Vegetable Tunnel House Technology in Tropical Island Countries

Zhiwen LIU *

Agricultural Foreign Economy Cooperation Center, Department of Agriculture and Rural Affairs of Hunan Province, Changsha 410005, China

Abstract A complete set of techniques for the design, installation, maintenance and use of vegetable tunnel houses in tropical island countries was developed, which achieved the goals of rain prevention, wind protection, corrosion resistance, insect and bird prevention, water-saving irrigation, and economic efficiency, significantly improving the production capacity and technical level of vegetables in Samoa. The techniques have become a key vegetable production technology promoted nationwide in Samoa, with universal promotion value for tropical island countries.

Key words Tropical island countries; Vegetable tunnel house; Design; Installation; Benefit

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Samoa is an island country in the tropical region of the South Pacific, with an Oceanic climate. It is warm and pleasant all year round, with abundant rainfall of 3 000 mm on average and average temperature of 26 ℃. In Samoa, the whole year is roughly divided into dry season and rainy season. Affected by southeast trade winds, it has relatively less rainfall from May to November, and the temperature is cool, making it the main season for vegetable production. The rainy season lasts from November to April of the following year, during which there is a large amount of rainfall, which affects the growth of vegetables in the field and is the off-season for vegetable production.

Samoa is mainly composed of two large islands, Upolu and Savaii, and eight small islands. With soil generated from volcanoes, the country is abundant with rocks, making the area have poor water and fertilizer retention abilities. The vegetable cultivation technology is relatively lagged behind, and most farmers adopt extensive planting methods, mainly planting vegetables in the open field. Due to the significant impact of concentrated rainfall, excessive sunlight, strong ultraviolet radiation, and other factors, the vegetable yield is low and unstable, and the supply of vegetable market is especially insufficient in the rainy season, when the prices of many vegetables are more than twice those in the dry season. A small number of farmers in Samoa have built their own simple plastic tunnel houses, which are not of high standards and have a short lifespan, making them prone to being blown down by strong winds. Samoa is a volcanic island country with frequent earthquakes, with 14 earthquakes of magnitude 6 or above occurring in the past 50 years. According to the seismic intensity zoning standards in China, the seismic fortification intensity of Samoa is 8 degrees, the tunnel house design basic acceleration of ground motion is 0.20 g, and the classification of design earthquake is in the first group. Affected by sea wind, Samoa has high air humidity with high moisture and salinity content, so the tunnel houses near the seaside are corroded 2 – 3 times faster than those in China. Samoa is susceptible to cyclone during the rainy season every year. According to local meteorological data, there is basically one cyclone every 5 years, and plastic tunnel houses need to have strong wind and rain resistance. The Cyclone "Gita" that struck Samoa in 2018 blew down most of the simple tunnel houses built by local farmers, causing significant losses.

The Samoa-China Agricultural Technical Aid Project (SCATAP) has been testing and demonstrating vegetable tunnel house technology in Samoa since 2010. From 2017 to 2020, the SCATAP Phase IV began to be promoted on a large scale, with 60 new plastic tunnel houses (30 m × 6 m) built for farmers, including 60 drip irrigation systems and 30 water tanks (5 500 L/unit), and updating 10 tunnel houses on the SCATAP Demonstration Farm (40 m × 6 m). During the SCATAP Phase V from 2020 to 2023, 60 double span tunnel houses were built for 30 farmers, with 2 tunnel houses per household. Each tunnel house was 30m in length and 6m in width, and was equipped with rainwater harvesting tank of 3 000 L. Years of research and development and promotion achieved the formation of a complete set of techniques for the design, manufacturing, installation, and utilization of vegetable tunnel houses in tropical island countries, which have the obvious advantages such as rain prevention, wind protection, corrosion resistance, insect and bird prevention, irrigation convenience, and economic efficiency, making it possible to meet the various technical indicators of vegetable production in tropical island countries with less investment, simple construction, and convenient use. The use of tunnel houses can quickly and efficiently achieve high-quality and high yield of vegetables by improving the microclimate, creating a good soil environment, and promoting improved varieties and methods, and it is a simple, practical, and efficient facility agriculture technology. In 2018, it earned a Chinese design patent and 2 utility model patents. Driven by China's aid to Samoa's agricultural projects, more than 400 vegetable tunnel houses have been promoted nationwide in Samoa. Tunnel house vegetable technology has become a key technology widely

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Zhiwen LIU (1964 –), male, P. R. China, Master, Senior Agronomist, devoted to the research on international agricultural technical cooperation.
* Corresponding author. E-mail: 1094384017@qq.com.

promoted in vegetable production in Samoa, significantly improving Samoa's vegetable production capacity and technical level, increasing farmers' income, and replacing some imported vegetables. This technology has universal reference value for vegetable production in tropical island countries.

Key Techniques for Vegetable tunnel houses in Samoa

The key techniques for vegetable tunnel houses in Samoa are as follows: appearance design techniques, wind resistance and corrosion resistance techniques, insect prevention techniques, water-saving drip irrigation techniques, maintenance techniques, and supporting cultivation techniques for vegetable tunnel houses. This includes engineering measures such as site stone removal and leveling, tunnel house installation, and supporting drip irrigation facilities.

Appearance Design Techniques for Vegetable Tunnel Houses

The vegetable tunnel house in Samoa is a prefabricated galvanized steel pipe plastic tunnel house, which has a simple structure, beautiful appearance, convenient installation and operation, and good universality and interchangeability. The tunnel house has strong wind and rain resistance. The main components are hot-dip galvanized and have a long service life. The inside space is spacious and convenient for manual and mechanical operation conditions.

Design features: Adopting a quadratic parabolic arch structure design, the greenhouse has novel and beautiful arch frame with a natural arc. It can be installed in a single shed or in jointed areas, providing an overall aesthetic feeling on site. The installation structure is designed with a reasonable axis, and given the production needs of tunnel house crops, the tunnel house has a span of 6m with a shoulder height of 2.00 m, a top height of 2.75 m, a length of 30 – 40 m, 6 columns at the head of the tunnel house, a width of 2 m door designed at the middle, and a total area of 180 – 240 m^2. Compared with arch stand columns, vertical columns improve the operating conditions in the tunnel house, and facilitate manual and mechanized operations in the shed, which is of special significance for tall Samoans people.

Tunnel house structure: The framework of the tunnel house is composed of arch rods, pull rods, shed head stand columns ABC, tension diagonal braces, arch connecting pipes, aluminum alloy slots; The connecting fixture consists of slot holders, U-shaped clamps, steel wire clamps, clamp keepers, film pressing clamps, and steel wire clamps, ensuring that the tunnel house has sufficient strength and stiffness; The door is designed as a sliding door of 2 m wide, which is convenient for operators and machines to get in and out.

Installation Techniques for Vegetable Tunnel Houses

Preparation before installation ① Understand the main technical parameters, structure, and installation dimensions of the pipe shed. ② Check whether the parts are complete according to the parts, standard parts, and outsourcing list; Check if the main components such as arch rods and pull rods are deformed during transportation. If there is any deformation, repair and calibrate them before installation. ③ Prepare installation and measuring tools: a 50 m tape measure, 4 wooden stakes, 100 m of nylon wire, 3 kg of lime, 1 – 2 φ steel drills, 1 – 2 8-pound hammers, 2 – 4 small hand hammers, 1 hand steel screwdriver, 1 – 2 screw extractors, 2 small adjustable spanner, 1 pliers, and 1 rechargeable electric hand drill. ④ Determine the position of the greenhouse. In general, the vertical direction of the tunnel house is perpendicular to the local main wind direction. ⑤ Determine the corner points and bury the positioning stakes by using the "3, 4, 5 law (*i.e.* Pythagorean theorem) or using the theodolite according to the specifications of the tunnel house (length and span). ⑥ Pull the axis and the level line (line rope). The axis is straight against the ground, and the level line is tied at the same level, generally 30 cm above the ground.

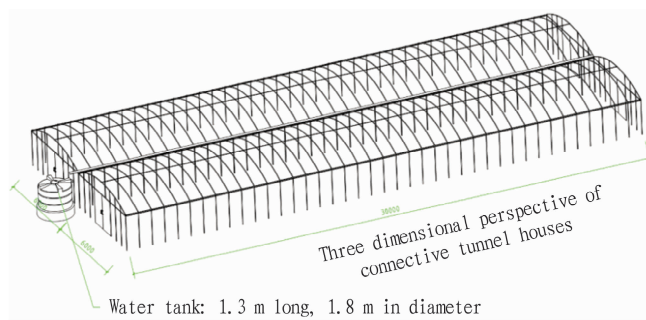

Fig. 1 Appearance design of vegetable greenhouses in tropical island countries

Installation steps ① Install reference lines at both ends of the tunnel house to hold up two pairs of arch rods, and insert the arch rods into the soil at a depth of 0.5 m, ensuring that the shed head is perpendicular to the ground. ② Starting from a shed head, insert each pair of arch rods into the land at a spacing of 0.80 m along the 2 reference lines (with a depth of 0.5 m and a foundation line marked with 0.5 m in the direction of the arch rod insertion), and be sure that all arch rods are parallel to each other and perpendicular to the ground, and the arch top is consistent in height (2.75 m). ③ For the installation of pull rod, butt joint the pull rods with a length of 6m and fasten it with 2 self-tapping screw #19 at the butt joint; Insert one end of the jointed rods into the pull rod sheath, connect the rods with the arch connecting pipe using steel wire clamps in sequence, and make sure that the spacing between the arch top is 0.75 m. ④ Install the card slots around the shed frame, with one at the head of the tunnel house and one on each side of the tunnel house (one at the shoulder height and one on each side). ⑤ Install 4 tension diagonal braces at both ends of the tunnel house from the arch to the center and from the top to the bottom. Each diagonal brace is connected to 6 arch rods, and the upper part of the diagonal brace is connected to the arch rods at the end of the tunnel house. ⑥ Insert the stand columns to the land according to the required length and installation position, with 6 at each end face. Connect the end stand columns and the horizontal columns on the 2 doors to the arch rods.

⑦ Install the tunnel house film when there is no wind. The film can be covered from one longitudinal end to the other, or from one side to the other. The film is laid on the tunnel house, and both sides and ends are clamped in the clamp groove with snap springs. The film must be tightened tightly. ⑧ Reinforce the tunnel house arch rods with C20 concrete cement piers after the complete installation of the tunnel house to further enhance the wind resistance and bearing capacity of the tunnel house.

Fig. 2 Reinforcement of greenhouse stand columns

Wind and Corrosion Resistance Techniques for Vegetable Tunnel Houses

The tunnel house is designed, manufactured, installed, and equipped with a complete set of wind and corrosion resistant technologies.

Strict material quality The arch frame, tie rods and diagonal braces of the main structure are made of hot-dip galvanized (in accordance with the national standard of steel) materials. The slots are hot dip-galvanized fixed film slots, with a galvanizing amount of $\geqslant$ 80 g/m^2. The wall thickness of all frame bars has been increased to 1.8mm (national standard of 1.2 mm)[1], and the pipe diameter has been increased to 25 mm (national standard of 22 mm), so as to enhance wind resistance, with a design life of more than 10 years.

Polyvinyl chloride (PVC) film is preferred for tunnel house film (national standard of not less than 0.08 mm), with light transmittance of more than 90% and service life of more than 5 years. The film pressing belt adopts high-strength plastic pressing belt (high elastic nylon wire, polypropylene wire or steel wire is added inside), with good tensile property, strong aging resistance and even pressure on the tunnel house film.

Strict installation and construction standards The selection of construction site is crucial for the tunnel house. The head of the tunnel house should be oriented towards the perennial wind direction of the area, and if the terrain cannot meet the requirement, the deviation from the perennial wind direction should be as small as possible.

Quality inspection After visual inspection, measuring tool inspection, and installation bearing capacity inspection, the tunnel house steel pipe has no defects such as cracking, twisting, plating leakage, and bubbles; The wall thickness, outer diameter and slot thickness of the arch pipe shall be measured with a precision of 0.1 mm Vernier scale, and the deviation shall be within ±5% of the national standard. The span, shoulder height, top height, land insertion depth of the tunnel house, and the tunnel house length, arch pipe spacing, and plastic belt spacing of the tunnel house shall be measured with a standard meter, and the installation standard deviation shall be within ± 5% of the national standard.

Load bearing capacity inspection, installation and testing standards: With the arch pipe top as the center and 1.5 m from the ground endpoint of the arch pipe as the 2 ends, 9 ropes are evenly distributed to hang heavy objects. The arch pipe shall not undergo permanent plastic deformation. The weight of the suspended load is Fn/9, and the test should be focused on the arch pipe at the joints of the longitudinal rods and the arch pipes at the middle of the longitudinal rods.

$$Fn = 0.55\ BL/n$$

Where, Fn determines the load on each arch rod; B is the span; L is the tunnel house length (m); n is the total number of arches in the tunnel house.

After testing, the load-bearing capacity of the tunnel house is 0.55 kN/m^2, and the wind resistance capacity reaches 26 m/sec (equivalent to whole gale). The thickness inspection of the galvanized layer is in accordance with national standards, and the weight of the galvanized steel pipe increases by 8.5% after hot-dip galvanizing. The surface of the galvanized outer wall has a complete galvanized layer, without leakage or bubbles. The outer surface is smooth and clean, and there is no leakage of plating on the inner wall surface.

Film removal before the cyclone Before the cyclone, remove the snap rings, take off the covering film and store it properly to prevent water ponding on the roof and protect the shed frame. Reinstall the tunnel house film after the cyclone.

Insect and Bird/Mouse Prevention Techniques for Vegetable Tunnel Houses

The vegetable production in Samoa suffers greatly from the insect, bird, and mouse damage, which has a significant impact on high-value vegetables such as tomatoes and watermelons. The full coverage of insect-proof net can maintain ventilation, as well as effectively avoid the harm of insects and birds[3]. The 32-mesh nylon silk insect-proof net is selected and mounted at the bottom corners of both sides of the tunnel house, with air vents and doors. The insect-proof net is the same length as thetunnel house, and the upper and lower sides of the insect net are fixed in the card slots, with both ends fixed on the card slots at both ends of the tunnel house. The mouse damage is controlled by raising cats and using bamboo tube rodent prevention stations to trap and kill in tunnel houses.

Water-saving Irrigation Techniques for Vegetable Tunnel Houses

Drip irrigation can save 30% -40% water compared to ditch irrigation, and does not damage the soil particle structure[4]. The drip irrigation system consists of a head pivot, branch pipe, capillary pipe, and drip heads, which are externally connected to a drip irrigation water tank. It is equipped with a 5 000 L or 3 000 L finished drip irrigation water tank and auxiliary base engineering, with a base diameter of 1.8 m and a height of 0.5 m. High pressure PVC pipes are used for drip irrigation system pipes. The diameter of branch pipes is 30 mm, the diameter of capillary pipes is 15 mm, and the distance between drip heads is 0.3 m. Each compartment of the tunnel house is equipped with 2 – 3 drip irrigation pipes, which can effectively save water consumption for vegetable farming in the greenhouse.

The water sink is installed between connected sheds to collect rainwater into the water tower, which can save a lot of irrigation costs.

There are many slopes in Samoa, and there are often many stones in the fields. Installing vegetable tunnel houses requires leveling the land and removing stones. Otherwise, it will be difficult to ensure the stability of the tunnel house and drip irrigation will not be effective.

Maintenance Techniques for Vegetable Greenhouses

First, the tunnel house should stay away from ignition sources. Second, the tunnel house shall be away from any damage caused by sharp tools such as puncturing, scratching, and hanging. Third, it shall avoid storing or using chemicals and preparations that have corrosive effects on the structure or cause serious environmental pollution in tunnel houses, such as acids and alkalis. Fourth, it should avoid exceeding the height and width of the entrance and exit gates for transporting goods, to avoid damaging the doors and related components. Fifth, if there is any looseness in the connecting parts of the tunnel house, it should be dealt with in a timely manner. Sixth, if dust or other factors affect the transmittance of the top film, the top film should be washed in time. Seventh, in case of severe weather such as cyclones and heavy rain, it is necessary to strengthen the inspection and management of the tunnel house. If necessary, the top film should be removed as much as possible to ensure the safety of the entire greenhouse. Eighth, a routine inspection of the top film should be carried out every six months. If any damage is found, special film repair tape should be used to repair it in a timely manner.

Supporting Cultivation Techniques for Vegetable Tunnel Houses

Tunnel house division In order to efficiently utilize the inside area of the tunnel house and conveniently carry out operations, the tunnel house of 6m wide is divided into 3 beds, each with a width of 1.4 m and a furrow of 0.4 – 0.5 m.

Vegetables suitable for tunnel houses The main vegetables in Samoa are pakchoi, Chinese cabbage, lettuce, eggplant, pepper, long bean, cucumber, pumpkin, tomato, spring onion, and water spinach, and watermelon and sweet corn are also popular. Pakchoi, Chinese cabbage, pepper, beans, cucumber, tomato, watermelon are suitable for growing in tunnel houses, while eggplant, onion, corn, pumpkin, and cabbage can be grown in the open air. A batch of Chinese vegetable varieties have good adaptability in Samoa, and 10 Chinese vegetable varieties have been registered locally. But some local varieties such as tomatoes and cucumbers have good disease resistance.

Fertilization The long-term and large-scale application of chemical fertilizer is likely to lead to the risk of heavy metal accumulation in tunnel house soil[2], affecting the quality of vegetables. The price of chemical fertilizer in island countries is very high, increasing costs. The application of organic fertilizer such as decomposed chicken manure can effectively improve soil fertility and achieve sustainable high yield. But the organic fertilizer must be decomposed, otherwise it is easy to aggravate pest and disease damage.

Proper rotation and fallow cultivation High intensity vegetable farming is easy to lead to the accumulation of diseases and pests in the tunnel house. The arrangement of rotation of different kinds of vegetables is conducive to reducing the harm of diseases and pests. Proper fallow and covering the ground with film for more than one month can reduce the harm of diseases and pests.

Economic and Social Benefits of Vegetable Tunnel Houses in Samoa

Significant economic benefits have been achieved from the 60 vegetable model farmers and 120 vegetable tunnel houses built by SCATAP in the 2 islands of Samoa, and the longest used tunnel house have been in use for over 6 years. Since the vegetable tunnel houses of farmers were successively put into operation in September 2017, many farmers have earned an annual income of over 5 000 Tara (about US $ 2 000) from each vegetable tunnel house, with the maximum reaching 20 000 Tara (about US 4 770). The vegetable prices during the rainy season in Samoa are 2 – 3 times higher than those during the dry season, and the role of tunnel house is particularly prominent during the rainy season, resulting in a higher income for farmers. Dora Maposua, a vegetable demonstration farmer in Alesa Village, Upolu Island, loaned more than 100 000 Tara (US $ 38 000) to construct 10 tunnel houses in addition to 4 vegetable tunnel houses assisted by SCATAP, and she almost finished repaying the loan within 3 years. In 2019, Samoa hosted the South Pacific Games, which received more than 6 000 foreign guests in a short period of time. The SCATAP produced 30 tons of vegetables by organizing vegetable tunnel house farmers, meeting the needs of the Games and changing the history of Samoa's large-scale activities requiring a large number of imported vegetables. Good varieties of vegetables, suitable farm tools and intensive farming techniques accompanied by the promotion of tunnel houses have greatly improved vegetable production and farmers' income, stimulated farmers' enthusiasm for planting vegetables, and led all parties to invest in this successful key technology. The number of tunnel houses imported from China has reached 300 through various funding channels. Chinese tunnel house cultivation technology is considered to be the best vegetable farming technology in Samoa, and more and more farmers need tunnel houses, The World Bank project, the Food and Agriculture Organization of the United Nations project, and foreign and local government projects have all promoted vegetable tunnel house technology.

Conclusion

The vegetable tunnel house technology in tropical island countries is essentially a facility agricultural technology for intensive planting. It is a comprehensive high-yield vegetable technology system integrating improved soil, sheltered cultivation, artificial irrigation, and good varieties and methods. It fundamentally changes Samoa's extensive vegetable farming practice, and it can significantly increase vegetable production, especially in rainy seasons. In the face of difficulties in developing arable land and excessive rainfall during the rainy season in Samoa, it has outstanding advantages and is therefore welcomed by the local government and people.

Tunnel house vegetable technology requires a certain amount of investment, requires good cyclone resistance and anti-corrosion measures, otherwise it is difficult to promote. This is the reason why vegetable tunnel houses have not been successfully promoted in some island countries.

The temperature inside the tunnel house is relatively high. Designing a ventilation structure at the top or increasing the height of the tunnel house can effectively reduce the temperature inside the tunnel house, but it affects the wind resistance, requiring an increase in material strength and cost.

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world population and the change of human life style, the scarcity of freshwater resources has attracted more and more attention. China is generally a country with water shortage, having a population of more than 20% of the world population, but water resources only account for 6%. The lack of water resources has seriously hindered China's economic development and damaged the ecological environment. Seawater desalination, as an open-source incremental technology, has become an important way to solve water resource problems. Utilizing renewable energy for seawater desalination is a new environmentally-friendly approach to resource conservation. The preliminary experimental results of three demonstration projects indicate that the use of wind and solar energy for reverse osmosis seawater desalination technology is practical and feasible. The systems are safe and reliable in operation, pollution-free, easy to maintain, and do not consume conventional energy such as oil, natural gas, and coal. They are widely welcomed by fishermen, and have more promotion value and application prospects especially for isolated islands and fishing rafts that lack electricity and water.

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