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Research paper

Environmental Factors Affecting Seed Germination and Seedling Growth of *Diospyros philippensis* (Desr.) Gürke on the Southern Tip of Taiwan: A Preliminary Study

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ABSTRACT

The fruits of maoshi (*Diospyros philippensis* (Desr.) Gürke) fall and ripen between mid-August and early September. After ripening, the seeds exhibited no dormancy and germinated immediately. The mean germination percentage of fresh seeds was 94.0% in our seed germination test, 78.6% under natural field conditions, and 92.5% under artificial conditions. Seed viability declined with water loss and was reduced by wet storage at 10℃ for 2–3 days. After germination, the maoshi seedlings produced two opposite primary leaves that were ovate to elliptical, followed by alternately arranged lanceolate true leaves. Most naturally regenerated seedlings ceased growth after the emergence of primary leaves or the first true leaves and remained in this stage throughout winter, with dormancy lasting up to five months or longer. In natural forests in Kenting, at the southern tip of Taiwan, young seedlings grew extremely slowly. One-year-old seedlings had an average height of 16.7 ± 3.1 cm, with 5.0 ± 1.8 leaves (excluding cotyledons), and a survival rate of 46.6%. Two-year-old seedlings reached an average height of 19.8 ± 4.8 cm, with 9.2 ± 5.1 leaves, and a survival rate of 38.6%. Under artificial conditions, the period of growth dormancy was significantly reduced. One-year-old seedlings attained an average height of 22.8 ± 4.9 cm, with 9.5 ± 2.3 leaves (excluding cotyledons), and a survival rate of 98.6%. Two-year-old seedlings reached an average height of 46.2 ± 10.4 cm, with 28.5 ± 5.6 leaves (excluding cotyledons), and a survival rate of 90.6%. Water availability and solar radiation were the most important factors promoting seedling growth, whereas the effects of growing media and fertilizer application were comparatively less pronounced. Cultivation under suitable artificial conditions can therefore significantly enhance the growth of maoshi seedlings.

Keywords: *Diospyros philippensis* (Desr.) Gürke, seedling production, growth rhythm, Ebenaceae

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INTRODUCTION

Diospyros philippensis (Desr.) Gürke, commonly known as maoshi (毛柿) in Taiwan, is native to the Philippines, with its northern distribution boundary extending to eastern and southern Taiwan. There are at least three commonly used scientific names for this species; this report follows nomenclature from the Flora of Taiwan, 2nd Edition (Huang 1998). Maoshi is often used for afforestation or landscaping purposes and is typically propagated sexually by seeds. The seeds are large, fresh weight per seed may exceed 5 g, and they have a high germination percentage. No barriers to sexual reproduction have been identified, making seed propagation a reliable method for seedling production. According to classification by Yang et al. (2008), maoshi seeds are tropical recalcitrant seeds with a moisture content of 44.0%, and germination completes within 21 days after sowing.

This study originated from the practical experience of maoshi seedling production, during which several phenomena were observed that warranted investigation. These included reduced germination percentages when cleaned seeds were not sown immediately, as well as marked differences in seedling growth rates among plants distributed across various artificial facilities due to space limitations. Consequently, a seed germination experiment was conducted, and a subset of seedlings was systematically observed and documented. Additional hypothesized factors that might influence seedling growth rate, along with samples collected from natural environments, were included for comparison. The aim of this preliminary study was to investigate the influence of various environmental conditions and variables on seed germination and early seedling growth, with the aim of providing practical references for seedling production and encouraging further, more detailed research.

Maoshi grow slowly, which is a significant factor limiting the efficiency of seedling cultivation. To date, there are no comprehensive studies available on its growth rhythm. Observations conducted in its native habitat of Kenting in southern Taiwan found that six-year-old seedlings under the forest canopy remain under 1 m in height, and the time required to reach maturity (flowering) remains difficult to estimate. Additionally, interviews with local residents who cultivate maoshi in their yards suggest that it takes at least 10 years, under artificial cultivation before flowering occurs. Although there is no definitive experimental data to confirm this, the slow growth rate of maoshi is consistently recognized.

Currently, the production of maoshi seedlings is primarily undertaken by nursery operators, mainly for landscaping and ornamental purposes. Government agencies also engage in small-scale propagation for afforestation and experimental research purposes. Although some studies have addressed seedling cultivation (Liu 1992, Liao et al. 1995), a comprehensive study of the entire process—from seed treatment, sowing, and cultivation to mature seedling—remains lacking. Prolonged nursery residence raises production costs; therefore, shortening the cultivation cycle and accelerating the growth of seedlings can effectively reduce nursery costs. This study documented a two-year process—from extracting seeds from the fruit to establishing seedlings—investigating the effects of environmental factors on growth and development to provide practical reference for propagation and seedling cultivation practices.

MATERIALS AND METHODS

Seed germination test

Mature maoshi fruit were collected from the Hengchun Peninsula. After piling, the fruits were allowed to soften, and the seeds were extracted. The extracted seeds were placed in mesh bags and rubbed under running water until all pulp was completely removed. Deformed or poorly developed seeds were discarded. The remaining seeds were then divided into four treatments:

1. **Direct sowing (No treatment):** Washed seeds were drained in a mesh basket for 30 minutes without any further treatment. The seeds were inserted tip-down (germination pore facing down) into the medium (shredded coconut coir: peat moss = 1:1) and cultivated in a greenhouse. They were misted for 3 minutes every hour. A total of 300 seeds weighing 1,276.5 g were used (30 repetitions of a 10-seed group).
2. **Air-dried (Shaded drying) seeds:** The same washed seeds as in Treatment A (300 seeds, 30 repetitions of a 10-seed group, total weight 1,268.3 g) were spread flat on three layers of newspaper and air-dried in a shaded, cool place for 24 hours. After weighing, they were sown using the same method as in Treatment A.
3. **Fan-dried (Forced airflow) seeds:** The same washed seeds as in Treatment A (300 seeds, 30 repetitions of a 10-seed group, total weight 1,272.6 g) were spread flat in a mesh basket and subjected to strong airflow from an electric fan for 18 hours. After weighing, they were sown using the same method as in Treatment A.
4. **Cold storage:** The same washed seeds as in Treatment A (300 seeds) were divided into three bags of 100 seeds each (sealed bags). An approximately equal amount of moist sphagnum moss was added, mixed thoroughly, and the bags were sealed and stored in a refrigerator at 10℃. Every 24 hours, one bag (100 seeds, 10 repetitions of a 10-seed group) was taken out from the refrigerator and sown using the same method as in Treatment A, 3 times, for a total of 72 hours.

Observations of seedling growth

The growth of maoshi from seed germination over a period of 2 years under various environmental conditions was observed and recorded. Surveyed criteria included seedling height, leaf development, and leaf fall. During the period, sunlight exposure was recorded irregularly to assess differences in light conditions among the treatments. Measurements were taken using a LI-COR sensor (Line Quantum Sensor, LI-191SA, US), and full sunlight data were obtained from the rooftop of the Seaview Tower (觀海樓) in Kenting National Forest Recreation Area (also known as Hengchun Tropical Botanical Garden). Each light measurement in the experimental areas was completed within 30 minutes, and there were no significant changes in sunlight conditions (such as the sun being obscured by clouds) recorded during the process. If noticeable changes were detected, the measurement was abandoned. Treatment conditions were as follows.

1. Observation of understory seedling regeneration

(1) Within the forest of Hengchun Tropical Botanical Garden, three mature female maoshi trees were selected in areas with flat terrain and similar environmental conditions except for differences in light transmittance. Using the aforementioned photometer, light intensity was measured in the morning (8–10 AM),

midday (11 AM–1 PM), and evening (4–6 PM) periods. Three female maoshi trees with a diameter at breast height (DBH) over 20 cm and with obviously different understory light transmittance levels—high light (H), medium light (M), and low light (L)—were selected for experimental plots.

(2) Under the canopy of each of the three selected female maoshi (H, M, and L experimental plots), three 30 × 30 cm small plots were marked on the ground. The plots were as flat as possible and independent from each other. So, a total of 9 small plots were established: high light H1 (15 seeds), H2 (15 seeds), H3 (15 seeds); medium light M1 (9 seeds), M2 (11 seeds), M3 (10 seeds); and low light L1 (14 seeds), L2 (15 seeds), L3 (8 seeds).

(3) Observation and recording began immediately after the maoshi fruiting period ended. Successful germination was defined as a seed unfolding one pair of primary leaves. Each seedling was numbered and tagged. Surveys were conducted once a month and continued for up to 2 years.

2. Glasshouse cultivation

(1) The glasshouse is located at the Guizijiao Nursery (龜仔角苗圃) of the Hengchun Research Center, Forestry Research Institute. It is an automatically controlled greenhouse equipped with internal and external shading, sprinkler irrigation, and a Fan-and-Pad cooling system. During the experiment, external shading (black polyethylene net, providing approximately 50% shading) was deployed automatically from 10 AM to 2 PM, and the automatic sprinkler system was set to spray for 1 minute every hour. The cooling system was activated when the temperature, at a height of 2 m inside the greenhouse, exceeded 28℃. Seedling bags, containing a mixture of seeds collected from the Kenting area were used for direct seeding. The seedling bags measured 9 × 16 cm, including growing medium composed of shredded coconut coir and peat moss in a 1:1 ratio. After germination, Hi-Control No. 2 fertilizer (N-P-K: 16-5-10, 100D, JP) was applied to the surface of the medium at approximately 1 g per bag, and then applied once every 4 months. This treatment included a total of 704 bags and is referred to as Treatment A.

(2) After sowing, surveys were conducted weekly for the first 2 months, biweekly from months 3 to 6, monthly from months 7 to 12, and every 6 months thereafter, continuing until the plants reached 2 years of age.

3. Net house cultivation

(1) The net house is also located at the Guizijiao Nursery of the Hengchun Research Center, Forestry Research Institute. The netting material is white, providing approximately 20% shading. The nursery is equipped with a sprinkler irrigation system. Automatic sprinkler settings and seedling bag specifications were the same as for Treatment A. The medium used was local natural topsoil, with no fertilizer applied. This treatment group consisted of a total of 25 bags and is referred to as Treatment B.

(2) Within the same net house but in a different area, Treatment C was set up with a total of 25 bags. It used manual sprinkler irrigation once a week for 5 minutes each time; irrigation was skipped if it had rained within three

days. Fertilization was the same as for Treatment A.

(3) In another area of the net house, Treatment D was set up with a total of 25 bags, differing from Treatment C in that no fertilizer was applied.

(4) In yet another section of the net house, Treatment E was set up with a total of 25 bags, differing from Treatment D in that the medium used was stream sand.

(5) A brief comparison of the conditions of Treatments A through E in the greenhouse and the net house is shown in Table 1. Beginning with sowing, surveys were conducted every 6 months, continuing until the seedlings reached 2 years of age.

Data analysis

Experimental data were processed using Microsoft Excel software, and the mean and standard deviation (SD) were calculated. The least significant difference (LSD) method was then performed using CoStat software (CoStat 6.4, UK). Graphing was done using Microsoft Excel software.

RESULTS AND DISCUSSION

Comparison of solar radiation levels across experimental zones

A total of 20 sets of data were successfully recorded during daytime under various weather conditions, excluding rainy days. Each data set included one solar radiation measurement from each zone (or plot) collected at the same time, with a maximum time difference of 30 minutes. These measurements were used to calculate the average solar radiation for each zone. These measurements were then compared with those recorded at the Seaview Tower to determine solar radiation transmittance among zones. The average solar radiation values, from highest to lowest, were: full sunlight at 1,459.1 μmol photons m^{-2} s^{-1}; net house, 840.5 μmol photons m^{-2} s^{-1}; glasshouse, 499.5 μmol

Table 1. Parameters of treatments A-E in glasshouses and net houses.

Factors	Treatments				
	A	B	C	D	E
Shading[a]	50%, 4 hrs/day	20%	20%	20%	20%
Sprinkler irrigation[b]	Automatic	Automatic	Manual	Manual	Manual
Cooling[c]	Yes	No	No	No	No
Medium[x]	Artificial	Topsoil	Topsoil	Topsoil	Stream sand
Fertilization[y]	Yes	No	Yes	No	No
External airflow	Isolation	Open	Open	Open	Open

[a] A Shading net (50% effect) is applied from 10 AM to 2 PM (4 hrs) to glasshouses. A shading net (20% effect) is applied full-time to net house.

[b] An automatic sprinkler system is set to spray for 1 minute every hour. Manual sprinkler irrigation is applied once a week for 5 minutes each time.

[c] The Fan-and-Pad cooling system is activated when the temperature at a height of 2 m inside the greenhouse exceeds 28℃.

[x] Artificial medium composed of shredded coconut coir and peat moss in a 1:1 ratio.

[y] Hi-Control No. 2 fertilizer (N-P-K: 16-5-10, 100D) was applied to the surface of the medium at approximately 1 g per bag, and then applied once every 4 months.

photons m^{-2} s^{-1}; high-light forest understory, 201.7 μmol photons m^{-2} s^{-1}; medium-light forest understory, 136.7 μmol photons m^{-2} s^{-1}; and low-light forest understory, 48.6 μmol photons m^{-2} s^{-1}. Corresponding transmittance rates were 100%, 57.6%, 34.2%, 13.8%, 9.4%, and 3.3%, respectively.

Seed germination properties

The germination percentage of maoshi seeds without any treatment was extremely high, reaching 94.0% (Table 2). The seeds had a high moisture content of 44.0%, typical of tropical recalcitrant seeds, and were highly sensitive to dehydration (Yang et al. 2008). Experimental results showed that after 24 hours of air drying, the seeds lost only 1.9% of their weight, equivalent to 4.3% water loss, resulting in a germination percentage of 83.7%, or about 10% loss (Table 2). Directly drying the seeds with a fan for 24 hours resulted in a weight loss of 13.9%, equivalent to 31.6% water loss, with the germination percentage rapidly dropping to 22.3% (Table 2).

Tropical tree species are generally sensitive to low temperatures, with adverse effects potentially occurring at temperatures below 15℃ (Bonner 1990). In this experiment, maoshi seeds were subjected to a 10℃ wet storage treatment, and results showed that a temperature of 10℃ indeed reduced the seed germination percentage. After 24 hours at 10℃, the germination percentage dropped to 89.0%; after 48 hours, it fell to 82.0%; and after 72 hours, it decreased to 74.0% (Table 2). Results indicate that maoshi seeds exhibit typical characteristics of tropical tree species, with temperatures as low as 10℃ already capable of affecting seed viability. Based on these characteristics, when conducting maoshi seedling propagation, seeds should be washed with water when the fruit is soft and rotten, and the washed seeds should be sown promptly avoiding storage, ensuring that seed vitality is not reduced due to dehydration, low temperature, or other adverse factors.

Germination process and seedling morphology

Maoshi fruit mature from mid-August to early September. Once mature, the fruits naturally fall off the tree. After falling, they exhibit an obvious ripening phenomenon, indicating that they are climacteric fruits.

Table 2. Effects of water-loss and 10℃ storage on the seed germination of *Diospyros philippensis*.

Projects	No treatment (Direct sowing) (300 seeds)	Air-dried (Shaded drying) (300 seeds)	Fan-dried- (Forced airflow) (300 seeds)	Wet storage at 10℃		
				24 hrs (100 seeds)	48 hrs (100 seeds)	72 hrs (100 seeds)
Original weight (g)	1276.5	1268.3	1272.6	318.7	321.6	320.2
Final weight (g)	1276.5	1244.5	1096.3	-	-	-
Weight loss (%)	0.0	1.9	13.9	-	-	-
Water loss (%)	0.0	4.3	31.6	-	-	-
Number of germinated seeds	282.0	251.0	67.0	89.0	82.0	74.0
Germination (%)	94.0 ± 0.50^{Ax}	83.7 ± 8.9^{B}	22.3 ± 5.7^{C}	89.0 ± 8.8^{a}	82.0 ± 10.3^{ab}	74.0 ± 7.0^{b}

According to Yang et al. (2008), the water content of seeds is 44.0%.

[x] Each value represents the mean ± SD. Different letters represent significant differences among different treatments at $p < 0.05$ according to the LSD test.

After ripening, the flesh softens and decays rapidly. Under natural conditions, the fruit peel gradually dries out and does not decompose along with the flesh. If not damaged by external forces, it does not completely disintegrate, forming a slightly wrinkled hollow spherical shape. Therefore, it is common to see a cluster of maoshi seedlings topped with a dried fruit peel in forest understories (Figure 1). Seeds lacking dormancy germinate immediately after the pulp decomposes, or after the pulp is washed off in artificially cultivated seeds. Seedlings exhibit epigeal germination, with the seed coat and cotyledons lifted above the soil surface (Figure 2A). As development progresses, the two cotyledons unfold, and the seed coat along with the endosperm detaches and falls off (Figures 2B and 2C). The cotyledons of the maoshi are somewhat thick; after the seed coat detaches, they

Figure 1. Seedling of *Diospyros philippensis* in a natural environment.
Under natural conditions, seeds have germinated before the maoshi fruit is completely rotten. The shell-like dried peel with cotyledons rises above the ground after seed germination.

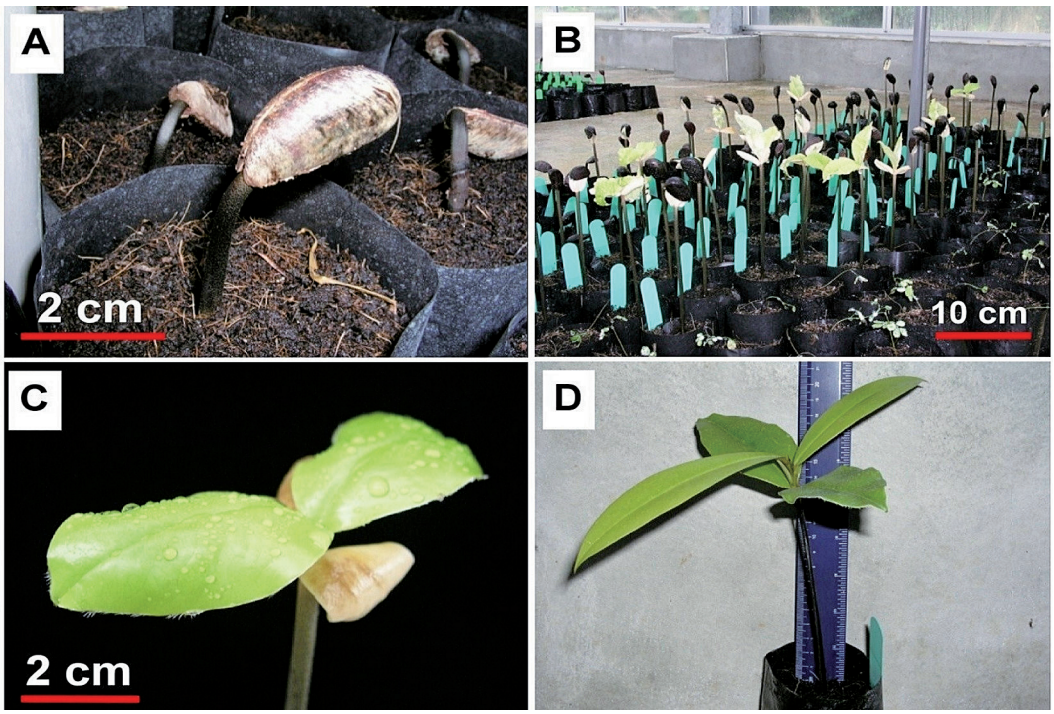

Figure 2. Germination of *Diospyros philippensis* seeds and morphology of the seedlings.
(A) The root grows first at germination followed by the seedling is epigeal cotyledon. (B) After cotyledons and primary leaves develop, the hull of the seed and residual endosperm drop. (C) Fully expended primary leaves are opposite and ovoid to elliptic in shape, cotyledons gradually wilt. (D) The true leaves continue to grow which are lanceolate in shape and alternate phyllotaxis, cotyledons have dropped.

appear yellowish and slightly curled (Figure 2C), quickly losing water and shrinking. Most cotyledons fall off about two weeks after germination (Figure 2D). The 2 primary leaves are ovate to elliptical and arranged oppositely (Figure 2C), with a lifespan typically exceeding one year. The first true leaf and subsequent leaves are lanceolate and alternate (Figure 2D), with a lifespan of approximately 8–9 months, shorter than that of the primary leaves. Therefore, when the first and second true leaves fall off, the primary leaves usually still remain (Figure 3).

Development of naturally regenerated seedlings

Under natural forest conditions, the average germination percentage of seeds was 78.6%, with little difference observed among different light exposure groups (Figure 4). Most naturally developing seedlings stopped growing after the emergence of the primary leaves or the first true leaf and overwintered in this state, with a dormancy period lasting more than 5 months. The average interval from the emergence of the primary leaf to the emergence of the first true leaf was 224.0 ± 111.7 days, while the average interval from the emergence of the first true leaf to the

Figure 3. Seedling morphology of *Diospyros philippensis* in a natural forest environment.
The 2 seedlings on the left are from the previous year (about 15 months old), and those on the right are from the current year (about 3 months old); the primary leaves are still present, but the 1st and 2nd true leaves have fallen off. The marked areas are leaf scars.

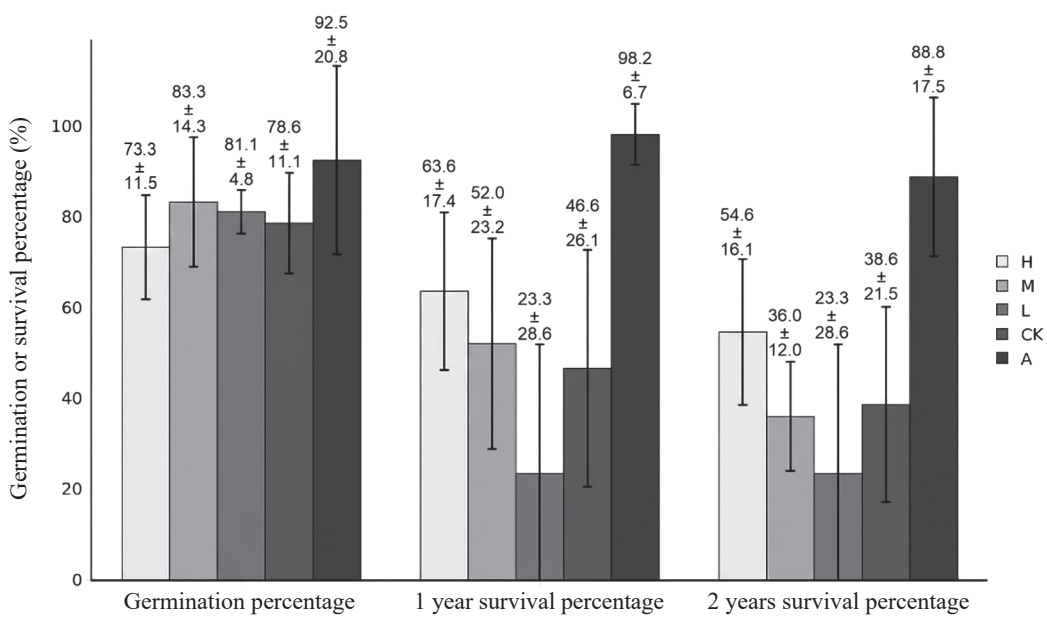

Figure 4. Germination and survival percentages of *Diospyros philippensis* seedlings under natural forest conditions (CK) and in artificial facilities (treatment A).
H, M and L: naturally regenerated seedlings under high (H), middle (M) and low (L) light conditions; CK is the total of all natural regenerated seedlings, including treatment H, M and L; treatment A designates an artificially controlled environment.

emergence of the second true leaf was 48.3 ± 63.1 days (Table 3). The large variability in the development time of true leaves suggests the influence of complex and heterogenous environmental factors. One-year-old seedlings had an average height of 18.3 ± 2.9 cm in high-light areas, 14.0 ± 2.2 cm in medium-light areas, and 16.6 ± 1.3 cm in low-light areas (Table 4), with an overall average height of 16.7 ± 3.1 cm (Figure 5). The number of leaves (excluding cotyledons) averaged 5.5 ± 2.1 in high light, 4.4 ± 1.3 in medium light, and 4.6 ± 1.3 in low light areas (Table 4), with an overall average of 5.0 ± 1.8 leaves (Figure 5). Two-year-old seedlings averaged 23.3 ± 3.3 cm in height in high light areas, 14.6 ± 2.8 cm in medium light, and 17.6 ± 1.2 cm in low light areas (Table 5), with an overall average height of 19.8 ± 4.8 cm (Figure 5). The average number of leaves in two-year-old seedlings was 12.5 ± 5.0 in high light, 5.8 ± 1.3 in medium light, and 5.3 ± 1.1 in low light areas (Table 5), with an overall average of 9.2 ± 5.1 leaves (Figure 5). The one-year survival percentage of naturally regenerated seedlings in the forest was 46.6%, and the two-year survival percentage was 38.6% (Figure 4), with a higher mortality percentage observed in the first year.

Development of seedlings cultivated in artificial facilities

The seed germination percentage in an artificial environment reached as high as 92.5%, similar to the data from the 'No treatment' group (94.0%, see Table 2) in the seed germination test (Figure 4). The growth stagnation period was significantly reduced, with an average of 51.9 ± 31.2 days from the emergence of the primary leaf to the emergence of the first true leaf, and an average of 22.5 ± 23.5 days from the emergence of the first true leaf to the emergence of the second true leaf (Table 3). The development time of the first two true leaves in the artificial environment was significantly shorter than that in the natural environment. In the first year, the average plant height was 22.8 ± 4.9 cm for Treatment A and 19.2 ± 2.4 cm for Treatment B. The number of leaves (excluding cotyledons) was 9.5 ± 2.3 for Treatment A and 7.7 ± 1.2 for Treatment B. In the second year, the average plant height was 46.2 ± 10.4 cm for Treatment A and 42.5 ± 8.8 cm for Treatment B. The number of leaves (excluding cotyledons) was 28.5 ± 5.7 for Treatment A and 23.3 ± 3.9 for Treatment B. Treatment C, D, and E showed poorer growth performance, falling between that of Treatment A and B and

Table 3. Growth days required from primary leaf to 1st true leaf, and from 1st true leaf to 2nd true leaf respectively.

	Intervals of leaf development			
	Primary - 1st		1st - 2nd	
	CK[x]	treatment A[y]	CK	treatment-A
Days	224.00 ± 111.72[az]	51.92 ± 31.17[b]	48.29 ± 63.06[A]	22.50 ± 23.51[B]

[x] CK is the total of natural regeneration seedlings data, including treatment H, M and L.
[y] treatment A represents the artificial cultivating environment.
[z] Each value represents the mean ± SD., Different letters represent significant differences among different treatments at $p < 0.05$according to the LSD test.

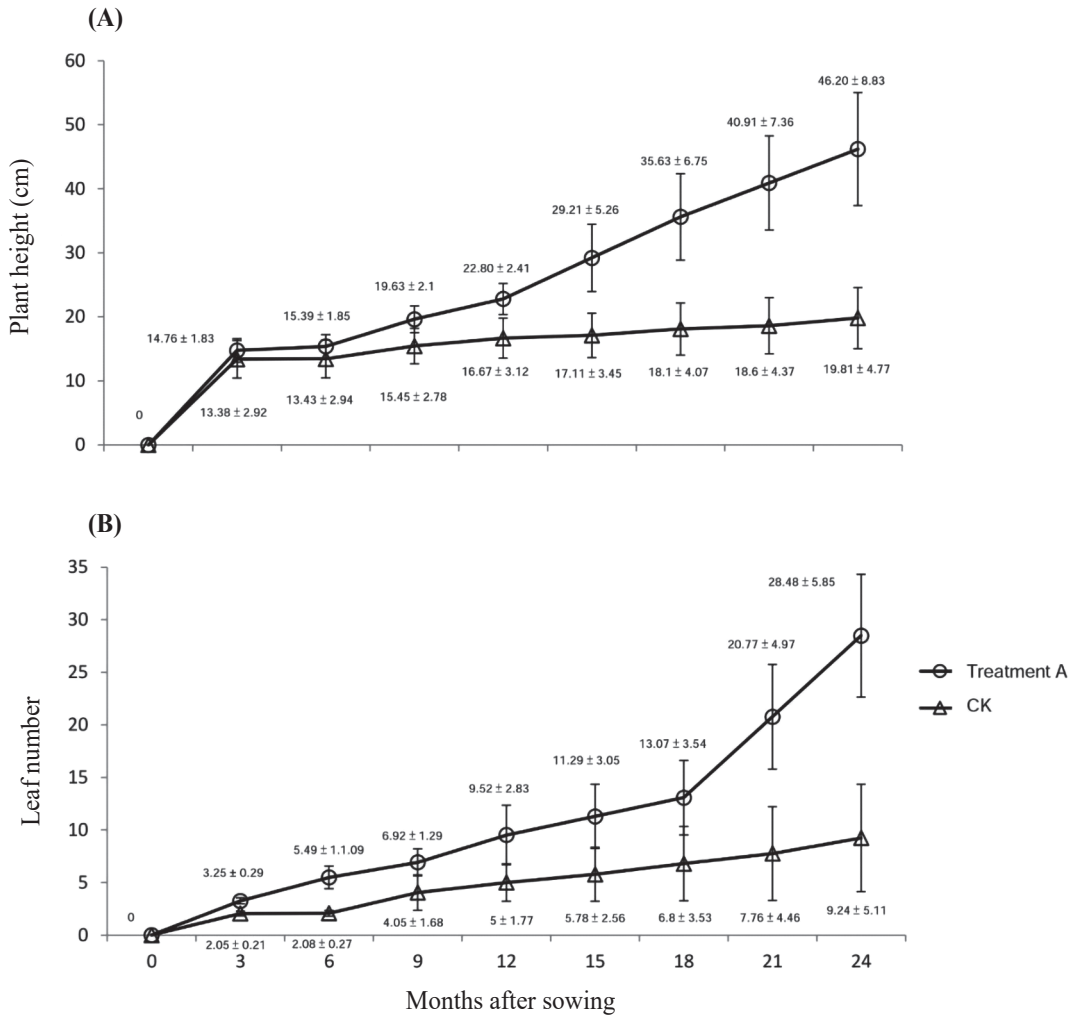

Figure 5. Plant (A) height and (B) number of leaves of *Diospyros philippensis* seedlings in a natural forest (CK) and in artificial facilities (treatment A: represents an artificially controlled environment.).

the naturally regenerated seedlings under the forest canopy (Plot H, M, and L), as detailed in Tables 4, 5 and Figure 5. Seedling survival rates were highest under Treatment A, with 98.2% survival after one year and 88.8% after two years, significantly outperforming the naturally regenerated seedlings under forest canopy (Figure 4).

Factors accelerating seedling growth

To effectively reduce seedling cultivation costs, accelerating seedling growth is essential. Despite sufficient irrigation and superior lighting to a glasshouse, the growth rate of seedlings cultivated in net houses still lags behind those grown in glasshouses. The reason may not be due to differences in the growing medium, but rather factors such as temperature, air humidity, or airflow. The Luoshan Wind (落山風，katabatic wind, northeast monsoon in Hengchun) affects the Hengchun Peninsula for up to half a

Table 4. Growth comparison of 1-year-old seedlings under different treatments.

Treatment[x]		H	M	L	A	B	C	D	E
H	LN:5.52±2.06[y]	-	0.0833[z]	0.2639	0.0000	0.0001	0.0008	0.0014	0.0001
	PH:18.33±2.93		0.0908	0.0478	0.0842	0.2957	0.2518	0.2438	0.3590
M	LN:4.38±1.26	0.0001	-	0.7563	0.0000	0.0000	0.0002	0.0001	0.0000
	PH:14.04±2.24	0.3903		0.0055	0.0884	0.6290	0.3638	0.4076	0.5135
L	LN:4.57±1.27	0.1390	0.0140	-	0.0000	0.0000	0.0062	0.0041	0.0015
	PH:16.57±1.34	0.0822	0.2915		0.0468	0.5426	0.2635	0.3061	0.4182
A	LN:9.52±2.31	0.0000	0.0000	0.0008	-	0.0001	0.2471	0.0334	0.8819
	PH:22.80±2.41	0.0252	0.0591	0.0170		0.0218	0.0020	0.0068	0.0000
B	LN:7.65±1.23	0.3021	0.0000	0.0112	0.0004	-	0.1358	0.3267	0.0255
	PH:19.17±2.40	0.0253	0.5387	0.2085	0.0183		0.0534	0.0247	0.1345
C	LN:8.90±3.71	0.5515	0.0003	0.2710	0.0000	0.0880	-	0.6101	0.6728
	PH:17.80±2.75	0.0092	0.3534	0.0482	0.0301	0.0693		0.0073	0.0056
D	LN:8.33±2.99	0.2153	0.0025	0.6018	0.0000	0.0187	0.4888	-	0.3352
	PH:17.17±2,83	0.0412	0.2735	0.0120	0.0343	0.1338	0.0134		0.0310
E	LN:9.43±3.32	0.0434	0.0406	0.7637	0.0000	0.0020	0.1165	0.3589	-
	PH:16.21±2.92	0.1180	0.1572	0.0049	0.0367	0.2425	0.0752	0.0281	

The triangular matrix in the upper right half of this table is the *p* value of comparison in leaf number between different treatments. The triangular matrix in the lower left half of the table is the *p* value of comparison in plant height between different treatments.

[x] Treatments H, M and L: Natural regeneration seedlings under 3 female maoshi trees at high (H), middle (M) and low (L) light; treatment A: shading, spray irrigation, temperature control, artificial medium and fertilization in glasshouse; treatment B: spray irrigation, natural soil and non- fertilization in net house; treatment C: limited irrigation, natural soil and fertilization in net house; treatment D: limited irrigation, natural soil and non-fertilization in net house; treatment E: limited irrigation, sand and non-fertilization in net house.

[y] LN, leaf number; PH, plant height; each value represents mean ± SD.

[z] The upper value is the *p* value, and the lower value is R^2.

year, during which the wind blows and the air is relatively dry (Appendix), potentially causing increased transpiration. Under these conditions, seedlings inside a net house face this additional environmental stress compared to those in a glasshouse. The inferior growth performance under shade net Treatment B compared to glasshouse Treatment A is likely caused by more than just light intensity; the loss of moisture due to airflow and resulting lower humidity are also likely a significant contributing factors. Each plant species has a temperature tolerance range for growth, within which optimal temperatures promote maximum growth performance; as temperatures approach the upper or lower limits, growth declines (Dreesen and Langhans 1992). Located in the tropics, Kenting does not experience extremely cold winters, but for tropical species like maoshi, temperatures are likely below optimal during winter. Glasshouses create a greenhouse effect that effectively raises temperatures. Informal observations in this study found that the temperature difference between the glasshouse and the net house during daytime

Table 5. Growth comparison of 2-year-old seedlings under different treatments.

Treatment [x]		H	M	L	A	B	C	D	E
H	LN:12.50±5.04 [y]	-	0.0006 [z]	0.0012	0.0000	0.0000	0.0296	0.0403	0.0401
	PH:23.25±3.33		0.3780	0.3735	0.1870	0.6068	0.1282	0.1249	0.1331
M	LN:5.78±1.30	0.0000	-	0.4385	0.0000	0.0000	0.0000	0.0000	0.0000
	PH:14.61±2.84	0.6390		0.0435	0.1942	0.8592	0.5981	0.6167	0.6566
L	LN:5.29±1.11	0.0003	0.0194	-	0.0000	0.0000	0.0000	0.0000	0.0000
	PH:17.64±1.18	0.4458	0.3322		0.1642	0.8457	0.5808	0.6025	0.6454
A	LN:28.46±5.65	0.0000	0.0000	0.0000	-	0.0000	0.0000	0.0000	0.0000
	PH:46.20±8.83	0.1256	0.1215	0.0811		0.0270	0.1250	0.1085	0.0954
B	LN:23.33±3.90	0.0000	0.0000	0.0000	0.1070	-	0.0000	0.0000	0.0000
	PH:42.50±8.81	0.6728	0.7513	0.6744	0.0042		0.4068	0.4058	0.4071
C	LN:16.21±4.91	0.3146	0.0000	0.0018	0.0000	0.0000	-	0.9891	0.9653
	PH:22.15±3.31	0.0281	0.5642	0.3274	0.1487	0.7061		0.0001	0.0001
D	LN:16.19±5.00	0.0319	0.0005	0.0688	0.0000	0.0000	0.1739	-	0.9569
	PH:20.50±3.82	0.1360	0.4139	0.1491	0.1383	0.7122	0.0537		0.0001
E	LN:16.29±4.83	0.4510	0.0000	0.0015	0.0000	0.0000	0.8569	0.1638	-
	PH:22.36±3.21	0.0191	0.6234	0.4211	0.1083	0.6682	0.0010	0.0680	

The triangular matrix in the upper right half of this table is the *p* value of comparison in leaf number between different treatments. The triangular matrix in the lower left half of the table is the *p* value of comparison in plant height between different treatments.

[x] Treatments H, M and L: Natural regeneration seedlings at high (H), middle (M) and low (L) light; treatment A: shading, spray irrigation, temperature control, artificial medium and fertilization in glasshouse; treatment B: spray irrigation, natural soil and non- fertilization in net house; treatment C: limited irrigation, natural soil and fertilization in net house; treatment D: limited irrigation, natural soil and non-fertilization in net house; treatment E: limited irrigation, sand and non-fertilization in net house.

[y] LN, leaf number; PH, plant height; each value represents mean ± SD.

[z] The upper value is the *p* value, and the lower value is R^2.

in the winter can reach up to 3℃, which represents favorable growth conditions for glasshouse-cultivated seedlings. Therefore, in Taiwan, it is recommended that maoshi seedling cultivation should at least use a simple greenhouse, for example a plastic film greenhouse, especially during the low temperatures of winter, to ensure continuous development of seedlings.

The growth of maoshi seedlings, whether in the first or second year, regardless of the number of developed leaves or plant height, showed no significant differences among the limited irrigation groups C, D, and E cultivated in the net house (see the 2-year-old seedling height section in Table 5). Comparing Treatment C to Treatment D, $p = 0.1739 > 0.05$, reveals that the growing medium had no significant effect; comparing Treatment D to Treatment E, $p = 0.1638 > 0.05$, shows that fertilization had no significant effect. Therefore, it can be concluded that fertilization and the type of growing medium may not be the main factors affecting the growth of maoshi seedlings. Between the unfertilized Treatment B and

Treatment D, where only irrigation conditions differed, the *p* values for both seedling height and the number of developed leaves in 2-year-old seedlings were all less than 0.001, which is highly significant (Table 5). This indicates that water availability is a very important factor influencing the growth of maoshi seedlings. Additionally, from field understory regeneration seedling experiments with different light penetration rates, it is evident that light conditions are also a crucial influencing factor. For 2-year-old regenerated seedlings, the high light plot (H) showed significant differences compared to the medium light plot (M) and low light plot (L); except for the number of developed leaves in plot H versus plot L, where the p value was between 0.01 and 0.001, all other comparisons had *p* values < 0.001.

Comprehensive discussion

Maoshi fruits and seeds are relatively large and, aside from dispersal by humans or monkeys (*Macaca cyclopis*) (Pan 1999), they typically fall directly onto the ground beneath the mother tree's canopy. According to Liu (1992), young maoshi seedlings are sensitive to intense sunlight and require shading during artificial propagation. He also noted that few maoshi fruit seeds are dispersed far from the forest, with the majority germinating under the shade of the mother tree. However, small seedlings rarely thrive unless the mother tree dies or a canopy gap opens, indicating that sunlight is essential for seedling growth and that an intermediate amount of light is a prerequisite for the healthy development of maoshi seedlings. Therefore, naturally regenerated seedlings are mostly concentrated beneath or near the parent canopy, making light conditions under the forest canopy a crucial factor influencing the survival of maoshi seedlings. In this experiment, whether in high, medium, or low light plots, the actual light penetration rates were quite low—only 13.8%, 9.4%, and 3.3%, respectively. Under these conditions, the differences in seedling growth performance—such as height, number of leaves, and survival rate—were significantly pronounced. This indicates that within this range of light intensity, the light available is insufficient for the growth of maoshi seedlings, and every bit of additional light is precious. Conversely, any reduction in light further starves the seedlings, potentially leading to energy depletion and death.

Shading experiments results reported by Liao et al. (1995) found that maoshi seedlings exhibited the best height growth under 80% shading (i.e., relative light intensity of 20%) when grown in black plastic pots in a medium of peat moss and vermiculite (1:1), and supplied with slow-release fertilizer (N:P:K = 3:1:1) every three months,. Seedling height declined when light intensity was either increased or decreased from this optimum. The effects of light intensity's on seedling height growth in our study are similar to those of Liao et al. (1995). The treatment groups in this study closest to 20% relative light intensity were the glasshouse (Treatment A) at 34.2% and the high-light area under the forest canopy (Treatment H) at 13.8%. Seedlings grown in the glasshouse attained greater mean heights (46.20 ± 8.83 cm) than those under shade nets. None of the seedlings cultivated under Treatments B, C, D, or E—under a relative light intensity of 57.6%—exceeded a height of 42.50 ± 8.81 cm). Similarly, seedling height growth in the high-light area under the forest canopy (Treatment H, 23.25 ± 3.33 cm) was higher than the medium-light area (Treatment M, 9.4% light intensity) and the low-light area (Treatment L, 3.3% light intensity) under the forest canopy, with heights of 14.61 ±

2.84 cm and 17.64 ± 1.18 cm, respectively. Additionally, according to Kuo et al. (2021), the photosynthetic potential of maoshi is 12.3 μmol CO_2 m^{-2} s^{-1}, making it an extremely shade-tolerant plant; with a light saturation point of 1,050 μmol photons m^{-2} s^{-1}. In the Kenting region, sunlight intensity far exceeds this threshold on sunny days. Does excessive sunlight have negative effects on growth? Shading can protect plants from strong light damage, but inappropriate shading may also have adverse effects on plants, such as stem elongation or plant weakening. The intensity and timing of shading are critical factors (Heiskanen 2004). Although Liao et al. (1995) indicated that 20% of full sunlight is the optimal growth condition; this is a relative value, and exploring the precise light requirement remains an important research topic.

In the Hengchun Peninsula, afforestation efforts should avoid the dry season, which coincides with the katabatic wind and winter seasons, and planting should be carried out as early as possible upon onset of the wet season to ensure a longer growing period before the onset of the next dry season. Therefore, the optimal planting season is April to May, which is also generally the best planting period for most plants. At this time, seedlings are approximately 0.5 years post-germination from the previous year. However, seedlings that are only 0.5 years or even 1 year old are still too small for outplanting. Outplanting closer to the end of the year is also detrimental to seedling performance. Thus, the optimal cultivation period for maoshi seedlings should be between N + 0.5 – N + 1 years. A larger value for N results in higher costs; therefore, reaching the outplanting standard when N=1 is the most cost-effective.

The optimal outplanting height for maoshi is 50 (40–60) cm (Liu 1992). Consequently, the goal is typically to cultivate seedlings to this specification within two years (i.e., N + 0.5 – N + 1 years, with N=1). Liu (1992) suggested achieving this goal through improvements in medium and containers, as well as maintaining soil moisture and shading, but did not provide detailed cultivation environments or experimental data, such as the type of artificial facility, irrigation frequency, or the proportion of seedlings reaching the standard. The two key factors he highlighted—soil moisture and shading, align with the findings of this study that water and light are the most critical factors affecting seedling growth.

In this study, seedlings cultivated in the glasshouse (Treatment A) for two years reached a mean height of 46.20 ± 8.83 cm, which is consistent with Liu (1992)'s mention of cultivating 40–60 cm seedlings within two years. Considering the optimal outplanting period, the most cost-saving scenario is cultivation for 1.5 years. Our glasshouse (Treatment A) produced 35.9% of seedlings exceeding 40 cm in height.

The seedling stage of maoshi appears to be insensitive to fertilizer application. The reason may not be solely due to the species' inherent characteristics, and a definitive conclusion cannot yet be drawn. It is possible that the amount of fertilizer applied so far has not been sufficient to elicit a noticeable response. Future studies could explore fertilizer type, composition, and dosage, since different plants respond differently to fertilization and different plant species have varying nutrient requirements. (Kao 2003).

After seedlings are produced, they are usually planted in the target site. Depending on the site, the seedlings will encounter various stresses. Only those that can pass the tests of stresses and grow into mature trees are high-quality seedlings. Different tree species respond differently to these

stresses. For example, competition from herbaceous plants can significantly impact seedling height growth, but has no effect on pine species (De Steven 1991). A healthy root system is essential for high-quality seedlings, so the seedling raising method and container selection are crucial aspects of seedling cultivation (Haase et al. 2021, Grossnickle and Ivetić 2022). Insufficient water can severely inhibit plant growth, but excessive water supply is wasteful and high soil moisture levels impair soil gas exchange (Carson 1974, Huang 1983). Oxygen deficiency in plant roots leads to reduced root vitality, decreased root dry weight, impaired new root growth and elongation, and accelerated new root death (Kozlowski 1984, Olien 1987, Buwalda 1993, Schaffer 1998), ultimately weakening root system structure and function. Even if the aboveground parts show good growth, the seedlings may die due to poor adaptation when transplanted into natural environments. This study currently focuses solely on the height and number of developmental nodes of *Diospyros philippensis* (Desr.) Gürke seedlings and does not address issues related to improving seedling quality, which also warrants further in-depth research.

CONCLUSIONS

This study experimentally characterized the seed germination and early seedling development of maoshi (*Diospyros philippinensis*), identifying critical limiting factors and physiological requirements. These findings provide a practical framework for optimizing nursery management and reducing costs in the artificial production of high-quality seedlings. The primary conclusions are summarized as follows:

1. Sowing strategy and seed viability: To maximize germination vigor and ensure seedling resilience, seeds should be sown immediately upon collection. Maoshi seeds exhibit characteristics typical of recalcitrant seeds; delayed sowing leads to a rapid decline in viability due to dehydration or low-temperature sensitivity. An "immediate sowing" approach is essential to maintain optimal germination rates.
2. Mitigation of growth stagnation: A distinct period of growth stagnation typically occurs following initial germination, serving as the primary bottleneck for early-stage development. Our results indicate that this phase can be shortened through the strategic application of water and light. Maintaining optimal metabolic activity through precise environmental control is the most effective way to overcome this developmental plateau.
3. Precision water management: While consistent irrigation significantly promotes vertical growth—with 35.9% of individuals exceeding 40 cm within 1.5 years—moisture levels must be meticulously balanced. Excessive soil moisture impairs rhizosphere gas exchange, inducing root hypoxia and inhibiting the development of new root primordia. Furthermore, rapid growth must be balanced with seedling hardening prior to outplanting; this ensures the plants develop the physiological toughness required to survive the transition from controlled environments to natural field conditions.
4. Photophysiological adaptation and shading protocols: Maoshi is a shade-tolerant species with a relatively low light saturation point. In tropical regions like the Hengchun Peninsula, intense summer irradiance can trigger photoinhibition or severe leaf scorch. Consequently, the use of shading nets is critical during the nursery stage. However, over-shading must be avoided to prevent

etiolation or general plant weakness. While Liao et al. (1995) recommended 20% of full sunlight as a baseline for the Kenting area, more precise experiments are required to define the optimal light intensity range for cultivation in other regions.

5. Future research and commercial outlook: The optimization of maoshi silviculture depends on the precise coordination of hydro-thermal conditions, light quality, and nutrient loading. As this study focused primarily on abiotic factors, future research should investigate specific fertilization regimes—including optimal N-P-K ratios, application frequencies, and slow-release formulations. Achieving a production goal where the majority of seedlings exceed 40 cm within 1.5 years will significantly enhance the commercial viability and efficiency of maoshi nursery stock production.

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研究報告

影響毛柿(*Diospyros philippensis* (Desr.) Gürke)種子活力及苗木生長之環境因子的初步探討

洪聖峰[1]、蔡佳彬[2]

摘要

背景

毛柿常做為造林或綠化樹種，墾丁地區林下6年生苗木高度均在1 m以下，在庭院栽植亦需10年以上才可開花，毛柿生長速率低是不爭的事實。如此緩慢的生長過程，需要花費較長時間培育苗木，如果無法縮短育苗期程會提高苗木生產成本，亦導致苗木售價高昂。較高價的種苗也可能降低採用意願，所以生長緩慢可能間接影響推廣。故如何加速其成長，成為種苗繁殖需致力的一個重要項目，本研究觀查從果實取出種子到播育成苗的2年過程，探討環境因子對生長發育的影響，作為繁殖育苗操作的參考。

材料與方法

種子發芽試驗

剝取並洗選優良種子分為4種處理：1. 無任何處理直播，植入介質後置於溫室內培育；2. 陰乾24小時後同1之方法播種培育；3. 強風吹乾18小時後同1之方法播種培育；4. 分別以10℃貯藏24、48、72小時後同1之方法播種培育。

苗期生長觀察

本試驗在各種環境下觀察並記錄毛柿從種子萌芽起2年之生長，調查項目包含苗高、葉片發育及葉片凋落等。期間亦不定期記錄日照量，用以評估試驗組間之光照差異。各試驗組為：1. 林下更新苗包含高(H)、中(M)、低(L) 3種光照條件。2. 溫網室培養，利用溫室(防

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風保溫)、網室、遮陰、噴灌、介質種類、施肥等變因，組合成A-E等5個試驗組，每6個月調查1次，調查至滿2年為止。

結果與討論

毛柿果實在8月中旬至9月上旬成熟掉落腐爛後，不具休眠性種子隨即發芽，平均發芽率為78.6%，人工條件下可達92.5%(育苗試驗數據)或94.0%(種子發芽試驗數據)，失水及10°C低溫都可降低種子活力。毛柿2片初生葉卵形至橢圓形呈對生狀，之後本葉披針形呈互生狀。大部分天然更新苗在初生葉或第1本葉展開後停止生長，並以此狀態渡冬，停滯時間可達5個月以上。小苗在墾丁(南臺灣)天然林中生長極為緩慢，一年生植株平均株高16.7 ± 3.1公分，葉片(不含子葉) 5.0 ± 1.8片，存活率46.6%；二年生植株平均株高19.8 ± 4.8公分，葉片9.2 ± 5.1片，存活率38.6%。人工環境下生長停滯期可大幅縮減，一年平均株高22.8 ± 4.9公分，葉片(不含子葉) 9.5 ± 2.3片，存活率98.6%；二年平均株高46.2 ± 10.4公分，葉片(不含子葉) 28.5 ± 5.6片，存活率90.6%。水分及日輻射量是加速苗期生長最重要因子，介質及肥料施用影響則小，適宜的人工條件下栽培可大幅縮短毛柿育苗期。

結論

本報告為毛柿育苗2年過程的初步研究，結果指出環境因子可大幅影響毛柿苗期生長速率，其中光照與水分影響最大，但最佳條件仍需更深入探討。除了光與水之外，尚有其它因子值得深入研究，如介質、施肥等本研究尚未探明的部分，期待盡可能縮短毛柿苗的育苗期程，降低生產成本以利推廣應用。另外，除了加速苗期生長，苗木品質與健化程度需兼顧，以提高初栽定植成活率。

關鍵詞：毛柿、種苗生產、生長節律、柿樹科

洪聖峰、蔡佳彬。2026。影響毛柿(*Diospyros philippensis* (Desr.) Gürke) 種子活力及苗木生長之環境因子的初步探討。台灣林業科學41(1): 21-42.

APPENDIX

Climate data (1981-2014) from Guizijiao weather station (龜仔角氣象站) of Taiwan Forestry Research Institute.

Month	Average temperature (℃)	Average relative humidity (%)	Average wind speed (m/s)	Summary of climatic characteristics
Jan.	18.7 (Min.)	72.6	5.4 (Max.)	Month with the lowest temperature, dry season, strongest period for Luoshan Wind (katabatic wind), highest average wind speed.
Feb.	19.3	74.0	5.3	Dry season, strong winds persist, significantly impacting outdoor facilities and plants.
Mar.	21.0	68.3 (Min.)	4.8	Late dry season, lowest relative humidity, wind speed begins to decrease.
Apr.	23.3	70.0	4.4	Temperature gradually rises, entering spring, wind speed continues a steady decline.
May	25.5	74.0	3.5	Entering summer and the wet season, noticeable temperature increase, significant drop in wind speed.
Jun.	26.5	77.0	3.0 (Min.)	End of the plum rain season, high temperature and humidity, lowest wind speed period of the year, summer breezes.
Jul.	27.0 (Max.)	78.4	3.2	Month with the highest temperature, hot summer, light breezes.
Aug.	26.8	82.4 (Max.)	3.6	Typhoon season, highest rainfall and humidity, occasional sudden strong winds due to typhoons.
Sep.	26.0	79.7	3.7	Humidity remains high, temperatures drop slightly, wind speeds remain low.
Oct.	24.3	75.8	4.1	Entering autumn, wind speed gradually increases, preparing to enter the Luoshan Wind dry season.
Nov.	22.2	74.8	4.9	Early dry season, Luoshan Wind begins, wind speed significantly increases.
Dec.	19.7	73.0	5.2	Mid-dry season, temperature drops, strong Luoshan Wind.
Annual average	23.4	74.0	4.2	Low annual temperature range (only 8.3℃), high average wind speed.