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Study on Suitable Producing Areas of *Wolfiporia extensa* (Peck) Ginns by TCMGIS-II

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Abstract Based on database of ecological factors and geographic information space analysis method, we analyzed suitability of *Wolfiporia extensa* (Peck) Ginns producing regions, in the hope of providing reference for scientific zoning and cultivation. Ecological factors we analyzed mainly include temperature, altitude, and soil. Our analysis shows that Hubei, Anhui, Yunnan, Guizhou and Sichuan provinces are regions that have highest similarity with original producing areas of *Wolfiporia extensa* (Peck) Ginns. This is basically consistent with actual conditions. In addition, we predicted some regions (for example, Gansu) that have not been recorded in literature, which provides scientific and reliable data support for seed introduction and expansion of *Wolfiporia extensa* (Peck) Ginns. Using the GIS-based program for the distribution prediction of traditional Chinese medicine (TCMGIS-II) to analyze suitability of *Wolfiporia extensa* (Peck) Ginns producing regions is scientific and accurate, and will provide important reference for seed introduction, cultivation and scientific zoning of *Wolfiporia extensa* (Peck) Ginns.

Key words *Wolfiporia extensa* (Peck) Ginns, Ecological factors, Suitability of producing regions

Wolfiporia extensa (Peck) Ginns (formerly known as *Poria cocos* F. A. Wolf) is a fungus in the Polyporaceae family. It is a wood-decay fungus but has a terrestrial growth habit. Normal in nature and sweet and bland in taste, it is attributive to heart, lung, attributive to heart and kidney, and has functions of water-discharging and damp-clearing, invigorating the spleen and tranquilizing heart[1]. It has many common names, such as hoelen, poria, tuckahoe, China root, Fuling, Fushen, and matsuhodo. With triterpeneid effective composition, such as Pachymic acid and Pachymaran, *Wolfiporia extensa* (Peck) Ginns is one type of raw materials of Guizhi Fuling Capsule and is a type of traditional health food[2-3]. Wide state of *Wolfiporia extensa* (Peck) Ginns is widely distributed and has been found in many parts of China. The *Identification of Production of Meteria Medica* has records that the most genuine *Wolfiporia extensa* (Peck) Ginns comes from Yunnan. Under the guidance of traditional Chinese medicine (TCM) theory, with over 2 000 years of clinical use, seed introduction and expansion, and cultivation, China has gradually established two genuine producing regions. One is wild *Wolfiporia extensa* (Peck) Ginns producing region in Lijiang of Yunnan Province, the other is artificial cultivation area in Dabie Mountain, including Luotian, Yingshan, and Macheng of Hubei Province, Yuexi, Huoshan and Jinzhai in Anhui Province, and Shangcheng in Henan Province[4]. To expand ranges of producing areas and ensure the quality of *Wolfiporia extensa* (Peck) Ginns, we determined suitable cultivation regions and optimal ecological factors influencing growth and development of *Wolfiporia extensa* (Peck) Ginns on the basis of database of ecological factors and geographic information space analysis method.

The Traditional Chinese Medicine Geographic Information System (TCMGIS) software is to analyze data based on national foundation geographic information database, climatic factor database, soil database and the third time national Chinese medicine census database, and analyze regions with closest similarity to genuine producing regions of *Wolfiporia extensa* (Peck) Ginns[5]. With the aid of TCMGIS, we extracted ecological factors of many sample points in main producing regions and genuine producing regions of *Wolfiporia extensa* (Peck) Ginns. In combination with literature analysis, we determined scope of most suitable ecological factors, obtained quantitative and space information of suitable producing regions, which will benefit the improvement of quality management regulation (*Good Agricultural Practices* or *GAP*) of *Wolfiporia extensa* (Peck) Ginns production and promote its sustainable utilization.

1 Materials and methods

1.1 Current situations and data collection of *Wolfiporia extensa* (Peck) Ginns Wild *Wolfiporia extensa* (Peck) Ginns grows in 30 - 90 cm weak acid soil that has good drainage and well ventilation or on dry pine root facing the sunny side. Wild resources of *Wolfiporia extensa* (Peck) Ginns are mainly distributed in Yunnan and Guizhou provinces. The old producing regions include Hubei, Anhui and Henan provinces. Producing regions through seed introduction include Sichuan, Guizhou, Guangdong, Guangxi, Chongqing, Shaanxi, Zhejiang, Jiangsu, Shandong, Liaoning, and Taiwan[6].

Through on-the-spot survey in Luotian of Hubei Province, Li-

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jiang of Yunnan Province and Shangcheng of Henan Province, the Biological Resource Center of Institute of Microbiology of Chinese Academy of Sciences (IMCAS-BRC) and relevant literature on distribution of *Wolfiporia extensa* (Peck) Ginns, as well as GAP base information, we selected 1 039 sample points in 19 counties of 8 provinces, including Shilongba Township in Huaping County, Jinping Township of Jingdong County, Caojian Township of Yunlong County, Pingshan Township of Luquan County, Anban Township of Zhenyuan County, Nuofu Township of Lancang County, and Simao Township of Menglian County in Yunnan Province, Jiuzihe Township, Shenglihe Township, and Baimiaohe Township of Luotian County, Taohe Township of Yingshan County, Muzidian Township, Futianhe Township and Huangtugang Township of Macheng County in Hubei Province, Manshuihe Township of Huoshan County, Changpu Township, Tiantang Township, Baojia Township, Laibang Township, and Hetu Township of Yuexi County, Yanzihe Township, Nanxi Township, and Shuanghe Township of Jinzhai County in Anhui Province, Fushan Township of Shangcheng County in Henan Province, Sifangshan Township, Gaoqiao Township and Longan Township of Liping County in Guizhou Province, Jinwutang Township of Suining County and Mashi Township of Jianghua County in Hunan Province, Chener Township of Luonan County in Shaanxi Province, and Yuanbao Township of Tongyuan County in Fengcheng City of Liaoning Province.

1.2 Analysis method of scope of ecological factors According to distribution situation and ecological characteristics of genuine producing regions of *Wolfiporia extensa* (Peck) Ginns, and based on administrative map of province, county and township of the state, 1 km^2 climatic grid database (mean value of 30 years of climatic data from 1971 to 2000), 1∶4 million soil database and 1∶1 million terrain database, we used TCMGIS system to conduct point and area overlay analysis and determined grid position of sample points in climatic map and soil map, so as to obtain corresponding meteorological and soil data grid value of the sample point. Using mathematical statistics method, we obtained scope of most suitable ecological factors for *Wolfiporia extensa* (Peck) Ginns.

1.3 Analysis method of suitable ecological regions On the principle of biological introduction of seed, we calculated the grid value of each drawing layer by the standardization method of mean absolute deviation, *i.e.* the formula of mean absolute deviation:

$$S_f = \frac{1}{n}(|x_{1f} - m_f| + |x_{2f} - m_f| + \cdots + |x_{nf} - m|$$

where $m_f = \frac{1}{n}(x_{1f} + x_{2f} + \cdots + x_{nf})$, standardization value $Z_{if} = \frac{x_{if} - m_f}{s_f}$, and data of each grid layer normalized to 0 to 100; the grid statistics distance formula adopts weighted Euclidean distance, *i.e.* $d_{ij} = [\sum_{k=1}^{n} |x_{ik} + x_{jk}|^2]^{\frac{1}{2}}$. In this formula, S_f signifies mean absolute deviation, m_f stands for mean value of n values, Z_{if} is standard value of i-th factor, and d_{ij} represents Minkowski distance. Then, we calculated statistic distance of most suitable factor corresponding to each grid. For statistic distance obtained, we divided them into different distance level according to equal distribution method, so as to determine regions that have different similarity with genuine producing regions of *Wolfiporia extensa* (Peck) Ginns[7-8].

2 Results

2.1 Scope of ecological factors of *Wolfiporia extensa* (Peck) Ginns sample points According to analysis method under section 1.2, we obtained scope of ecological factors of *Wolfiporia extensa* (Peck) Ginns sample points: average temperature of the whole year: 18.1 to 24.7 ℃; average temperature of January: 0.95 to 11.6 ℃; the lowest temperature of January: −19.1 ℃; average temperature of July: 20.91 to 26.39 ℃; highest temperature in July: 32.9 ℃; average precipitation of the whole year: 1 025 to 1 544 mm; mean annual hours of sunshine: 1400 to 2296 hoa−1; annual relative humidity: 61.8 to 78.4%; altitude: 696 to 830 m; soil: lateritic red, red, yellow, yellowish-brown, brown, purple and rice soil.

2.2 Mathematical statistics and most suitable scope of ecological factors Through mathematical statistics of scope of ecological factors of *Wolfiporia extensa* (Peck) Ginns sample points, we obtained coefficient of variation of each factor. The result shows that the coefficient of variation of 4 factors (average temperature of the whole year, annual relative humidity, mean annual precipitation, and average temperature of July) is below 20%, indicating growth of *Wolfiporia extensa* (Peck) Ginns have strict requirements for these factors; while the coefficient of variation of 3 factors (altitude, mean annual hours of sunshine and average temperature of January) is higher than 20%, indicating growth of *Wolfiporia extensa* (Peck) Ginns have general requirements for these factors, so these factors are secondary limiting factors of growth and distribution of *Wolfiporia extensa* (Peck) Ginns. The scope of most suitable ecological factors is calculated through the formula of peak width at half-height (PWHi = 2.354 Si). The upper limit of most suitable scope is Xi + 0.5 PWHi and the lower limit is Xi-0.5PWHi (Xi is the average value of the index, Si is the standard deviation of the index, and weight value of each factor is 0.1). Results are listed in Table 1.

2.3 Analysis results of suitable ecological regions of *Wolfiporia extensa* (Peck) Ginns According to the scope of most suitable ecological factors obtained, by the analysis method under section 1.3, we adopted TCMGIS system to conduct the grid-based hierarchical spatial clustering algorithm, and obtained regional distribution of 90 to 100% ecological similarity of *Wolfiporia extensa* (Peck) Ginns (shown in Fig.1). This region mainly includes Hubei, Anhui, Yunnan, Guizhou, Sichuan, Chongqing, Zhejiang, Fujian, Guangdong, Guangxi, Shaanxi, Liaoning and Henan provinces (or cities) (shown in Fig.2).

Table 1 Mathematical statistics of ecological factors of *Wolfiporia extensa* (Peck) Ginns sample points

Ecological factors	Mean value ± Standard error	Standard deviation	Coefficient of variation // %	Scope of most suitable ecological factors
Average temperature of the whole year	21.43 ± 0.08	2.83	13.22	18.1 to 24.7
Average temperature of January	6.28 ± 0.14	4.52	71.98	0.95 to 11.6
Average temperature of July	23.65 ± 0.07	2.33	9.83	20.91 to 26.39
Annual relative humidity	763.04 ± 1.77	56.948	7.46	61.8 to 78.4
Mean annual precipitation	1 285.40 ± 6.86	220.428	17.15	1 025 to 1 544
Mean annual hours of sunshine	1 848.63 ± 11.84	380.726	20.59	1 400 to 2 296
Altitude	1 127.53 ± 17.02	547.260	48.54	696 to 830

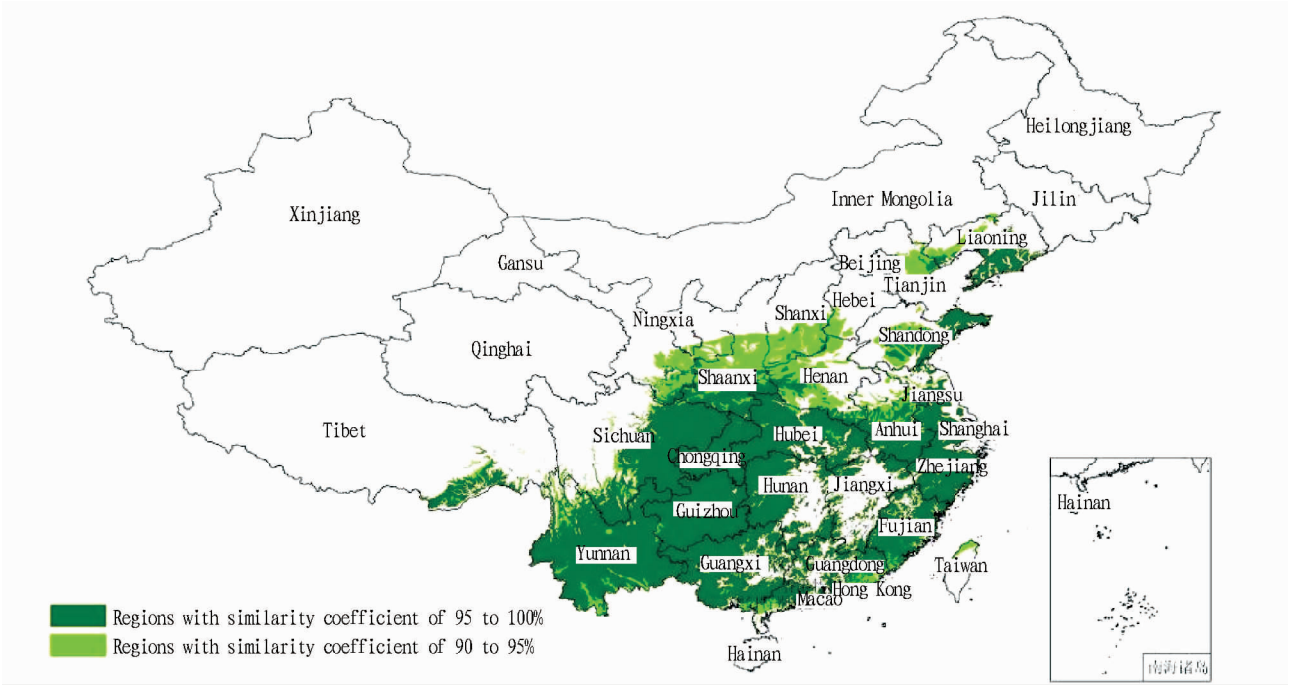

Fig. 1 National distribution of *Wolfiporia extensa* (Peck) Ginns with ecological similarity of 90 to 100%

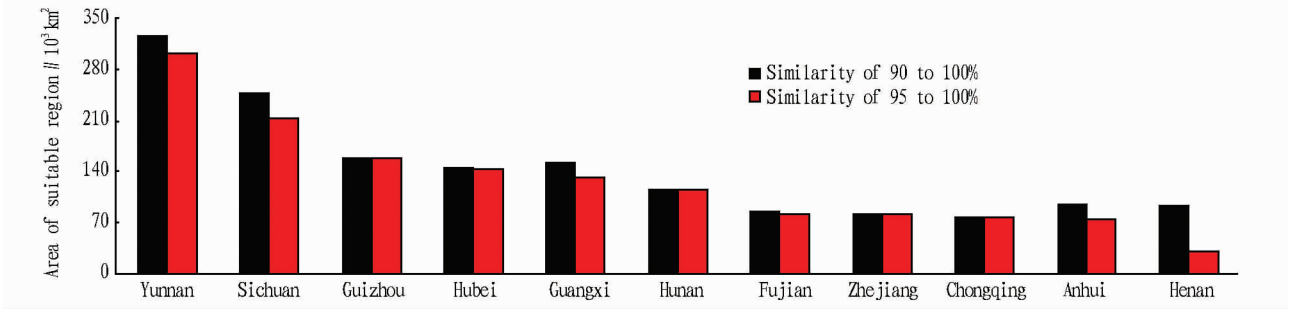

Fig. 2 Area of regions with ecological similarity of 90 to 100% of *Wolfiporia extensa* (Peck) Ginns

3 Discussion

3.1 Comparison of analysis results and actual distribution

According to on-the-spot survey and consultation of literature, we found that there are two major regions producing *Wolfiporia extensa* (Peck) Ginns: one is wild *Wolfiporia extensa* (Peck) Ginns producing region in Lijiang of Yunnan Province, the other is artificial cultivation area in Dabie Mountain, including Luotian, Yingshan, and Macheng of Hubei Province, Yuexi, Huoshan and Jinzhai in Anhui Province, and Shangcheng in Henan Province. The collected data shows that there is large cultivation area in Jingning of Zhejiang Province, Yongtai of Fujiang Province, Xinfeng of Guangdong Province, Longsheng and Pingxiang of Guangxi Zhuang Autonomous Region, Jingzhou and Suining of Hunan Province, Liping and Jinping of Guizhou province[9-10]. This data overlays analysis results of suitability of *Wolfiporia extensa* (Peck) Ginns producing region by TCMGIS, verifies the science and accuracy of this system to a certain extent, and provides theoretic basis for seed introduction and cultivation of traditional Chinese medicinal materials.

3.2 Recommendation for seed introduction and cultivation

In the big tide of "Back to Nature", traditional Chinese medicine gets an unprecedented opportunity, but also suffers a huge

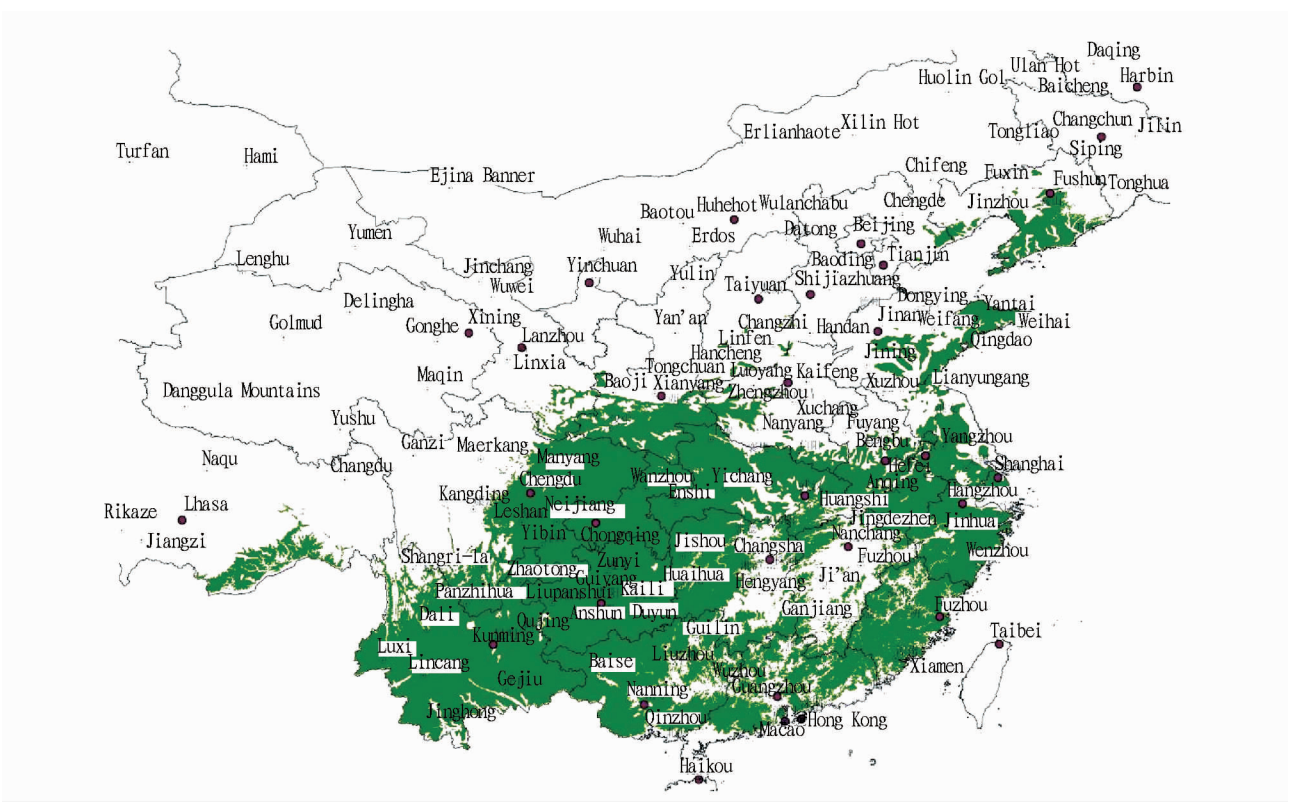

Fig. 3 Major regions with ecological similarity of 95 to 100% of *Wolfiporia extensa* (Peck) Ginns

impact and challenge. To avoid exhaustion of wild traditional Chinese medicinal resources and ensure sustainable development, we recommend combining actual situations in the practical production, carrying out production and utilization of resources with macro-management system of traditional medicinal material resources, and making pertinent development plan[11]. In the course of seed introduction and cultivation, it is recommended to bring into full play guiding role of information and overcome blindness of medicinal material producers[12].

Research on suitability of traditional medicinal material producing regions indicates correlation between quality awareness of traditional medicinal material types and ecological and environmental awareness of producing regions, and strengthens the idea of "suiting measures to local conditions and planting in suitable regions". If there is distribution of wide medicinal materials, it is preferred to introduce such wide material and enhance cultivation of new types of traditional Chinese medicinal materials[13]. When introducing traditional Chinese medicinal materials, apart from considering similarity of natural environment, it is also required to pay attention to zoning of traditional Chinese medicinal materials, to ensure effectiveness of medicinal materials to the utmost degree[14]. Analysis of suitability of *Wolfiporia extensa* (Peck) Ginns producing regions is helpful for carrying out on-the-spot seed introduction, reducing blindness of seed introduction, and guide practical production.

At present, artificial seed introduction and cultivation of *Wolfiporia extensa* (Peck) Ginns are limited by many factors, such as pine varieties, slope of cultivation hillside, quantity of microorganism in soil, content of tracing elements, and human factors. Parasitic source suitable for growth of *Wolfiporia extensa* (Peck) Ginns mainly includes masson pine, Huangshan pine, Yunnan pine and Japanese red pine; gentle slope can provide basic conditions of humidity and sunshine; as a type of wide spread fungi, quantity of microorganism in soil and content of tracing elements play an important role in the growth of *Wolfiporia extensa* (Peck) Ginns. Besides, *Wolfiporia extensa* (Peck) Ginns has higher requirement for humidity and temperature. Above 35 ℃, hyphae are subject to aging; below 10 ℃, it will grow very slowly; below 0 ℃, hyphae will stay in resting state. Continuous cropping is not suitable in *Wolfiporia extensa* (Peck) Ginns cultivation field[15].

Stable development of traditional Chinese medicinal material industry is based on stable supply of medicinal materials. Therefore, seed introduction and cultivation of *Wolfiporia extensa* (Peck) Ginns should be carried firstly in regions with ecological similarity of 95 to 100% (shown in Fig. 3).

Besides, it should establish production base in combination with local situations, expand scopes and look for regions with close similarity with suitable producing regions[16]. Meanwhile, it should take full consideration of those factors not included into the TCMGIS system, such as soil fertility, content of tracing elements and quantity of microorganism in soil (and plant diseases and insect pests), slope, and pine types. Finally, it is required to further study whether medicinal material quality is acceptable, if efficacy drops, and change of pharmacological action in the course of seed introduction and cultivation.

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reduction. An important role of applying GTAP-E model is the impact of analyzing the implementation of this policy on the agricultural sector. As we all know, at this stage, the main mode of production of the agricultural sector is the household responsibility system. In order to improve the income of the farmers and inspire the enthusiasm of the farmers to grow food crops, government has abated the agricultural tax, and given subsidies in food and farm machinery. From a long-term perspective, with the deepening of China's modern agriculture construction, scale land management, and burgeoning of agricultural enterprises, the feasibility of the implementation of the carbon tax can not be excluded. Therefore, this study can be used as a prospective study of greenhouse gas emission reduction.

Finally corresponding recommendations are put forward as follows:

(1) China has emitted the most emission of CO_2 greenhouse gases, and this trend is more pronounced in the future. Therefore, in the face of global climate change, China can reduce non-CO_2 emission, to reduce the international pressure of CO_2 emission reduction in China, and provide more flexible space and policy options for China's low-carbon economy.

(2) High carbon tax could result in high emission reduction of non-CO_2, but there is little difference in the policy efficiency between the high carbon tax and low carbon tax. Therefore, in the implementation of carbon tax policy of non-CO_2 emission reduction, the carbon tax should be controlled at a lower level. This study derives that 30 U. S. dollars / t carbon is reasonable, so that the emission reduction policy can achieve the best emission reduction target, and have the minimum negative impact on the economy.

(3) It is necessary to take full advantage of international clean energy carbon trading mechanism, actively adjust the non-CO_2 emission target, and fight for dominance in the international non-CO_2 emission trading.

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