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陕西省‘冬枣’气候优生区区划研究

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摘 要:【目的】进一步掌握陕西省优质‘冬枣’气候优生区的地域分布特征。**【方法】**采用1981—2018年全省98个国家气象站的日数据资料,结合‘冬枣’生物学特性,选取影响全省‘冬枣’生长发育的关键气候因子作为全省‘冬枣’气候优生区区划因子,采用模糊数学方法建立隶属函数,用层次分析法确定权重,三维二次趋势面法分区建立各区划因子模型,利用GIS绘制优生区区划因子的单因子细网格图层,最后通过模糊综合评价法得出全省‘冬枣’气候优生区区划图,按照优生区、适宜区、次适宜区、不适宜区将全省分为四个区。**【结果】**‘冬枣’种植的气候优生区和适宜区主要分布在关中中东部大部分地区的平原地带,陕北黄河沿线各县海拔低于900 m的浅山地带,呈径向分布;‘冬枣’种植的气候不适宜区主要分布在陕北的西部各县、陕南秦巴山区及秦岭山脉沿线海拔较高地区。**【结论】**陕西省‘冬枣’优生区和适宜种植区主要位于渭南市、阎良区、临潼区,长安区、鄠邑区、三原、泾阳、蓝田、周至的北部,府谷、神木、佳县、米脂、绥德、吴堡、清涧等低海拔地区,该区域地势平坦,土地肥沃,气候资源配置优势明显,适宜规模种植,建议在此区优先发展‘冬枣’种植产业。另外,影响此区‘冬枣’生长的主要气象灾害是果实成熟期的连阴雨及秋淋,应重点防御。

关键词:‘冬枣’;陕西省;优生区;区划;GIS技术

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Study on the regionalization of optimum areas for ‘Dongzao’ growing in Shaanxi province

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Abstract:【Objective】The study aims at clarifying the geographical distribution characteristics of the high-quality ‘Dongzao’ growing zones in Shaanxi province.【Methods】Based on the daily data with 98 national meteorological stations in the whole province from 1981 to 2018, the biological characteristics of ‘Dongzao’ were combined with eight key comprehensive climatic factors including negative accumulated temperature, annual maximum temperature, frost-free period, average temperature from March to May, sunshine hours from June to August, precipitation in September, sunshine hours in September, accumulated temperature during the whole growth period, which may influence the growth and development of ‘Dongzao’ in the whole province, so that they served as the optimum zoning index. The membership function of each region index was established by fuzzy mathematics method and the weight was determined by analytic hierarchy process. In addition, three-dimensional quadratic trend surface method was used to set up the index model for each region (northern Shaanxi, southern Shaanxi and central Shaanxi) and GIS method was used to draw the single-factor sub-grid layer of the whole province's ‘Dongzao’ zoning index. Finally, the whole province was divided into four zones including optimum zone, suitable zone sub-suitable zone and unsuitable zone. The optimum climatic zoning map for

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‘Dongzao’ was obtained by fuzzy comprehensive evaluation.【Results】The optimum zone and e suitable zone were distributed along the Yellow River in Northern Shaanxi and the middle and eastern parts of Guanzhong area. The annual average temperature in the optimum zone for ‘Dongzao’ growing was 10-14 ℃, the average temperature from the blooming to the young fruit set stage was 12-15 ℃, the frost-free period was 200-220 d and the annual precipitation was 400-600 mm. It was the optimum zone that developed ‘Dongzao’ industry in Shaanxi province with the aid of well matched water and heat resources, the gentle terrain, fertile soil and good site conditions. Secondly, some parts in the eastern part of the county along the Yellow River in northern Shaanxi and some parts in southern Shaanxi, the Yellow River coastal areas and the low hill areas with an elevation less than 800 m were also the optimum zone for ‘Dongzao’ growing. The suitable zone for ‘Dongzao’ growing was mainly distributed in the shallow mountain belt with an elevation less than 900 m along the Yellow River counties including west part of Fugu county, Shenmu county, Yulin city, Jiaxian county, Mizhi county, Wubao county, Suide county, Zizhou county, Qingjian county, Yanchuan county, Yanchang county, Hengshan county, etc. in northern Shaanxi. In these areas, the average temperature was 9-10 ℃, the average temperature from bud break to blooming was 11-13 ℃, the frost-free period was 170-190 d, and the annual precipitation was between 400-440 mm, the fertile soil and the well matched climate resources were very suitable for ‘Dongzao’ growing. The unsuitable areas for ‘Dongzao’ growing were mainly distributed in the western part of northern Shaanxi, the higher elevation areas along the Qinling Mountains as well as the mountainous areas, and the woodland and gully areas. In these areas, the terrain was complex, the altitude was high and the slope was abrupt, which was not suitable for ‘Dongzao’ growing.【Conclusion】The optimum and suitable areas for ‘Dongzao’ growing in Shaanxi province were mainly located in the low-altitude areas like Weinan city, Yanliang district，Lintong district, the north of Chang’an district, Huxian county, Sanyuan county, Jingyang county, Lantian county, the north of Zhouzhi county, Fugu county, Shenmu county, Jiaxian county, Mizhi county, Suide county, Wubao county and Qingjian county, the optimum zones had flat terrain, fertile soil and obvious advantages in climate resource allocation, which was suitable for large-scale planting. It was suggested to give priority to the development of ‘Dongzao’ growing industry in these areas. In addition, the main meteorological disasters that affected the growth of ‘Dongzao’ in this area included the continuous overcast rains and autumn shower during the fruit ripening period, which should give more concern. From the meteorological point of view, combed with the altitude, the climatic optimum zone for ‘Dongzao’ growing was obtained and it was also a prerequisite for trees to live and grow into forests with high quality and stable yield. Due to the lack of the introduction and cultivation efficacy by soil fertility factors and land usage status, the physiological and biochemical indexes of trees as well as soil and social factors should be combined to further enrich the results of the climatic optimum zones for ‘Dongzao’ growing, so as to make it more valuable for guiding introduction and cultivation in the future.

Key words: ‘Dongzao’; Shaanxi province; Eugenic zone; Regionalization; GIS

‘冬枣’是一种我国特有的优良晚熟鲜食枣品种，其果肉肉质细嫩多汁，甜酸可口，富含维生素C，因鲜食品质极佳而深受广大消费者喜爱。前些年‘冬枣’种植规模小，出现严重的供需不平衡，市场价格居高不下，致使全国各地开始不同程度地引种栽培[1-2]。有学者研究指出[3-6]，受当地气候条件影响，不同地区‘冬枣’引种栽种品质差异明显，各地‘冬枣’口感不一，果径差异大，果皮厚度也存在显著差异，如若早春气温偏低，‘冬枣’开花期将推迟，若在果实发育期不足120 d的地区栽培将表现出坐果率低、产量不稳、果实偏小、不能正常成熟、商品质量降低等现象。

目前，陕西‘冬枣’产业发展非常迅速，截至2018年，大荔县‘冬枣’栽种面积达3万hm²，总产量40万t。全省‘冬枣’种植区也出现由南向北不断拓展的趋势，在陕北红枣种植区也开始尝试引种栽培‘冬枣’，但陕西省地域广阔，南北跨越了3个气候带，气候类型多样，且地形地貌复杂，在进行栽培决策时，既要考虑影响鲜食‘冬枣’生长、分布的重要气候因素状况，也要考虑‘冬枣’正常开花结果、优质稳产对气候条件的要求，不能盲目引种栽培。前期学者[7-17]多围绕‘冬枣’花期病虫害、品质与种植区气候条件、遗传特性、灾害防御措施等方向开展研究，针对‘冬枣’气候优生区精细化区划方面的研究很少。笔者根据气候相似论，结合‘冬枣’优质生产区的气候条件，利用陕西省1:25万DEM数据建立气候因子的三维二次趋势面模型，得出全省‘冬枣’种植的气候优生区。本次区划打破以县域为区划单位使区划不够精细的弊端，使优生区区划结果更加精准，将为‘冬枣’产业布局、指导农民引种及科学栽培提供依据。

1 材料和方法

1.1 气象资料来源与处理

根据陕西省气象局气象信息中心获取98个国家气象站(1981—2018年)的日数据资料（包括日降水量、日平均气温、日照时数、气温日较差、日相对湿度），统计各站点≥10 ℃活动积温、负积温、不同时段（3—5月、6—8月、9月）气温、降水、日较差和日照时数等气候因子。陕西省1:25万DEM资料来源于陕西省农业遥感与经济作物服务中心。气象数据基础处理、相关分析、层次分析、三维二次趋势面模型均采用SPSS 17.0软件，优生区区划因子的单因子图层、综合区划图层制作采用ArcGIS 10.2软件。

1.2 区划方法

采用模糊数学方法，建立优生区区划因子的隶属函数；层次分析法确定优生区区划因子的权重；采用三维二次趋势面法分区（陕南、陕北、关中）建立优生区区划因子模型[18-23]，运用ArcGIS10.2软件将全省各站点的热量和降水量资源细化到30 m×30 m的细网格数据，建立全省‘冬枣’气候优生区区划因子的单因子细网格图层，最后通过模糊综合评价法得出全省‘冬枣’气候优生区区划图，并将全省分为四个区：优生区、适宜区、次适宜区、不适宜区。

2 结果与分析

2.1 区划因子的选择

‘冬枣’优生区区划因子是通过分析影响大荔县（1981—2018年）‘冬枣’发育28个气候因子，其中包括‘冬枣’全生育期气候因子（≥10 ℃积温、负积温、年降水量、年平均气温、年最高气温、年最低气温、无霜期、年日照时数）、‘冬枣’萌动-花期（3—5月平均气温、降水量、日照时数、相对湿度）、‘冬枣’幼果期-果实快速膨大期（7月平均气温、降水量、日照时数、相对湿度，8月平均气温、降水量、日照时数、相对湿度，6—8月平均气温、降水量、日照时数、相对湿度）、‘冬枣’成熟期（9月平均气温、降水量、日照时数、相对湿度）。分析气象因子的相关性，得出与‘冬枣’显著相关的气候因子，结合前期‘冬枣’适宜气候条件分析研究成果，选取≥10 ℃积温、负积温、年最高气温、无霜期、3—5月平均气温、6—8月日照时数、9月降水量、9月平均气温等8个显著影响‘冬枣’生长发育的气候因子作为‘冬枣’优生区区划的区划因子，并确定各区划因子的适宜性指标（表1）。

表1 ‘冬枣’气候优生区的适宜性指标

Table 1 The climatic regionalization index for ‘Dongzao’

气象要素 Meteorological factor	最适宜 Optimum	适宜 Suitable	不适宜 Un-suitable
≥10 ℃积温 ≥10 ℃ accumulated temperature/(℃·d)	[5 000，5 210]	[3 450，5 000)	>5 210，<3 450
无霜期 Frost-free period/d	[217，235]	[201，217)	>235，<201
最高气温 Maximum temperature/℃	[40，42.5]	[37.1，40）	>42.5，<37.1
负积温 Negative accumulated temperature/(℃·d)	[-123，-77]	[-77，-43)	>-43，<-123
3—5月平均气温 March to May temperature/℃	[9.2，14.0]	[5.4，9.2)	>5.4，<14.0
6—8月日照时数 June to August sunshine/h	[630，710]	[580，630)	>710，<580
9月平均气温 September average temperature/℃	[19.9，21.3]	[18.7，19.9)	>21.3，<18.7
9月降水量 September precipitation/mm	[70，103]	[103，140)	>140，<70

2.2　‘冬枣’气候指标的隶属函数和权重确定

根据‘冬枣’气候优生区的适宜性指标，采用模糊数学方法分别建立隶属函数，各区划因子的隶属函数见表2。

表2　‘冬枣’优生区区划指标的隶属函数表

Table 2　The Membership Function Table of Regionalization Index of jujube

区划因子 Zone factor	隶属函数 Membership function	区划因子 Zone factor	隶属函数 Membership function
≥10 ℃积温 ≥10 ℃ accumulated temperature/(℃·d)	$\mu(x_i)=\begin{cases}1 & 5000\le x_i\le 5210\\ \dfrac{x_i-3450}{550} & 3450\le x_i<5000\\ 0 & x_i>5210, x_i<3450\end{cases}$	无霜期 Frost-free period/d	$\mu(x_i)=\begin{cases}1 & 217\le x_i\le 235\\ \dfrac{x_i-201}{16} & 201\le x_i<217\\ 0 & x_i<201, x_i>235\end{cases}$
最高气温 Maximum temperature/℃	$\mu(x_i)=\begin{cases}1 & 40.0\le x_i\le 42.5\\ \dfrac{x_i-37.1}{2.9} & 37.1\le x_i<40.0\\ 0 & x_i>42.5, xi<37.1\end{cases}$	3—5 月平均气温 March to May temperature/℃	$\mu(x_i)=\begin{cases}1 & 9.2\le x_i\le 14.0\\ \dfrac{x_i-5.4}{3.8} & 5.4\le x_i<9.2\\ 0 & x_i<5.4, x_i>14.0\end{cases}$
6—8 月日照时数 June to August sunshine/h	$\mu(x_i)=\begin{cases}1 & 630\le x_i\le 710\\ \dfrac{x_i-580}{50} & 580\le x_i<630\\ 0 & x_i>710, x_i<580\end{cases}$	9 月降水量 September precipitation/mm	$\mu(x_i)=\begin{cases}1 & 103\le x_i\le 140\\ \dfrac{x_i-70}{33} & 70\le x_i<103\\ 0 & x_i>140, x_i<70\end{cases}$
9 月平均气温 September average temperature/℃	$\mu(x_i)=\begin{cases}1 & 19.9\le x_i\le 21.3\\ \dfrac{x_i-18.7}{1.2} & 18.7\le x_i<19.9\\ 0 & x_i<18.7, x_i>21.3\end{cases}$	负积温 Negative accumulated temperature/(℃·d)	$\mu(x_i)=\begin{cases}1 & -123\le x_i\le -77\\ \dfrac{x_i+77}{34} & -77<x_i\le -43\\ 0 & x_i<-123, x_i>-43\end{cases}$

2.3　全省气候因子三维二次预测模型

考虑到陕西气候资源空间分布格局的复杂性，实行分区域建模，即在建立≥10 ℃积温、负积温、年最高气温、无霜期、3—5 月平均气温等优生区区划因子的细网格资料时将陕西分为陕北、关中、陕南3个区。首先将经度、纬度、海拔按照三维二次趋势面展开，再利用逐步回归方法建立推算模型，最后利用 GIS 软件将全省各气象观测站资料气候资源推算到 30 m×30 m 空间分辨率的细网格上，建立各区划因子与大地形因子经度、纬度及海拔的关系式，全省≥10 ℃积温的三维二次趋势面逐步回归模型见表3，其余区划因子的模型从略。

2.4　优生区综合评价图层

根据层次分析确定优生区区划因子的权重，区

表3　陕西省≥10 ℃积温三维二次趋势面逐步回归模型

Table 3　The stepwise tegression model of three-dimensional quadratic trend surface of accumulated temperature ≥10 ℃ in Shaanxi province

地域 Zone	模型 Model	样本数 Sample size	相关系数 Correlation index	F	检验水平 Test level
陕北 Northern Shaanxi	y=44 005.526+4.452λ−2 289.371θ+34.586θ^2+0.002h^2+0.010λh −0.185θh	26	0.881	10.373	0.01
关中 Central Shaanxi	y=1 981.797+0.658λ^2−2.051E−4h^2−1.269$\lambda\theta$−0.028θh	41	0.971	14.32	0.01
陕南 Southern Shaanxi	y=12 572.229−82.539λ+0.001h^2+0.621$\lambda\theta$−0.441θh+0.109λh	27	0.970	6.449	0.01

注：y 为积温估算值，λ 为经度，θ 为纬度，h 为海拔，各模型的相关系数均大于 0.85，通过 0.01 的显著性水平检验。

Note: y is the estimated value of accumulated temperature, λ is longitude, θ is latitude, h is altitude, the correlation coefficient of each model is greater than 0.85 and tested by the significance level of 0.01.

划因子的判断矩阵和权重见表4；采用模糊综合评价法，利用小网格数据的回归模型、隶属函数式分别得出各区划因子的评价栅格图，并将单因子评价图层与权重相乘后叠加，得出全省综合评价栅格图层，按照综合评价法将全省依次划分为优生区、适宜区、次适宜区和不适宜区（图1）。

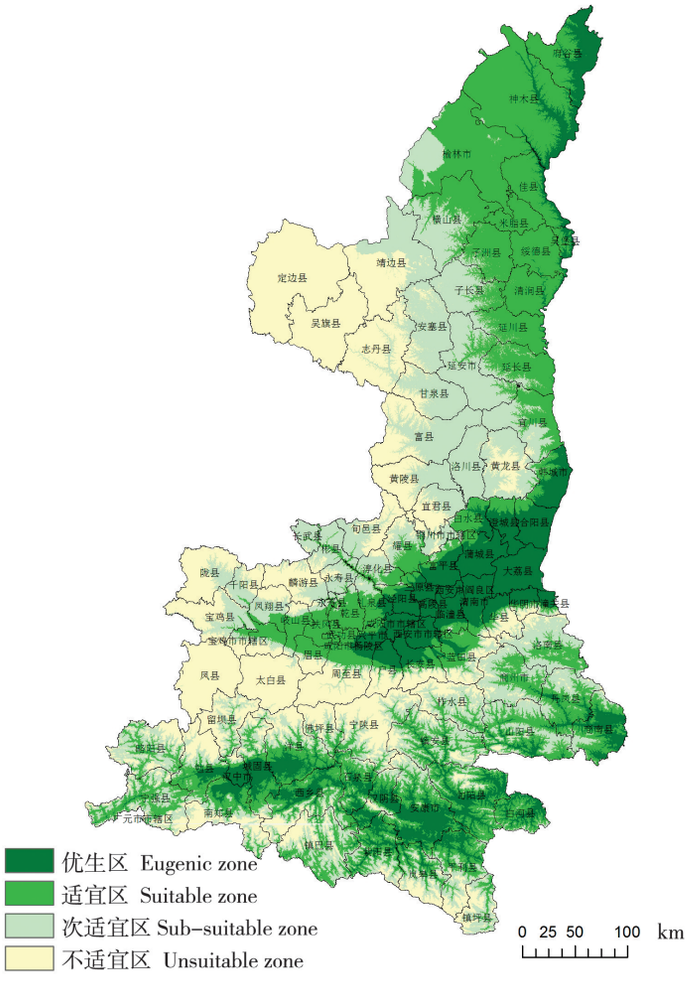
表4 ‘冬枣’优生区区划因子的判断矩阵和权重

Table 4 The judgment matrix and weight of the division factors in the eugenics zone of ‘Dongzao’

	AT	FAT	TM	FD	T2	R	T1	E1
≥10 ℃积温 ≥10 ℃ accumulated temperature（AT）	1	1	1	3	1/3	1/4	1/2	1
负积温 Negative accumulated temperature（FAT）	1	1	1	3	1/3	1/3	1/2	1
最高气温 Maximum temperature（TM）	1	1	1	3	1/3	1/3	1/4	1
无霜期 Frost-free period（FD）	1/3	1/3	1/3	1	1/6	1/6	1/4	1/4
9月平均气温 September average temperature（T2）	3	3	3	6	1	3	2	1/2
9月降水量 September precipitation（R1）	4	3	3	6	1/3	1	2	1/3
3—5月平均气温 March to May temperature（T1）	2	2	4	4	1/2	1/2	1	1/2
6—8月日照时数 June to August sunshine（E1）	1	1	1	4	2	3	2	1
权重 Weightiness	0.23	0.09	0.08	0.03	0.08	0.17	0.17	0.17

注：‘冬枣’优生区区划因子判断矩阵的最大特征根 λ_{max}=7.57，具有满意的一致性，不用再进行调整。

Note: The maximum characteristic root λ_{max}=7.57 in the judgment matrix of the division factors in the eugenics zone of ‘Dongzao’ has satisfactory consistency and no further adjustment is needed.



地图来源：陕西省气象局。Map source: Shaanxi Meteorological Bureau.

图1 陕西省‘冬枣’气候优生区区划图

Fig. 1 The climatic eugenics map of ‘Dongzao’ in shaanxi province

2.5　优生区区划结论

优生区：‘冬枣’种植优生区主要分布在关中中东部大部分地区的平原地带，该区年平均气温为10~14 ℃，花序出现至幼果期平均气温为12~15 ℃，无霜期200~220 d，年降水量在400~600 mm，本区水热资源匹配良好，加之地势缓、土壤肥厚、良好的立地条件，是陕西省发展‘冬枣’产业的最优区域。其次在陕北沿黄各县的东部局地及陕南局地等海拔低于800以下的黄河沿岸地带和低山丘陵地带也属于‘冬枣’种植的最优区。

适宜区：‘冬枣’种植适宜区主要分布在陕北沿黄各县海拔低于900 m的浅山地带，呈径向分布，其中包括府谷西部、神木、榆林市、佳县、米脂、吴堡、绥德、子洲、清涧、延川、延长、横山等地，该区年平均气温为9~10 ℃，发芽至花序出现期平均气温为11~13 ℃，无霜期为170~190 d，年降水量介于400~440 mm，本区土地肥沃，气候资源配置良好，适宜‘冬枣’种植。关中中东部局地和陕南部分低洼地带也属于‘冬枣’种植的气候适宜区。

次适宜区：‘冬枣’种植次适宜区主要分布在陕北中部、关中东部局地的中低海拔地带，该区年平均气温为9~10 ℃，年降水量介于480~500 mm，发芽至花序出现期平均气温为10~12 ℃，无霜期为170~180 d，本区‘冬枣’发芽初期温度略低，无霜期略短，气候资源能基本满足‘冬枣’正常生长发育需求，但受地形影响，该区种植区较分散，易受倒春寒等气象灾害影响。

不适宜区：‘冬枣’种植不适宜区主要分布在陕北的西部，陕南秦巴山区及秦岭山脉沿线海拔较高的地区，以山地、林地和沟壑区为主，地形复杂，海拔高坡度大，不适宜‘冬枣’种植。

3　讨　论

本研究分析1981—2018年大荔县‘冬枣’全生育期和关键生育期的气候特征，得出大荔县多年年平均气温为13.6 ℃、≥10 ℃积温为4 603.8 ℃·d、年日照时数为2 275.8 h、无霜期为217 d、负积温为76.6 ℃·d，该区域热量充足，‘冬枣’果实膨大期降水充沛，负积温累积量适宜‘冬枣’安全越冬，立地条件非常适宜‘冬枣’栽种，这与樊保国等[24]、刘金玉等[25]研究沾化、黄骅等地‘冬枣’适宜气象条件的结果相同。同时大荔‘冬枣’种植规模大、产量高、品质佳而畅销国内外，苏娟娟等[2]在陕北红枣种植区引种试验栽培‘冬枣’，‘冬枣’苗均选自大荔县‘冬枣’种植乡镇，故笔者选择大荔县‘冬枣’生育期长期气候特征为‘冬枣’优生区气候特征，分析并选择与‘冬枣’物候期显著相关的气候因子开展‘冬枣’气候优生区区划研究。

陕西地形地貌特征复杂，如何将各气象站气候资源进行精确插值也是提高气候区划准确性的关键因素之一，袁爱民等[26]研究表明，三维二次趋势面法与常规插值法（反距离权重、克里格、径向基函数）对比，能提高插值模拟精度，更适用于复杂地形气候指标空间插值。赵平伟等[27]研究指出，使用三维二次趋势面法，积温插值后平均相对误差在5%以下，平均气温插值后平均绝对误差低于5%。故笔者根据陕西地形地貌及气候特征将全省分为三个区分别进行建模，并生成30 m×30 m的单因子细网格区划图层，确保各要素在空间分布的准确性，提高全省‘冬枣’优生区区划的精细化程度。但本次‘冬枣’气候优生区划在气象角度出发结合海拔得出全省‘冬枣’的气候优生区域，也只是满足‘冬枣’成活成林、优质稳产的先决条件，未考虑到土壤肥力因子、土地利用现状等对引种栽培的影响，后期还应结合树木生理生化指标、土壤、社会因素等进一步完善和丰富‘冬枣’气候优生区区划结果，使其更具引种栽培指导价值。

4　结　论

‘冬枣’气候优生区区划采用层次分析法确定区划因子权重、三维二次趋势面法提高气候因子在复杂地形中的插值精度，结合‘冬枣’不同生育期生物学特征，使全省‘冬枣’气候优生区区划结论能够在气候条件上满足‘冬枣’优质生产，较以行政区域为单元的区划结论，结果更为精确。区划研究结果表明，‘冬枣’优生区和适宜种植区主要位于关中中东部大部分地区的平原地带及陕北黄河沿线各县海拔低于900 m的浅山地带，主要包括渭南市、阎良区、临潼区，长安区、鄠邑区、三原、泾阳、蓝田、周至的北部，府谷、神木、佳县、米脂、绥德、吴堡、清涧等低海拔地区，该区域热量充足，果实膨大期光照充足、降水充沛，负积温累积量适宜‘冬枣’安全越冬，可产业化种植‘冬枣’，但应重点关注秋季连阴雨或秋淋天气对‘冬枣’的影响。陕南气候优生区

和适宜区受当地地形特征影响，多集中在河谷和山间盆地，且空间差异比较显著，故在该区域引种栽种时还需综合考虑地形等因素综合评估。

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