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RESOURCE STOCK, AGE STRUCTURE, AND SEED YIELD PREDICTION OF *FERULA SINKIANGENSIS* K.M. SHEN

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Abstract

Ferula sinkiangensis K.M. Shen (FS) is an endemic species in Xinjiang, China. It has extremely high economic and medicinal value but is on the brink of extinction. A comprehensive survey of the distribution area of FS was conducted to study its resource stock, age structure and yielding capacity of seeds. Results show that there is one existing distribution area of FS with an area of 322.84 hm^2 and a total plant quantity of 907,100. The age structure of FS population is reasonable showing a growing type of population. After low-temperature treatment and indoor germination of the seeds of FS, the utilization efficiency of seeds was increased by 15.45 times and 1165.81 times respectively. The establishment of the original habitat protection zone has played a huge role in promoting the recovery of the population of FS and the indoor germination of seeds would greatly alleviate the problem of seeds shortage of FS.

Introduction

Ferula sinkiangensis K.M. Shen, belongs to Umbelliferae, is a short-lived perennial desert plant that blooms and bears fruit once in early spring (He and Tan 2002). It is a unique species in Xinjiang, China and sparsely distributed in the Yili Valley. It is classified as a national Class II protected wild plant and is listed in the "National Key Plant Protection List". In 2012, there were only 3191 individuals of *Ferula sinkiangensis* with a cluster leaf diameter of more than 0.3 meters, and the species is at risk of extinction (Xie *et al*. 2024).

Ferula sinkiangensis is a precious medicinal plant with anti-inflammatory and anticoagulant effects. It can treat diseases such as gastric ulcers, gastric cancer and cervical cancer (Xiong *et al.* 1993, Li *et al*. 2007, Yang *et al*. 2018, Muguli *et al*. 2021). It is a species used in traditional medicine by ethnic minorities such as Mongolian, Uyghur and Tibetan. It was officially included in the 1977 edition of the Chinese Pharmacopoeia as a legally used traditional Chinese medicine. Asafetida gum, produced from FS, is its main medicinal substance and is priced at over 10,000 yuan per kilogram (Li *et al*. 2016). If artificial cultivation of FS is achieved, it will open the door of enormous economic potential.

Ferula sinkiangensis seeds production requires plants to reach an age of over 8 years (He and Tan 2011). Additionally, the annual germination rate in the field is only 0.003 (Li *et al*. 2008). The survival rate is greatly affected by hot and dry weather conditions that occur after seedling germination. The limited seeds yield and low utilization efficiency of FS pose significant challenges for expanding its wild population and implementing field planting initiatives.

There are few species of FS in narrow ranges and one of the important reasons is habitat destruction (Karaer and Celep 2007, Faiz and I-Abas 2019) followed by a sharp decline in population and thus the extinction (Manole and Banciu 2018). In 2015, the Ministry of Agriculture

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and Rural Affairs of China established a protected area in the Yili Valley to prevent FS from being consumed by cattle and sheep and from being dug up and harvested by human with the aim of promoting the rapid recovery of the FS population. The factors that affect the speed and effectiveness of plant population recovery include species distribution area, population size, individual number, age structure, reproductive method and ability (Malik *et al*. 2016). Therefore, this study conducted a comprehensive survey of the distribution area of FS to answer the following three questions: (1) What are the existing resources of FS? (2) What is the age structure of the FS population? (3) What is the predicted seeds yield of *Ferula sinkiangensis* and what is the required amount for cultivation and field propagation under different utilization methods? Answering these questions will provide important data and references for both the recovery of wild populations and artificial cultivation of *Ferula sinkiangensis* and will offer theoretical support for understanding the endangerment and recovery mechanisms of short-lived perennial desert plants in arid areas.

Materials and Methods

The study area is located in the FS Habitat Protection Zone, Yili Kazak Autonomous Prefecture, Xinjiang, China. The region features is a northern temperate continental climate with an average annual temperature of 10.5°C, an average annual precipitation of 245.1 mm, a frost-free period of 190 days, an average annual sunshine duration of 3080.8 hrs and an average altitude of 850 m. The soil is sierozem with a pH ranging from 7.3 to 8.8. The organic matter content is 15.5-22.41 g/kg, available nitrogen ranges from 56.2-124.0 mg/kg, phosphorus ranges from 2.51-6.53 mg/kg and potassium ranges from 173.1-434.8 mg/kg. The average annual soil moisture content ranges from 21.1-33.7 percent and the average annual soil temperature ranges from 12.2-12.7℃ (Wei . 2019). The main associated species include *Salsola collina* Pall., *Gymnocarpos przewalskii.*, *Polygonum aviculare* L., *Petrosimonia sibirica* (Pall.) Bge., *Ceratocarpus arenarius* L., *Camphorosma monspeliaca* L., *M.vulgare* L., *Hyoscyamus niger* L. (Wei . 2019).

In May 2022, a comprehensive survey was conducted to assess the distribution area of FS. Data on population number, distribution area, plant number, and leaf number were collected to determine the existing resources and age structure of FS.

The population count was determined through a comprehensive manual investigation of the distribution region considering both the boundary demarcation and population size. In instances where there existed distinct geographical or physical barriers (such as hills, roads, rivers, or long-term fences) between distribution areas A and B of FS, or when the distance between any two strains of FS in distribution areas A and B exceeded 50 meters, separate populations were documented for each species.

To determine the distribution area of FS, the area measurement function of GPS toolbox software was used. The researchers walked along the boundary of each population and the distribution area of each population was measured. The sum of the distribution area of all populations was defined as the core distribution area of FS. The measured area represents the total distribution area of FS, while the difference between the total distribution area and the core distribution area is defined as the other distribution areas of FS.

Based on Fig. 1, *Ferula sinkiangensis* is found in only one distribution range in Xinjiang, with 12 dense populations of plants. The number of distribution ranges and population counts are relatively low.

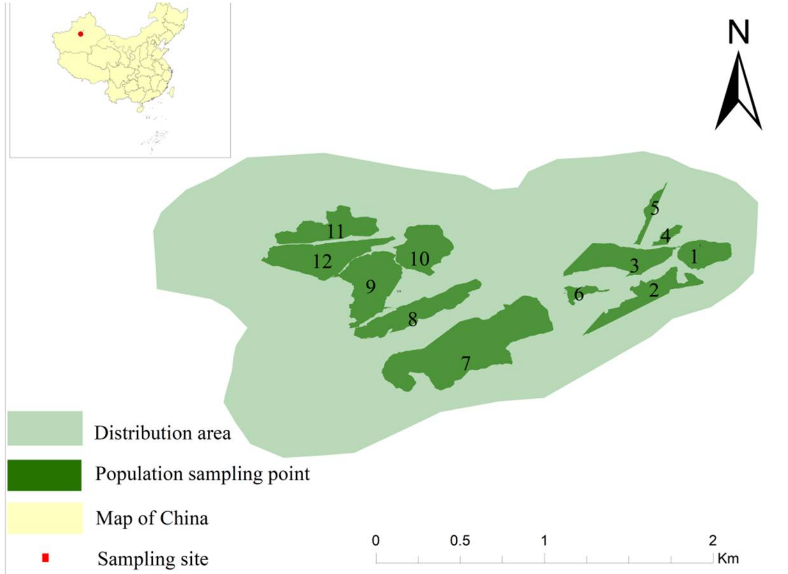

Fig. 1. Distribution area and population distribution of *Ferula sinkiangensis*.

To determine the number of plants, different methods were used depending on the size and distribution of the FS populations in Xinjiang. For populations with a distribution area smaller than 400 m^2, the total number of plants within the population was counted. For larger populations, a sampling method was utilized (Xu and Lai 2022). 10 m×10 m samples were randomly selected from the top, middle, and bottom of the slope in each population and the number of plants within each quadrat was counted separately to calculate the overall number of plants in the population. In areas where FS plants were sporadically distributed between populations (other distribution areas), a different approach was employed. 25 m × 5 m samples were randomly selected within this region and the total number of plants was calculated by combining the count of plants in each sample with the respective distribution area. The total number of FS plants in Xinjiang was determined by summing up the total number of plants in various populations as well as the other distribution areas.

The number of wheel leaves was used as an indicator of age. Based on the number of cluster leaves, the plants were categorized into four age periods: I (1-3 wheel leaves, juvenile stage), II (4-6 wheel leaves, early vegetative growth stage), III (6-9 wheel leaves, late vegetative growth stage), IV (more than 10 wheel leaves, waiting for flowering stage). All FS plants were sorted according to their age, allowing for the determination of the population's age structure.

The production of FS seeds relies on plants that are at least 8 years old (He and Tan 2011). According to this article, it is assumed that within the next 5 years, FS plants with at least 10 whorls will flower, while those with at least 6 whorls will flower within the next 9 years.

Seed production in the core (other) distribution region 2023-2027 year = The number of *Ferula sinkiangensis* plants with more than 10 wheel leaves in core (other) distribution region×4500×0.6.

Seed production in the core (other) distribution region 2023-2031 year = The number of *Ferula sinkiangensis* plants with more than 10 wheel leaves in core (other) distribution region×4500×0.6＋The number of *Ferula sinkiangensis* plants with 6-9 wheel leaves ×4500×0.4.

The value of 4500 represents the average seed production per individual *Ferula sinkiangensis* plant. The value of 0.6 represents the survival rate for *Ferula sinkiangensis* plants with more than 10 leaf whorls and 0.4 represents the survival rate for *Ferula sinkiangensis* plants with 6-9 leaf whorls. The determination of leaf whorls as an indicator of plant age and the survival rates are based on empirical values obtained from interviews with local farmers and herders.

Seed production weight (kg) = Seed production quantity/58800

(58800 means that the seed number of 1kg *Ferula sinkiangensis* is 58800)

Ferula sinkiangensis is primarily cultivated using two different sowing methods: row sowing (conventional) and hole sowing (precision). Row sowing requires a seed rate of 37.5 kg/hm^2 (He and Tan 2002), while hole sowing requires a seed rate of 2.43 kg/hm^2.

The amount of burrowing per hectare = 100000/0.7/58800

(0.7 represents the seed germination rate under artificial intervention (Liu *et al.* 2023) and 100,000 represents the number of *Ferula sinkiangensis* seedlings to be transplanted per hectare, equivalent to 10 plants per square meter). The seeds quantity required for hole sowing is 15.4 times higher than that for row sowing.

The number of plants for field propagation is determined using different methods: conventional and precision.

Number of plants propagated in the field by conventional methods = Seed production quantity×0.006×0.2.

(The value 0.006 represents the germination rate of seeds in the wild, with *Ferula sinkiangensis* seeds having a germination rate of 0.003 (Li *et al.* 2008). Since the wild seeds lifespan is approximately 2 years, it is considered as 0.006. The value 0.2 represents the seedling survival rate).

Number of plants propagated in the field under fine method = Seed production quantity×0.7×0.2 (The value 0.7 represents the seeds germination rate under controlled conditions (Liu *et al.* 2023), while 0.2 represents the seedling survival rate).

The distribution area and main population of FS were mapped by Arc Gis. Spss20.0 was used for ANOVA and its LSD multiple comparison, and Origin 2021 was used for plotting.

Results and Discussion

Based on Fig. 2, the total distribution area of FS is estimated to be 322.84 hm^2. This includes a core distribution area of 63.66 hm^2, while the remaining distribution areas cover approximately 259.18 hm^2. The populations of *Ferula sinkiangensis* are categorized as populations 1 to 12, with respective areas of 2.96, 4.33, 5.48, 0.89, 1.01, 0.65, 17.70, 5.84, 7.51, 5.04, 5.19, and 7.04 hm^2. Notably, population 7 occupies the largest area, while population 6 has the smallest area.

The population density of *Ferula sinkiangensis* in the distribution area of Xinjiang is reported to be 2809.8 plants per hectare (hm^2). Notably, the core distribution area has a much higher population density of 10115 plants per hm^2, whereas the other distribution areas have a relatively lower density of 1015.4 plants per hm^2. Specifically, the population density in the core distribution area is approximately ten times higher than that in the other areas. Moreover, populations 2 and 6 in the core distribution area exhibit significantly higher densities compared to other populations, with densities exceeding 16800 plants per hm^2.

The distribution area of FS is home to a total of 907100 plants, out of which 643942 plants are found in the core distribution area, while the remaining 263158 plants are distributed in other areas. Within the core distribution area, population 7 boasts the highest number of plants, whereas population 4 has the lowest number.

Based on Fig. 3, it can be observed that the populations of *Ferula sinkiangensis* in the entire distribution area, core distribution area, and other distribution areas consist of a higher proportion of young plants, suggesting a growing population. In the overall distribution area, approximately 39.13% of *Ferula sinkiangensis* plants are in the juvenile stage, while only 4.36 % have reached the flowering stage. Within the core distribution area, populations 1, 4, 5, 6, 7, 10, and 11 exhibit a significantly higher proportion of plants in the pre-nutrient growth stage compared to the juvenile stage indicating a stable population. On the other hand, populations 2, 3, 8, 9, and 12 have the highest proportion of young plants and belong to the growing population, showing no signs of an aging population.

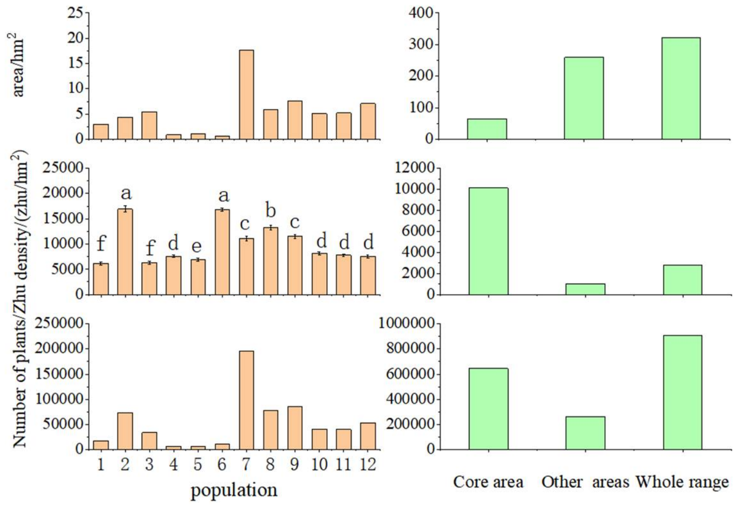

Fig. 2. Population area, density and plant quantity of *Ferula sinkiangensis.*

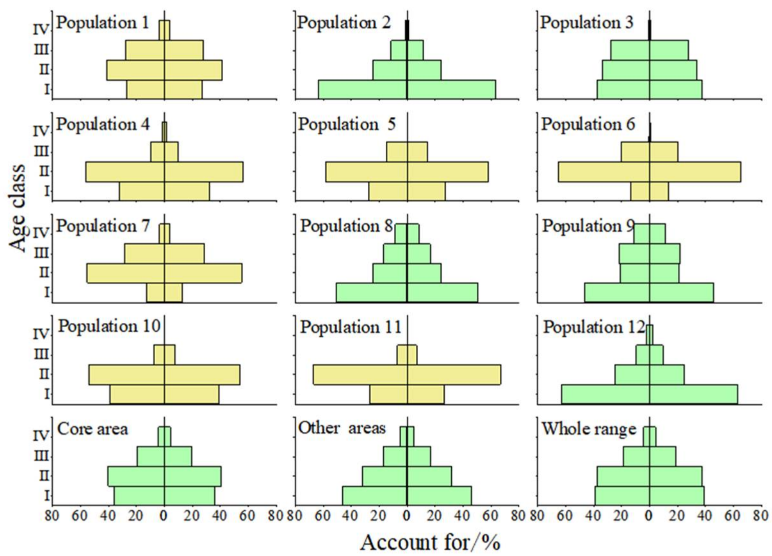

Fig. 3. Age structure of the population of *Ferula sinkiangensis.*

Based on Fig. 4, it can be observed that the number of seed produced by *Ferula sinkiangensis* in the core distribution area, other distribution areas, and the overall distribution area from 2023 to 2027 and 2023 to 2031 are 72.63×107, 34.22×107, and 106.85×107 seeds, respectively, and 297.77×107, 113.43×107, and 411.21×107 seeds, respectively. Additionally, the weight of seed produced in the core distribution area, other distribution areas, and the overall distribution area from 2023 to 2027 and 2023 to 2031 are 1235.2 kg, 582.0 kg, and 1817.2 kg, respectively, and 5064.2 kg, 1929.2 kg, and 6993.4 kg, respectively.

Based on Fig. 4, it is evident that the seed production of *Ferula sinkiangensis* in the core distribution area, other distribution areas, and the overall distribution area from 2023 to 2027 and 2023 to 2031 can sufficiently meet the requirements for different planting methods and corresponding planting areas. For direct sowing, the seed quantity can cater to a planting area of 32.9, 15.5, and 48.4 hm^2, respectively, during the mentioned periods. Similarly, for transplanting, the seed production can meet the needs of planting areas totaling 135.1, 51.4, and 186.4 hm^2. Moreover, the seed are also adequate for hole sowing, enabling planting in areas measuring 508.3, 239.5, and 747.8 hm^2. Lastly, the total planting area, including all methods, can be fulfilled with seed quantities sufficient for 2084.0, 793.9, and 2877.9 hm^2, respectively, in the respective time frames.

According to Fig 4, the number of *Ferula sinkiangensis* plants produced through conventional field propagation in the core distribution area, other distribution areas, and the overall distribution area from 2023 to 2027 and 2023 to 2031 are 87.15×103 plants, 41.1×103 plants, and 128.2×103 plants, respectively. These numbers represent the plant quantities resulting from the use of conventional methods during the mentioned periods. Furthermore, for fine-grained field propagation, the plant numbers are 101.6×105 plants, 47.9×105 plants, and 149.5×105 plants. These figures indicate the plant quantities achieved through the implementation of fine-grained field propagation techniques. Overall, in the respective time frames, the total plant numbers comprised of both conventional and fine-grained field propagation methods are 416.8×105 plants, 158.8×105 plants, and 575.6×105 plants for the core distribution area, other distribution areas, and the overall distribution area, respectively.

Seven years after the establishment of the original habitat protection area, the resources of FS significantly increased. The distribution area expanded to 322.84 hm^2, and the population density reached 2809.8 strains/hm^2. Compared to 2012 (Li *et al*. 2016), the distribution area grew by 142%, and the population density rose by 67.2%. These results suggest that drawing fences to prevent indiscriminate harvesting and digging effectively promotes the population renewal of cattle and sheep. The core distribution area covered 19.7% of the total distribution area, with 70.1% of the total number of plants. This indicates a certain degree of habitat preference for FS. Among the 12 populations in the core area, most were found in slope bottoms with abundant water or areas with good soil quality. Meanwhile, the distribution density of FS was lower in drought-stricken areas and regions with poor soil nutrients. These findings align with the research conducted by Wei (2019) and Xu and Lai (2022).

The young and early vegetative growth stage of FS plants accounted for 77.0% of the total, indicating a reasonable population age structure. However, only 4.4% of the plants were at the flowering stage, which suggests that seed production in the next few years will be low. Therefore, improving seed use efficiency is critical for field planting and propagation. The primary reason for the low seed use efficiency of FS is the low germination rate of seed in the field (Li *et al*. 2008). To address this issue, researchers such as Tian (2008), Zhu *et al*. (2016), and Liu *et al*. (2010) have found that low-temperature treatment or auxin treatment can significantly improve the seeds germination rate of FS, achieving rates of over 70%. Therefore, artificially treating seeds indoors before planting them in the field or expanding their cultivation in the field can significantly enhance seed utilization efficiency. This solution can also solve the problem of insufficient seed production in the coming years.

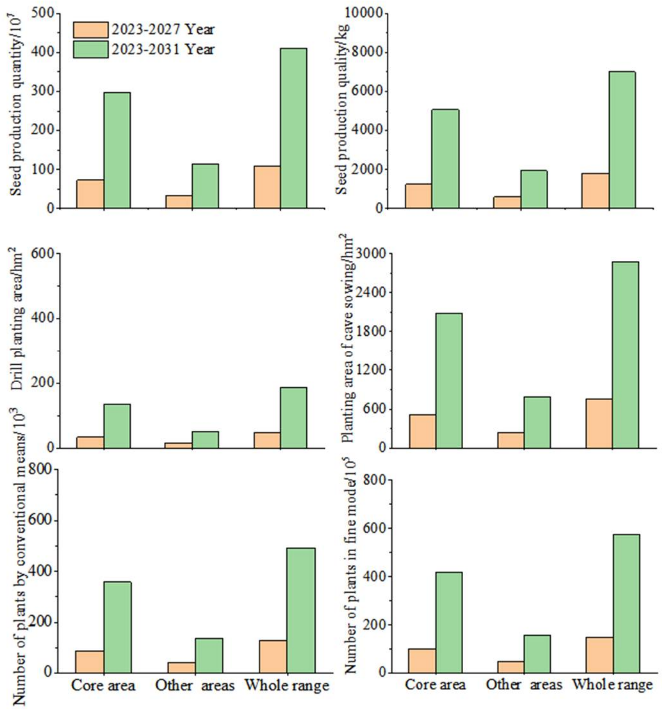

Fig. 4. Prediction of seed production, planting area, and number of wild expanded plants of *Ferula sinkiangensis* from 2023 to 2027 and 2023 to 2031.

There is currently one distribution area of FS, covering an area of 322.84 hm^2, with 12 densely populated plant populations. The plant density in the core distribution area is ten times higher than in other areas, resulting in a total population of 907, 100 plants. Compared to 2012, the resources of FS have shown significant improvement. The entire distribution area, including both other areas and the core distribution area, has seen population growth. Among them, the seven populations in the core distribution area are stable populations. The age structure of the population FS is reasonable, indicating favorable conditions for future population recovery. In the next eight years, the seeds yield of FS is expected to be low. Therefore, improving seed utilization efficiency is crucial. One approach is to treat seeds indoors at a low temperature and then cultivate them in the field using cave sowing and field propagation techniques. Compared to traditional field drilling, this method can increase the planting area by 14.4 times and the number of propagated plants by 116 times when compared to field broadcasting.

In conclusion, the establishment of protected areas for the original habitat has played a crucial role in promoting the recovery of the FS population, providing a fundamental source for field planting and propagation in the future. The number of FS has shown significant growth. However, the key challenge in the conservation of FS lies in expanding its distribution area and increasing the population within the protected areas. This aspect poses a difficult and crucial task for the future protection efforts of FS.

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