this study conducted a climate suitability regionalization for Taiwan green jujube introduction and expansion in Fujian Province using GIS. Based on the crop' s meteorological growth indices, lifecycle, and production management characteristics, five meteorological factors were selected as zoning indicators: annual active accumulated temperature 10 °C (T 10 °C), annual mean temperature (Tavg), annual extreme minimum temperature with 90% guarantee rate (T90%JDW), annual precipitation (R), and annual sunshine hours (S). A climate suitability index algorithm was established using expert scoring and the Analytic Hierarchy Process (AHP) for weight analysis. Small-grid estimation models for the five indicators were developed through linear regression based on meteorological element values, longitude, latitude, and altitude. The climate suitability regionalization was then performed by integrating these models with the suitability index algorithm. The reliability of the zoning results was validated using previous research findings and current planting status of Taiwan green jujube. The results showed that suitable cultivation areas are mainly distributed in coastal counties south of Quanzhou City and some inland counties of Zhangzhou. Sub-suitable areas are primarily located in central coastal Fujian and parts of Yongding and Shanghang counties in southern Longyan, where cold and freezing damage may occur and low-temperature protection measures are necessary. All other counties are unsuitable for cultivation. These zoning results are consistent with previous studies and the actual planting distribution of Taiwan green jujube in Fujian, providing valuable guidance for introduction, expansion, and planting structure adjustment of Taiwan green jujube in the province.

Keywords: Taiwan green jujube; suitability index; climate regionalization; AHP method; GIS

Taiwan green jujube (*Zizyphus mauritiana*), also known as hairy-leaf jujube or Indian jujube, belongs to the Rhamnaceae family and is native to tropical regions such as India and North Africa. Around 2000, Taiwan green jujube emerged as a new fruit crop in Fujian Province, attracting considerable interest from local growers and leading to large-scale cultivation, primarily of the 'Gaolang No. 1' and 'Cuimi' varieties. In recent years, expanding cultivation areas have been driven by high economic returns. However, the introduction process has been characterized by large-scale, widespread, and often blind planting by farmers, frequently resulting in agrometeorological disasters. Conversely, some climatically suitable areas remain underutilized, leading to wasted climate resources. Therefore, conducting a climate suitability regionalization for Taiwan green jujube introduction and expansion is essential for guiding rational climate resource utilization and reducing planting risks.

Current research on Taiwan green jujube has primarily focused on cultivation management techniques and biological characteristics [1–4]. Studies on introduction and expansion remain limited: Liu Daixing [5] proposed preliminary opinions on planting regionalization for Taiwan green jujube in Yunnan' s tropical regions, while Sun Haoyuan et al. [6] analyzed and compared temperature, humidity, and precipitation between the crop' s native region and potential introduction areas, conducting a suitability regionalization at the prefecture-city level across China. Numerous scholars have investigated climate suitability regionalization methods [7–17], though validation of zoning accuracy has received less attention. Indicator selection represents the most fundamental and critical step in regionalization research, directly affecting result accuracy. While most existing studies consider meteorological indicators related to light, temperature, and water, they fail to reprocess these indicators based on crop lifecycle and production management characteristics. Moreover, no fine-scale regionalization studies using GIS for Taiwan green jujube introduction and expansion have been reported, leaving a gap in guidance for crop introduction and expansion decisions.

This study aims to construct a climate suitability indicator system for Taiwan green jujube that comprehensively integrates meteorological growth indices, lifecycle characteristics, and production management features. Based on this system, we conduct a fine-scale GIS-based climate suitability regionalization for Taiwan green jujube introduction and expansion in Fujian, validating the reliability of our results against previous research and current planting status. This approach clarifies the spatial distribution of climate suitability for Taiwan green jujube cultivation across Fujian' s complex terrain, providing scientific and practical guidance for crop introduction, expansion, and planting structure adjustment.

1.1 Data Sources

The study utilized climate data from 67 surface meteorological stations in Fujian Province for the period 1971–2011, including geographic information (longitude,

latitude, altitude) and meteorological elements such as annual mean temperature, historical extreme minimum temperature, annual precipitation, and annual sunshine hours (either multi-year averages or extreme values), all provided by the Fujian Meteorological Bureau. Geographic information data were obtained from the "Digital Fujian" 1:250,000-scale dataset, from which raster data for longitude, latitude, and altitude were extracted using GIS technology.

1.2 Data Processing

1.2.1 Calculation of 90% Guarantee Rate Extreme Minimum Temperature

Using extreme minimum temperature data from 67 meteorological stations in Fujian during 1971–2011, we performed normality tests on the annual extreme minimum temperature series for each station, applying normalization transformations to non-normally distributed samples. The distribution function was established using the sample mean ( ) and standard deviation ( ) of extreme minimum temperatures. The NORMINV function in Excel was then used to calculate the value at the 0.9 probability point of the normal distribution, yielding the 90% guarantee rate extreme minimum temperature.

1.2.2 Data Standardization

Since the model includes multiple zoning indicators with different magnitudes, we standardized indicator values using the raster calculator in the GIS platform to eliminate dimensional effects, transforming all values to a 0–1 range.

2.1 Zoning Indicator System and Weight Calculation Method

Taiwan green jujube is a tropical fruit with strong adaptability to tropical environments and suitability for South Asian tropical regions. It can generally be cultivated in tropical and subtropical areas with annual mean temperature 19 °C, accumulated temperature 6,500 °C, extreme minimum temperature -5 °C, annual rainfall 500 mm, relative humidity >50%, and essentially frost-free conditions [6,18-19], though dry-hot valley areas with annual precipitation below 1,200 mm are most suitable.

Temperature represents the primary limiting factor for Taiwan green jujube growth, with optimal development occurring at 20–35 °C and slow growth below 15 °C. Based on literature review [5–6,18–23], expert consultation, and field observations, Taiwan green jujube experiences: mild leaf damage with partial yellowing at extreme minimum temperatures below 4 °C; fruit freezing and alcoholic fermentation at 0 to -1 °C; branch and flower bud death at -1 to -2 °C; and death of above-ground parts of mature trees at -4 °C. As a perennial but fast-growing fruit tree managed with annual pruning, Taiwan green jujube can

recover and produce normally after pruning if the main trunk survives cold damage. The crop is light-loving and drought-tolerant. In Fujian, frequent typhoons during September–October bring excessive rainfall that adversely affects flowering and pollination, though the long flowering period ensures good yields if one batch of flowers successfully pollinates. As a light-demanding crop, adequate sunshine benefits flowering, and farmers often use artificial lighting to regulate flowering periods.

Based on Taiwan green jujube' s meteorological growth indices, lifecycle, development rate, and field management characteristics, combined with expert interviews, field surveys, and phenological observations, we identified five key meteorological factors determining cultivation suitability: annual active accumulated temperature 10 °C, annual mean temperature, annual extreme minimum temperature, precipitation, and sunshine hours. Considering the crop' s perennial nature and annual pruning/fruiting cycle, we reprocessed the annual extreme minimum temperature using a 90% guarantee rate approach. The final zoning indicators were: T 10 °C, Tavg, T90%JDW, annual precipitation (R), and annual sunshine hours (S). Indicator grading standards were established based on biological characteristics, literature review, and expert consultation (Table 1).

For weight determination, we adopted a combined subjective-objective scoring method [24] to avoid the one-sidedness of single methods like pure expert scoring or AHP. Multiple agrometeorology experts used the 1–9 scale method in AHP [25] to pairwise compare the importance of the five indicators, constructing a judgment matrix (Table 2). The "sum-product method"[24–25] was then applied to calculate weight vectors, with consistency verified through CR testing. The resulting indicator weights are shown in Table 3 .

As shown in Table 3, T 10 °C and Tavg carry the highest weights as the most critical meteorological factors determining cultivation suitability. T90%JDW ranks second but holds substantial weight as the key factor for safe overwintering. Sunshine and precipitation have lower weights, primarily affecting fruit quality rather than overall cultivation suitability.

2.2 Small-Grid Estimation Models for Zoning Indicators

Climate resources exhibit significant spatial variation due to differences in latitude and altitude. Fujian Province covers 123,700 km² but has only 67 standard meteorological stations, with each station representing approximately 1,800 km² —insufficient to capture the three-dimensional diversity of climate resources or meet the fine-scale regionalization requirements for Taiwan green jujube. Therefore, establishing spatial analysis models for zoning indicators is necessary to estimate climate conditions in areas without meteorological stations.

Based on 1971–2011 surface observation data and kilometer-grid geographic information, we developed multiple regression models for the five indicators as functions of longitude (, km), latitude (, km), and altitude (h, m) (Table 4

). These small-grid estimation models all passed significance tests at the 0.001 level.

2.3 Climate Suitability Index and Classification

Using normalized indicator values and weights, we established the climate suitability index formula:

$$I = \sum_{i=1}^{5} W_i X_i$$

where I is the climate suitability index, W is the weight of indicator i, and X represents the normalized values of the five indicators (T 10 °C, Tavg, T90%JDW, R, and S).

The natural breaks method (an unequal-interval classification approach) was applied to classify the climate suitability index by identifying characteristic points based on differences between all station values and their mean, combined with field investigations and iterative testing. The resulting classification standards are shown in Table 5 .

3.1 Taiwan Green Jujube Climate Suitability Zoning

Based on the five indicator values and the climate suitability index formula, we used the raster calculator in the GIS spatial analysis module to standardize, integerize, and overlay the spatial distribution maps of the five climate indicators, generating the climate suitability index distribution map for Taiwan green jujube in Fujian (index range: 0.71–0.92). Representative station values are listed in Table 6 .

Considering land use constraints such as forest protection and unsuitable land types (highways, reservoirs, rivers), Taiwan green jujube cultivation can only occur on arable land and orchard plots. Therefore, we integrated land use data into the climate zoning by masking urban areas, transportation and water infrastructure, and water bodies. The comprehensive climate zoning layer was logically multiplied with arable land and orchard layers to exclude unsuitable areas. Combined with the suitability classification standards (Table 5), this yielded the fine-scale climate suitability regionalization map for Taiwan green jujube introduction and expansion in Fujian (Figure 1 [Figure 1: see original paper]).

As shown in Figure 1, the climate suitability distribution comprises three zones:

1) **Suitable Zone**: Located mainly in coastal counties south of Quanzhou City and some inland counties of Zhangzhou (including Zhangpu, Changtai, Nanjing, and Pinghe). These areas have abundant heat resources with T 10 °C >7,000 °C and annual mean temperature >20 °C. The T90%JDW

>4 °C ensures safe overwintering and fruit production [1,5]. Annual precipitation ranges 1,200–1,900 mm and sunshine hours 1,600–2,000 h, representing sub-optimal conditions for water and light but with low weighting in the index. Overall climate conditions favor yield and quality formation. Waterlogging risks can be mitigated through ditch drainage and soil mounding, while insufficient sunshine can be compensated by artificial lighting—practices already widely adopted in Fujian' s main production areas.

2) **Sub-suitable Zone**: Primarily in central coastal Fujian and low-lying areas along the Min, Jiulong, and Ting Rivers, including parts of Yongding and Shanghang counties in southern Longyan. These areas have moderate heat conditions (T 10 °C >6,000 °C, Tavg >17 °C) with T90%JDW between 0–4 °C, and precipitation and sunshine in the sub-optimal range. Taiwan green jujube in these areas may suffer from low-temperature damage, requiring protective measures such as film covering for safe production. Without such defenses, adverse impacts on growth are likely. For example, during a 6-day frost event in Yongding County (December 21–26, 1999), most open-field Taiwan green jujube planted in July–August was killed, though larger trees regrew and fruited the following year. On December 17, 2010, open-field crops in Pinghe County experienced frozen fruit with poor development and yield reduction, though branches remained undamaged.

3) **Unsuitable Zone**: Includes northern coastal and central-northern inland areas, particularly the northwestern mountainous region with the poorest comprehensive meteorological conditions. Although some counties have acceptable temperature and accumulated heat conditions, extremely low minimum temperatures (mostly below 0 °C) cause regular fruit freezing during overwintering periods, preventing effective yield and quality formation and offering no clear economic benefits.

3.2 Validation of Zoning Results

The zoning results were validated against previous research findings [6,24,26] and current planting status of Taiwan green jujube in Fujian, confirming their reliability for guiding introduction, expansion, and planting structure adjustments.

3.2.1 Consistency with Previous Research

The climate suitability map (Figure 1) shows that suitable cultivation areas correspond to regions with high-to-medium climate similarity between Fujian and Taiwan, sub-suitable areas match medium-to-low similarity regions, and unsuitable areas align with poor or no similarity [26]. According to Chen et al. [24], coastal counties south of Quanzhou represent low-to-medium frost risk areas for Taiwan green jujube introduction, consistent with our suitable zone

classification. Other areas classified as high-to-severe frost risk correspond to our sub-suitable zone. Sun et al. [6] identified Zhangzhou as suitable, Fuding and Ningde as sub-suitable, and Changting, Pucheng, Shaowu, and Jianyang as unsuitable—all consistent with our results.

3.2.2 Consistency with Planting Status in Fujian

Current large-scale Taiwan green jujube cultivation in Fujian is concentrated in Zhangzhou, falling within our suitable and sub-suitable zones. Small-scale cultivation occurs in localized favorable microclimate areas in central-northern coastal and southern inland regions, corresponding to our sub-suitable zone. This alignment between actual planting distribution and zoning results demonstrates the objectivity of our findings.

4 Conclusions and Discussion

1) Southern and central coastal counties and some southern inland counties constitute the suitable and sub-suitable cultivation zones for Taiwan green jujube in Fujian. Coastal areas south of Quanzhou in southern Fujian are particularly favorable due to abundant heat and low frost risk [24]. Other areas are unsuitable due to poor matching of light, temperature, and water conditions, excessive precipitation, and critically low extreme minimum temperatures that prevent yield formation. The consistency between our zoning results, previous research, planting status, and historical disaster cases confirms the reliability of our approach, providing a valuable reference for planting layout decisions.

2) In climate zoning research, indicator system construction and weight determination directly affect result reliability. Our study improved accuracy by comprehensively considering meteorological growth indices, lifecycle characteristics, and production management features, particularly through the 90% guarantee rate processing of extreme minimum temperature. While our selected indicators generally reflect the crop' s meteorological requirements throughout its growth period, key growth stage indicators were not included. Although land use status was incorporated, other underlying surface factors such as slope, aspect, and soil were not considered and should be addressed in future research to further improve accuracy. The combination of expert scoring and AHP for weight determination overcame limitations of purely subjective scoring while eliminating the one-sidedness of relying solely on statistical probability.

3) Small newly-planted areas currently exist in northern Longyan (unsuitable zone), where alternative crops or protected cultivation are recommended. In Zhangzhou' s coastal region (mostly suitable zone), counties like Zhao' an and Yunxiao with small cultivation areas offer expansion potential. Sub-suitable zones in central-southern coastal areas can develop Taiwan green jujube selectively based on local conditions, such as in Putian and

Quanzhou coastal counties where current cultivation is limited. These areas can introduce and expand cultivation according to economic needs, with careful attention to field management, particularly low-temperature protection in winter.

These research results provide a scientific basis for adjusting Taiwan green jujube planting structures in Fujian Province.

References

[1] Luo H J, Luo S, Lai Y C, et al. Study on fruit development of Taiwan green jujube[J]. Journal of Fruit Science, 2002, 19(6): 436-438
[2] Li H W, Li Q X, Wei P H. Introduction expression and high-yielding culture technology of Taiwan green jujube[J]. Guangdong Agricultural Science, 2007(8): 30-32
[3] Wang Z H. Pollution-free culture technology with high yield of Taiwan green jujube[J]. Chinese Horticultural Abstract, 2011(12): 167-168
[4] Lu Y W. Pollution-free culture technology with high yield of Taiwan green jujube[J]. China Agricultural Technology Extension, 2009, 25(6): 29-30
[5] Liu D X. Varieties, fertile plant technique and plant division of *Zizyphus mauritiana* in Yunnan[J]. Tropical Agricultural Science & Technology, 2003, 26(2): 6-10
[6] Sun H Y, Xu J R, Wang Y Z, et al. Selection of suitable climatic regions for introduction of *Ziziphus mauritiana* using the methods of gray clustering and gray connecting analysis[J]. Chinese Agricultural Science Bulletin, 2006, 22(4): 143-146
[7] Gu X P, Yu F, Ma J Y, et al. Assessment indices of climate suitability and division for *Jatropha curcas* in Guizhou Province[J]. Chinese Journal of Agrometeorology, 2013, 34(4): 434-439
[8] Jin Z F, Deng R, Huang J F. Regional planning for planting *Myrica rubra* based on GIS in Zhejiang Province[J]. Transactions of the CSAE, 2008, 24(8): 214-218
[9] Huang Y L, Su Y X, Zhong S Q, et al. Division of banana for climatic suitability based on a decision tree[J]. Journal of Tropical Meteorology, 2012, 28(1): 140-144
[10] Min C C, Ma H L, Wang X S, et al. Climatic adaptability division for rape planting in Hubei Province based on GIS[J]. Chinese Journal of Agrometeorology, 2010, 31(4): 570-574
[11] Su Z S, Qin Q M, Chen X G, et al. Application of GIS for climate mapping of Chinese wolfberry in Ningxia Hui Autonomous Region[J]. Resources Science, 2006, 28(6): 68-72
[12] Xue S L, Liu M C, Zhang H L. Analysis and division of ecological and climatic conditions for maize planting in the Hexi Corridor[J]. Chinese Journal of Agrometeorology, 2003, 24(2): 12-15
[13] Li Y C, Zhang J P. Climate division of planting bamboo based on GIS in the Jinggang Mountain Area[J]. Chinese Journal of Eco-Agriculture, 2002,

10(4): 94-96
[14] Guo W L, Wang Z H, Zhao X P, et al. Climate division in fine grids of high quality chestnut in Beijing area[J]. Journal of Applied Meteorological Science, 2004, 15(3): 382-384
[15] Liang P, Wang H B, Long X J, et al. Climatic and ecological suitability division for *Pseudostellaria heterophylla* growing in southeast Guizhou prefecture[J]. Chinese Journal of Agrometeorology, 2008, 29(3): 329-332
[16] Zhang X Y, Li H Y, Chen W P, et al. Ecological regionalization of wine grape varieties in Ningxia[J]. Chinese Journal of Ecology, 2014, 33(11): 3112-3119
[17] Su Y X, Li Z, Sun H. Climate division of sugarcane planting based on GIS in Guangxi[J]. Chinese Journal of Agrometeorology, 2006, 27(3): 252-255
[18] Lai H L, Chen S W, Yu X R. Growth characteristic and culture technology of Taiwan green jujube[J]. New Agricultural Technology, 2004(1): 8-9
[19] Yao Z W, Huang Q M. Analysis of agricultural climatic condition of the planting of Taiwan green jujube in Xinfeng area[J]. Guangdong Meteorology, 2004(4): 26-27
[20] Lu X K, Lin Q H, Zhuang W B. A preliminary report for the introduction experiment of Taiwan green jujube in Zhangzhou[J]. South China Fruits, 2012, 41(2): 95-97
[21] Xu Z H, Chen J J, Lin L F, et al. Analysis of low temperature injury to Taiwan green jujube in Zhangzhou by GIS[J]. Journal of Guangxi Meteorology, 2005, 26(S1): 12-13
[22] Chen Q X. Free-pollution planting of Taiwan green jujube[M]. Fuzhou: Fujian Science and Technology Publishing House, 2006: 18-19
[23] Huang G M, Liu W, Wang G L. The effect of low temperature on plantlet, flower morphology, florescence of fruit tree[J]. Guangdong Meteorology, 2010, 32(5): 39-41
[24] Chen J J, Wang J Y, Huang C R, et al. Risk analysis and regionalization of cold and freezing damage to Taiwan-based *Zizyphus mauritiana* in Fujian Province[J]. Chinese Journal of Eco-Agriculture, 2013, 21(12): 1537-1544
[25] Xu J H. Mathematical Method in Contemporary Geography[M]. Beijing: China Higher Education Press, 2002: 224-250
[26] Li L C, Chen J J, Lin J, et al. Using fuzzy similarity priority ratio to analyse climate similarity between Fujian and Taiwan for fruit tree cultivation[J]. Chinese Journal of Eco-Agriculture, 2013, 21(9): 1149-1156

Note: Figure translations are in progress. See original paper for figures.