Introduction and Cultivation Experiment of *Amygdalus tangutica* in Arid Desert Areas

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Abstract [**Objectives**] *Amygdalus tangutica* is a new and excellent tree species for afforestation in arid areas of central China for soil and water conservation. It has the characteristics of drought resistance, cold resistance and tolerance to poor soil, and has strong ecological, landscape and economic value. To provide a theoretical basis for the propagation and application of *A. tangutica* in Minqin and similar arid sandy areas of Northwest China, this paper explored its introduction and cultivation technology through field experiments, considering the natural geographical conditions of the study area. [**Methods**] High-quality seeds were introduced from forest farms of Chankou Town, Anding District, Dingxi City, and Dian'ga Town, Diebu County, Gannan Prefecture, and the introduction and cultivation experiments of *A. tangutica* were carried out in the greenhouse of Wuwei Oasis Station. [**Results**] (1) Soaking treatment at different temperatures combined with gibberellin treatment and stratification germination could effectively break the dormancy of *A. tangutica* seeds, thereby accelerating germination and shortening the germination cycle. The germination peak appeared 15 –20 d after sowing, and the final germination rate could reach about 50%. (2) In the introduction and cultivation of *A. tangutica* in arid areas, large fruit seeds with higher thousand-grain weight should be given priority. The emergence rate of large fruit seeds was significantly higher than that of small fruit seeds, with the highest reaching 57%, while the highest of small fruit seeds was only 20%. Soaking treatment at different temperatures had no significant difference in the germination performance and germination potential of *A. tangutica* seeds, but the germination index of large fruit seeds was higher than that of small fruit seeds. (3) Under the current conditions, seedling propagation is a reliable way to propagate *A. tangutica* in arid areas. The cutting propagation technology, particularly hardwood cutting which exhibits an extremely low survival rate, is not yet mature and is currently unsuitable for large-scale production. Consequently, future efforts should prioritize more in-depth research on softwood cutting techniques. [**Conclusions**] This study provides a theoretical foundation for the propagation and broader application of *A. tangutica* in Minqin and similar arid sandy areas of Northwest China.

Key words *Amygdalus tangutica*; Introduction; cultivation; Germination rate; Growth; Arid desert area

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Amygdalus tangutica, also known as Tangut almond or Sichuan almond, is a dense dwarf shrub and a unique species of Prunus in Rosaceae endemic to China. It is primarily distributed in southern Gansu Province, northwestern Sichuan Province, and other regions[1 –2]. Due to its long-term adaptation to arid valley shrublands or sparsely vegetated semi-desert environments, it has developed xerophytic characteristics such as thorny stems, small and thick leaves, and a well-developed root system. It exhibits traits such as photophilous nature, drought tolerance, cold resistance, and tolerance to poor soil, with its one-year-old dormant branches capable of withstanding temperatures as low as –19.24 ℃. With strong environmental adaptability, it is an excellent tree species for afforestation and vegetation restoration in barren hills in arid valley areas[3 –6]. Its seed kernel is nutrient-rich, high in oil content, and abundant in various bioactive compounds. Additionally, it has significant energy value, presenting substantial potential as a source of nutritional and health-promoting oil as well as biodiesel feedstock[7 –9]. Its flowers serve as an early spring nectar source. Its young shoots and leaves contain up to 19.56% crude protein, making it high-quality forage for livestock during winter[10]. As an excellent shrub for establishing soil and water conservation forests and fuelwood forests in the arid areas of central China, *A. tangutica* possesses significant ecological, landscape, and economic value, with broad prospects for development[11 –12].

Currently, research on the conservation and utilization of *A. tangutica* resources in China primarily focuses on germplasm resource distribution[13], superior tree selection techniques and comprehensive evaluation[4], kernel oil content and nutritional composition[8], as well as the physicochemical properties and fatty acid composition of the oil[7]. Li[6] and Li *et al.*[10] conducted studies on seed propagation and planting techniques for *A. tangutica* in Diebu, Gansu, and semi-arid loess areas, respectively. Zhao *et al.*[14] investigated the introduction adaptability and cultivation performance of *A. tangutica* in the shallow mountain areas of the Qilian Mountains. To date, there have been no reported studies on the introduction and cultivation techniques of *A. tangutica* in arid desert areas. Therefore, in this study, the introduction and cultivation of *A. tangutica* in the arid desert area of Wuwei was investigated, with a focus on Minqin, aiming to explore key technologies for the introduction and cultivation of *A. tangutica* in arid desert areas, and to grasp its survival rate, physiological,

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ecological, and phenological adaptability performance in the study area. Active seedling cultivation and extensive afforestation under suitable site conditions in arid desert areas can not only enrich the germplasm resources of the province and improve tree species composition, but also enhance stand quality and increase economic and social benefits. Additionally, this study provides reference for the introduction, afforestation, and broader application of *A. tangutica* in arid desert areas.

Generation Situation of Experimental Site

The experimental site is located within Wuwei Oasis Ecological Station, at an elevation of 1 378 m. The region has a temperate continental arid climate, characterized by intense solar radiation, low precipitation, abundant sunshine, high evaporation, and significant diurnal temperature variations. The annual sunshine duration is 2 873.4 h, with a sunshine percentage of 67%. The solar radiation reaches 139.05 $Kcal/cm^2$, classifying it as a high solar radiation zone. The average annual precipitation is 110 mm, while the average annual evaporation is 2 020 mm. The predominant wind direction is northwest, with a calm wind frequency of 26%. The average annual temperature is 7.7 ℃, with July being the warmest month at 29 ℃ and January the coldest at −14.9 ℃. The effective accumulated temperature (≥10 ℃) is 3 003 ℃. The annual sunshine duration is 2 873.4 h, with a sunshine percentage ranging between 62% and 74%. The average frost-free period lasts 155 d. Northwest winds prevail throughout the year, with an average annual wind speed of 2.5 m/s. Major meteorological hazards include strong winds, blowing sand, sandstorms, and dry hot winds.

Materials and Methods

The tested seeds and cuttings were sourced from the forest farms of Chankou Town, Anding District, Dingxi City, and Dian'ga Town, Diebu County, Gannan Prefecture. The seed purity was 98.2%, and the thousand-grain weight was 1 144.25 g for large fruits and 452.52 g for small fruits. The field germination rate was 96.3%. The number of seeds tested was 700 for both large and small fruits, each of which was divided into 7 parts, each with 100 seeds for later seed soaking treatment. Field trials for seed propagation and cutting propagation of *A. tangutica* were conducted within Wuwei Oasis Station.

Seed treatment

Seeds were first soaked in either an 0.8% potassium permanganate solution or a 1% carbendazim solution for 24 h, and then taken out and rinsed thoroughly. Subsequently, seeds from both large and small fruits were separately placed in hot water at 100, 90, 80, 70, 60 and 50 ℃, and a control group (CK, 0 ℃), stirred, and allowed to cool naturally for 48 h. Next, the seeds were soaked in a 4% gibberellin solution for 8 h. After being taken out, the seeds were mixed with fine moist sand at a volume ratio of 1 : 3, maintaining 30% − 50% humidity. Stratification was carried out at 18 − 25 ℃ for 20 d before sowing.

Seed propagation experiment

In mid-April 2023, a field strip-sowing experiment was conducted in the experimental area. The plot was first plowed to a depth of approximately 20 cm, followed by the application of organic fertilizer and uniform raking. After sufficient pre-irrigation, furrows 2.5 − 3.5 cm in depth were created when the soil became loose. The pre-germinated seeds were evenly sown into the furrows at a furrow spacing of 25 cm, covered with 2 − 3 cm of soil, lightly compacted, and then thoroughly watered. After seed germination commenced, daily observations were made to record the seedling emergence rate for seeds subjected to different soaking temperature treatments.

Data analysis

Data processing and statistical analysis were performed using Excel 2023 and SPSS 19.0 software. One-way analysis of variance (ANOVA) and Duncan's multiple comparison test were conducted to analyze the significance ($\alpha = 0.05$) of seedling emergence rate, crown width, ground diameter, and other related indicators of *A. tangutica* seeds subjected to different soaking temperature treatments.

Results and Analysis

Effects of different soaking temperature treatments on seed emergence rate

The emergence rates of *A. tangutica* seeds varied depending on seed size and the temperature of the soaking treatment. As shown in Fig. 1, the emergence rate of small fruit seeds treated with the control (0 ℃) soaking temperature was 0%. The highest seed emergence rate for small fruits was 20%, achieved after soaking at 50 ℃, followed by 19% at 60 ℃. As the soaking temperature increased beyond these points, the emergence rate gradually decreased. For large fruit seeds, the highest emergence rate of 57% was achieved after soaking at 80 ℃, followed by 53% at 90 ℃. The lowest emergence rate of 3% was observed after soaking at 100 ℃. From the control (0 ℃) up to 70 ℃, the emergence rate of seeds gradually increased with rising soaking temperatures. Overall, large fruit seeds demonstrated better emergence performance than small fruit seeds.

Effects of different soaking temperature treatments on seedling growth

A. tangutica seeds of different sizes exhibited varying seedling growth performance after soaking treatments at different temperatures. As shown in Table 1, for small fruit seeds, the 50 ℃ treatment resulted in the highest seedling survival rate of 95% and the maximum plant height of 60.79 cm. Under the 50 ℃ treatment, the maximum branch length reached 63.06 cm. While the 80 ℃ treatment yielded the lowest average seedling height of 38.00 cm, it produced the largest crown area (2 784.00 cm^2) and ground diameter (9.13 cm). With further increase in treatment temperature, the number of surviving seedlings gradually decreased, though the differences were not statistically significant ($P \geqslant 0.05$). The 100 ℃ treatment was lethal to seedlings developed form seeds of small fruits, resulting in a 0% survival rate. Meanwhile, the control (CK) group produced only one surviving seedling. The plant height, ground diameter, and branch length of small-fruited seedlings showed varied trends with increasing temperature, and the differences were not statistically significant ($P \geqslant 0.05$). However, the crown width of seedlings treated at 70 ℃ differed significantly from those in the control and the 50, 80, and 100 ℃ treatments ($P \leqslant 0.05$).

For seeds from large fruits, the control treatment resulted in the highest seedling survival rate (91.10%), followed by the 80 ℃ treatment (87.72%) taking the second place. Under the 50 ℃ treatment, seedlings showed better performance in plant height (51.25 cm) and branch length (54.50 cm). Similarly, the 100 ℃ high-temperature treatment severely inhibited seedling growth, reducing the survival rate to 33.33%. Analysis of variance indicated that seedlings treated at 70 ℃ exhibited smaller values in plant height, crown width, ground diameter, and branch length than other treatments, and these differences were statistically significant ($P \leqslant 0.05$) when compared with the control and the 100 ℃ high-temperature treatment. For the remaining temperature treatments, the differences in various growth indicators between seedlings developed from large and small fruit seeds did not reach statistical significance ($P \geqslant 0.05$).

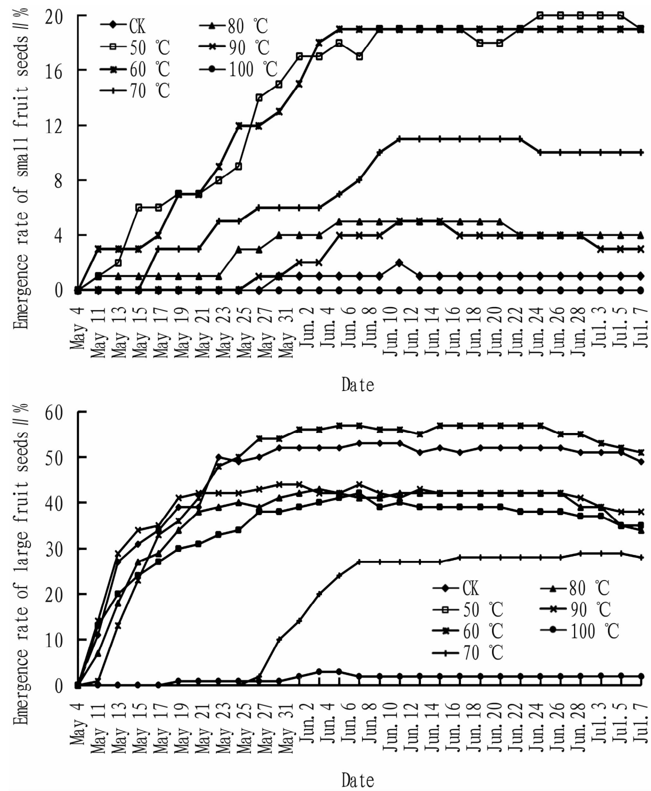

Fig. 1 Statistical comparison on cumulative emergence rates of *A. tangutica* seeds of different sizes after soaking treatment at different temperatures

Table 1 Seedling growth indicators and survival rates after various soaking temperature treatments on *A. tangutica* seeds of different sizes

Type	Temperature	Number // plants	Plant height // cm	Crown width // cm^2	Ground diameter // cm	Branch length // cm	Survival rate // %
Large fruit	CK	1	45.00 ± 0.00 a	3 600.00 ± 0.00 a	8.66 ± 0.00 a	57.00 ± 0.00 a	50.00
	50 ℃	19	60.79 ± 4.98 a	1 256.53 ± 224.65 a	7.09 ± 0.50 a	61.26 ± 4.71 a	95.00
	60 ℃	17	59.18 ± 4.79 a	1 673.76 ± 276.35 ab	7.24 ± 0.30 a	63.06 ± 4.38 a	89.47
	70 ℃	9	46.56 ± 4.29 a	1 086.56 ± 265.37 b	6.97 ± 0.71 a	48.72 ± 3.47 a	81.82
	80 ℃	4	38.00 ± 10.17 a	2 784.00 ± 645.18 a	9.13 ± 0.84 a	50.38 ± 2.58 a	80.00
	90 ℃	3	58.00 ± 11.14 a	1 592.67 ± 364.26 ab	7.26 ± 0.26 a	56.00 ± 8.50 a	60.00
	100 ℃	0	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00
Small fruit	CK	27	49.43 ± 2.85 a	1 126.93 ± 156.01 a	6.83 ± 0.30 a	54.91 ± 2.69 a	91.10
	50 ℃	36	51.25 ± 3.30 a	821.37 ± 167.43 ab	5.69 ± 0.31 b	54.50 ± 3.04 a	85.71
	60 ℃	36	44.77 ± 2.60 ab	578.57 ± 85.77 b	5.29 ± 0.25 bc	46.22 ± 2.41 b	83.72
	70 ℃	37	38.73 ± 2.47 b	559.30 ± 92.07 b	4.92 ± 0.18 c	43.58 ± 2.34 b	86.05
	80 ℃	50	46.90 ± 2.27 a	554.80 ± 72.69 b	5.29 ± 0.16 bc	49.05 ± 1.78 ab	87.72
	90 ℃	49	44.12 ± 1.99 ab	758.13 ± 129.09 b	5.32 ± 0.22 bc	44.90 ± 1.95 b	85.97
	100 ℃	1	30.00 ± 0.00 a	240.00 ± 0.00 a	5.35 ± 0.00 a	34.5 ± 0.00 a	33.33

Data in the table are presented as mean ± standard error. Different letters following data within the same column indicate significant differences among different temperature treatments ($P < 0.05$). The same applies below.

Effects of different rooting agent concentrations on cutting propagation

Experimental observations indicated that the softwood cutting propagation experiment conducted in the Wuwei experimental area were unsuccessful. The primary reasons likely include inadequate moisture preservation measures for the cuttings collected from the forest farms of Chankou Town, Anding District, Dingxi City, and Dian'ga Town, Diebu County, Gannan Prefecture, coupled with long-distance transportation leading to significant water loss. Given that the survival rate of hardwood cuttings for *A. tangutica* generally ranges between 5% and 8%, this may have been a major factor contributing to the experimental failure. Additionally, the outcome could be related to the physiological, ecological, and phenological adaptability of *A. tangutica*.

Conclusions and Discussion

(1) The results of this study confirm that *A. tangutica* seeds possess a hard seed coat. Through a combination of hot water soaking, gibberellin treatment, and stratification, seed dormancy was effectively broken, accelerating germination and shortening the germination cycle. The peak germination period occurs between 15 to 20 d after sowing, with a final germination rate reaching approximately 50%. These findings align with the germination patterns observed in many species with hard-coated seeds[15].

(2) During the seedling propagation process, seed treatment is a crucial step. The emergence rate, seedling yield, and seedling quality are all closely related to the effectiveness of seed treatment. Common seed treatment methods include soaking for germination promotion and seed-sand mixture burial treatment, both aiming at facilitating rapid water absorption by the seeds to achieve the moisture content necessary for normal germination. During the experiment, a combined treatment of soaking for germination promotion and seed-sand mixture burial was applied to both large and small *A. tangutica* seeds sourced from the forest farms of Chankou Town, Anding District, Dingxi City, and Dian'ga Town, Diebu County, Gannan Prefecture. Field sowing and seedling trials demonstrated that, after soaking treatment at different temperatures, large fruit seeds achieved a better emergence rate of 57%, while small fruit seeds reached a maximum emergence rate of only 20%. This indicates that selecting seeds from large fruits is a key factor in improving seedling success when introducing and cultivating *A. tangutica* in arid areas. The primary reason for this is that seeds from large fruits likely store more abundant nutrients, providing ample energy for early seedling growth and thereby enhancing their resistance to adverse conditions. Therefore, when introducing and cultivating *A. tangutica* in arid areas, selecting large fruit seeds is recommended.

(3) For the propagation of *A. tangutica* through cuttings, softwood cuttings are preferable over hardwood cuttings. The failure in this experiment suggests that asexual propagation techniques for *A. tangutica* require further in-depth exploration. Future research should focus on optimizing factors such as the timing of cutting collection, the specific branch sections used, the concentration ratios of growth regulators, and the composition of the rooting medium. Additionally, strict moisture preservation measures during cutting collection and transportation are essential to minimize the adverse effects of water stress on cutting survival.

In summary, this study provides a feasible technical approach for the successful introduction and large-scale seedling propagation of *A. tangutica* in the arid sandy areas of Northwest China. It has significant practical value for enhancing regional biodiversity and combating desertification.

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