Exploration of High-quality and High-yield Cultivation Techniques for Early-spring Open-field Watermelon under Small Arch Tunnels in Eastern Henan

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Abstract Eastern Henan (including Shangqiu, Xiayi, Yucheng, Lankao, and surrounding areas) is located in the hinterland of the Huang - Huai - Hai Plain, with abundant light and heat resources and soil types suitable for watermelon growth. "Xiayi Watermelon", as a National Geographical Indication agricultural product, is predominantly cultivated in the early-spring open-field small-arch-tunnel model, which is the leading high-efficiency cultivation system in the region. This model features low input costs and early market availability, maturing 25 to 35 days earlier than conventional open-field cultivation, with significant economic advantages. However, the spring climate in eastern Henan is highly variable, with frequent late spring frosts, strong winds, and intermittent rainy weather. In addition, long-term continuous cropping in traditional production areas and varying levels of standardized management among growers have led to prominent problems, including poor seedling quality, extensive temperature and humidity management, frequent malformed and cracked fruits, worsening soilborne diseases, and irrational water and fertilizer management. Based on the climatic characteristics, soil conditions, and years of field experiment and demonstration experience in eastern Henan, this paper systematically summarizes the standardized cultivation techniques for the entire process of early-spring small-arch-tunnel watermelon production, analyzes existing production shortcomings, and proposes corresponding optimization measures. The aim is to improve the marketable fruit rate, fruit quality, and yield per unit area of watermelon, and promote the green, sustainable, and high-quality development of the early-spring watermelon industry in eastern Henan. This paper provides technical references for watermelon cultivation in similar ecological regions of the Huang - Huai area.

Key words Eastern Henan; Early-spring watermelon; Small arch tunnel; Open-field cultivation; High-quality and high-yield; Cultivation techniques

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Early-spring open-field small-arch-tunnel watermelon cultivation adopts a double-layer covering system of plastic mulch and simple arch film, and relies on natural light and heat resources to achieve early transplanting and avoid the threat of low-temperature frost in early spring. It is a widely adopted cultivation model by numerous households in eastern Henan. The early-maturing watermelons produced under this model can be marketed in bulk from mid-to-late May, seizing the market gap, and the planting returns are significantly higher than those of post-wheat open-field watermelons. However, with the years of cultivation increasing, industrial shortcomings have become increasingly apparent. Most growers manage based on traditional experience, with insufficient standardization in grafted seedling production. Ventilation and insulation operations for small arch tunnels are carried out arbitrarily, while freezing damage from late spring frosts and heat damage from high temperatures occur every year. Long-term continuous cropping has led to soil acidification, pathogen accumulation, and combined outbreaks of Fusarium wilt, gummy stem blight, bacterial diseases, and viral diseases. Imbalanced water-fertilizer management frequently leads to excessive vegetative growth, poor fruit setting, fruit cracking and malformed fruits with large navels, which severely restrict watermelon quality and economic benefits. Based on the unique spring climatic conditions and local production status in Eastern Henan, this paper integrates a set of standardized cultivation protocols for stable yield and improved quality according to local conditions to tackle production bottlenecks. It possesses important practical significance for consolidating the regional brand of early-maturing watermelon in Eastern Henan and facilitating farmers' income increase.

Variety Selection

Based on the early-spring climatic characteristics of eastern Henan, varieties with low-temperature tolerance, early maturity, strong disease resistance, stable fruit setting, transport tolerance, and resistance to fruit cracking should be selected[1]. Suitable main cultivars for the region include Zaojia 8424, Zhengza 5, Meidu, and the Tianwang series. For small gift-type watermelons, Xinongmi 1 and Hongyu can be selected. Late-maturing varieties with poor low-temperature and low-light tolerance and temperature-sensitive flowering stages should be avoided. For continuous cropping fields, rootstock-scion combinations with good grafting compatibility and resistance to Fusarium wilt should be prioritized.

Cultivation of Vigorous Seedlings

Seedling cultivation is the foundation for successful early-spring cultivation. In eastern Henan, plug seedling production in

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greenhouses is generally carried out in mid-to-late February, with a seedling age of 30 to 35 d, and transplanting is conducted when seedlings have 3 to 4 true leaves. Seeds are sun-dried for 4 to 6 h, and then soaked in warm water at 55 ℃ for 15 min with continuous stirring. After the water temperature drops to 30 ℃, soaking is continued for 6 to 8 h. The mucilage on the seed coat is washed off, and the seeds are germinated at a constant temperature of 28 to 30 ℃. Sowing can be performed in 50-cell plug trays once the seeds show radicle protrusion. For continuous cropping fields, grafted seedling production is recommended, using white-seeded pumpkin as the rootstock. The rootstock is sown 5 to 7 d earlier, and grafting is performed using the top insertion method.

Temperature and humidity management during the seedling stage

Before emergence: The temperature is kept at 28 – 32 ℃ in daytime, and the night temperature should not drop below 16 ℃. From emergence to expansion of the first true leaf: Appropriate temperature reduction is adopted to prevent excessive seedling growth, with temperatures of 22 – 25 ℃ during the daytime and 12 – 14 ℃ at night. For the seedling-formation stage, temperatures are maintained at 25 – 28 ℃ in the daytime and 14 – 16 ℃ at night. Low-temperature training is conducted 7 d prior to transplanting. The seedbed temperature is gradually decreased to enhance stress resistance of watermelon seedlings. Strict water management is implemented throughout the seedling stage, and irrigation is performed only when the substrate becomes dry for the prevention of damping-off and sheath blight.

Standards for vigorous seedlings

Watermelon seedlings should have 3 to 4 true leaves, with stout stems, short internodes, thick and dark green leaves, and a well-developed root system with dense white roots. They are free from pests and diseases. Grafted seedlings should have firmly healed graft unions.

Land Preparation and Fertilization

Priority should be given to fields with high and dry terrain, convenient drainage and irrigation, deep soil layers, and no cultivation of cucurbit crops within the past 3 years. Low-lying and waterlogged fields should be avoided. After the previous crop is harvested, deep plowing should be carried out to a depth of more than 30 cm[2]. Ten days before early-spring transplanting, rotary tillage and leveling should be performed, with high ridges running north – south. The ridges should be 18 – 22 cm in height and 2.2 m in width, and drainage ditches are reserved between ridges to prevent waterlogging and root rot during the rainy season. The fertilization principle should follow "emphasis on organic fertilizer, control of nitrogen fertilizer, increase of phosphorus and potassium, and supplementation of medium and trace elements". Per hectare, the following should be applied: fully decomposed organic manure 45 000 – 60 000 kg, potassium-sulfate-based N-P-K compound fertilizer (15-15-15) 600 kg, superphosphate 450 kg, borax 15 kg and magnesium sulfate 75 kg.

Timely Transplanting

The suitable transplanting period in eastern Henan is late March. Transplanting should be carried out only when the 10 cm soil temperature is stably maintained above 13 ℃, and the operation should be performed on sunny mornings. For ground-creeping cultivation, a single row is planted on each ridge, with a plant spacing of 60 – 70 cm, resulting in a planting density of 7 200 – 8 250 plants per hectare. After transplanting, the seedlings should be watered thoroughly with root-establishing water, and black plastic mulch should be immediately covered. The seedlings are then pulled out through holes, and a small bamboo arch tunnel is immediately erected, and covered with 0.06 mm thick film, and the edges are firmly sealed with soil.

Post-transplanting Field Management

Temperature and humidity management

During the slow-release period of 5 – 7 d after transplanting, the arch tunnels should be kept closed to maintain warmth, with daytime temperatures at 30 – 35 ℃ and nighttime temperatures not below 15 ℃, to promote rapid seedling establishment. After the slow-release period, ventilation should be gradually increased to regulate temperature: daytime temperatures should be controlled at 25 – 28 ℃. When the greenhouse temperature exceeds 32 ℃, ventilation should be initiated from both ends of the arch tunnels, with the openings gradually enlarged from small to large, avoiding sudden large openings at noon that could cause chilling injury to the seedlings[3]. When cold air or late spring frosts are approaching, the film should be sealed in advance, and non-woven fabric may be additionally covered outside the tunnels at night if necessary. In mid-to-late April, when the external temperature rises steadily and the vines elongate into the flowering stage, and the nighttime minimum temperature is stably above 12 ℃, the small arch tunnels can be removed on sunny mornings. Prior to removal, ventilation should be increased for 5 to 7 d consecutively to allow the seedlings to acclimate to the external environment and prevent stress injury after removal. Greenhouse humidity should be controlled, with timely ventilation to reduce humidity and minimize the risk of fungal and bacterial disease outbreaks.

Water and fertilizer management

During the vine extension stage, topdressing should be delayed as much as possible when sufficient base fertilizer has been applied. If plant growth is weak, a small amount of high-nitrogen water-soluble fertilizer may be applied through irrigation, combined with foliar spraying of potassium dihydrogen phosphate and boron fertilizer. Excessive nitrogen fertilizer should be strictly avoided to prevent vine etiolation and difficulty in fruit setting. During the fruit enlargement stage, when young fruits lose fine pubescence and reach the size of an egg, the first fruit-enlarging fertilizer application should be applied through irrigation, with 150 – 180 kg of high-potassium water-soluble fertilizer per hectare. A second fruit-enlarging fertilizer application should be applied 10 d later. Foliar spraying of fluid calcium and boron fertilizers should

be carried out regularly to improve rind toughness and effectively reduce fruit cracking. During the maturation stage, watering and fertilization should be stopped 7 to 10 d before harvest, maintaining moderate soil dryness to promote sugar accumulation and enhance watermelon sweetness[4]. Watering should be carried out in the morning or evening, so as to avoid large-volume irrigation at noon. Flooding after drought should be avoided to prevent rapid flesh expansion from cracking the rind.

Pruning and vine training

For watermelon cultivation under small arch tunnels in eastern Henan, the double-vine training method is commonly adopted. The main vine and one robust side vine at the base are retained, while all other side vines and sub-vines are promptly removed. Pruning should be carried out on sunny mornings to reduce the risk of infection through wounds. When the vines reach 50 cm in length, they were pressed down every 4 to 5 nodes to guide them to spread evenly across the ridge surface, improving ventilation and light penetration.

Artificial pollination

Before the small arch tunnels are removed, insects cannot easily enter the tunnels, so artificial pollination is required. From 7:00 to 10:00 each morning, freshly opened male flowers should be collected and their pollen is evenly applied to the stigmas of female flowers. Priority should be given to pollinating the second and third female flowers on the main vine (nodes 12 to 18), while the first female flower (root fruit) should be firmly discarded. After pollination, the date should be marked to facilitate later judgment of maturity and harvest time. In case of continuous rainy weather, fruit-setting regulators may be used in a standardized manner, with concentrations strictly adjusted according to temperature. The solution should be prevented from contacting the fruit navel to reduce the incidence of large-navel and malformed fruits.

Fruit thinning and fruit setting

When the young fruits reach the size of an egg, fruit setting should be carried out promptly. Only one well-shaped young fruit free from pests and diseases should be retained per plant, while malformed fruits and those affected by pests or diseases should be removed. After fruit enlargement, straw should be placed under the fruit to prevent contact with soil, which could cause mottled rind or fruit rot[5].

Disease and Pest Control

Management of major diseases

Common diseases of watermelon include fungal and bacterial diseases. In continuous cropping fields, Fusarium wilt and gummy stem blight are prominent[6]. Under high-humidity conditions, the risk of anthracnose and *Phytophthora* blight outbreaks is high. In protected cultivation, powdery mildew and bacterial fruit blotch are prone to occur. Disease control should prioritize agricultural prevention, with timely application of chemical control at the early stage of disease onset, and rotation of pesticides to prevent the development of resistance.

Fusarium wilt of watermelon Fusarium wilt is a soilborne vascular disease, with severe occurrence in continuous cropping fields. It can occur from the seedling stage to the fruiting stage, causing plant wilting, longitudinal cracking at the base of the stem, and browning of the vascular bundles. Agricultural control: Crop rotation is implemented, and grafted seedlings with pumpkin rootstocks are adopted. Fully decomposed organic manure is applied. Flood irrigation is avoided, and field drainage and humidity reduction are ensured. Chemical control through root drenching (after seedling recovery following transplanting): 30% hymexazol aqueous solution is diluted 800-fold, and applied at 200 – 250 ml per plant, and 25% fludioxonil suspension concentrate is root-drenched at 1 200-fold dilution. At the early onset of disease: Mixture of 40% difenoconazole suspension concentrate (1 500-fold dilution) and 2×10^8 CFU/g *Bacillus subtilis* wettable powder (500-fold dilution) is applied as root drench. Treatments are performed at intervals of 7 – 10 d for two consecutive times.

Gummy stem blight High humidity and poor ventilation can easily lead to outbreaks, affecting stems and leaves. Brown sunken lesions appear on stems, with gum exudation in the later stage, causing stem rot and death. Agricultural control: Rational planting density is adopted, and pruning and side-shoot removal are carried out on sunny days to reduce humidity inside tunnels. Plant wounds are minimized during field operations. Following agents can be selected for spraying: 45% prochloraz emulsion in water, 1 200-fold dilution, and 32.5% difenoconazole-azoxystrobin suspension concentrate, 1 500-fold dilution[7]. Chemical paste application can be conducted on gum-exuding stem lesions: 25% azoxystrobin suspension concentrate at 50-fold dilution is applied onto diseased tissues. Sprays are performed at 7 d intervals for 2 – 3 consecutive times.

Anthracnose Leaves, petioles and fruits can all be affected. The disease is prevalent under high-temperature and high-humidity conditions, and sunken and cracked lesions appear on fruits. Following chemical agents can be selected: 25% bromothalonil wettable powder 800-fold solution, and 10% difenoconazole water-dispersible granules 1 500-fold solution. Supplementary spraying should be carried out promptly after rain, ensuring even coverage on fruit surfaces, and spraying should be stopped 7 – 10 d before harvest.

***Phytophthora* blight** Roots, stem bases and leaves are affected, with rapid disease progression. The disease is highly prone to outbreak after rain, causing rapid wilting and death of plants. Chemical agents: 72% cymoxanil · mancozeb wettable powder 600-fold solution, or 50% dimethomorph water-dispersible granules 1 200-fold solution is applied by foliar spraying and stem base drenching, once every 7 d.

Powdery mildew Powdery mildew occurs frequently in shelter-cultivated watermelon. Leaves are covered with white powdery substances, and photosynthesis is impaired. Following chemical agents can be selected: 43% fluopyram-trifloxystrobin suspension concentrate at 2 000-fold dilution, or 25% kresoxim-methyl sus-

pension concentrate at 1 500-fold dilution. Heavy spraying is conducted on the abaxial leaf surfaces. Rotation of chemical agents is adopted to avoid long-term application of a single agent.

Bacterial fruit blotch It is a bacterial disease that infects leaves and young fruits and causes spot and rot on fruits. Seed-borne bacteria serve as the primary initial infection source. Agricultural control: Healthy and disease-free seeds are selected; seed disinfection is performed; and prolonged leaf surface dew formation is avoided. Following chemical agents can be selected: 30% zinc thiazole suspension concentrate at a dilution of 600 to 800 fold and 20% thiodiazole-copper suspension concentrate at 500-fold dilution. Spraying is carried out at the early disease onset, with treatments applied at intervals of 5 – 7 d for 2 – 3 consecutive times.

Pest control

The main pests of watermelon can be divided into piercing-sucking pests and leaf-feeding and fruit-boring pests. Aphids and *Bemisia tabaci* transmit viral diseases. Spider mites break out under high-temperature and drought conditions. *Diaphania indica* and *Spodoptera litura* feed on leaves and fruits. Soil-dwelling pests damage seedling roots. A combination of physical trapping and chemical control should be implemented, with attention to the critical control period of young larvae.

Aphid control Aphids transmit watermelon viral diseases, suck leaf sap, and cause leaf curling and malformation. Physical control: Yellow sticky traps can be installed for trapping, with 375 – 450 sheets per hectare. Following chemical agents can be selected: 10% imidacloprid wettable powder 1 500-fold solution, and 20% clothianidin suspension concentrate 2 000-fold solution. The spraying is carried out once every 7 – 10 d with attention to the undersides of leaves.

B. tabaci *B. tabaci* occurs severely in facility arch tunnels with a rapid reproduction rate, and it induces sooty mold disease. Chemical agents: 22% spirotetramat suspension concentrate at 2 000-fold dilution and 25% thiamethoxam water dispersible granules at 2 500-fold dilution are applied twice consecutively at a 7 d interval.

Spider mites Spider mites erupt under high-temperature and drought conditions. They infest the abaxial leaf surfaces and cause leaf chlorosis, whitening and desiccation. Following chemical agents can be selected: 43% bifenazate suspension concentrate at 2 000-fold dilution and 15% etoxazole suspension concentrate at 1 800-fold dilution. The two agents are applied in combination to control adult mites and eggs simultaneously. Uniform coverage of abaxial leaf surfaces is ensured during spraying.

D. indica Larvae feed on leaves, and bore into vines and young fruits. Young larvae have low resistance to pesticides, representing the optimal control window. Following chemical agents can be selected: 5% emamectin benzoate microemulsion 1 500-fold solution, and 20% chlorantraniliprole suspension concentrate 3 000-fold solution. Application in the evening yields better results.

S. litura* and *Spodoptera exigua They are polyphagous pests with voracious feeding habit. Larvae feed on leaves and fruit rinds. For chemical agents, 14% chlorantraniliprole · lambda-cyhalothrin suspension concentrate at 2 000-fold dilution can be selected. Spraying is conducted at the young-larva stage. Supplementary spraying is performed at a 7-d interval under high pest population density.

Soil-dwelling pests (white grubs and wireworms) They damage seedling roots, causing plant death. Soil treatment is conducted before transplanting: 5% thiamethoxam granules, 22.5 – 30.0 kg/hm^2, broadcast with base fertilizer. During the seedling stage, 40% phoxim emulsifiable concentrate 800-fold solution can be adopted for root drenching.

Timely Harvesting

Harvest maturity should be determined based on pollination marking dates, rind glossiness, and tendril withering. Early-maturing varieties mature 28 to 34 d after pollination. For long-distance transportation, harvest should be advanced by 1 to 2 d, while for local fresh-market sales, fruits should be harvested at full maturity. During harvesting, a short pedicel should be retained, and fruits should be placed gently. Grading and packaging should be carried out according to fruit weight, appearance, and sugar content to enhance market value.

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