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Solar Plastic Greenhouses: An Epochal Revolution of Horticulture in China

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ABSTRACT

China is one of the earliest countries to grow vegetables in greenhouses in the world. The history of protected vegetable production in China can be traced back to 2000 years ago and divided into three phases according to the ways in which greenhouses were heated. The first phase began in 200 BC when greenhouses were heated by hot-spring water, as documented by Wei Hong (a man of the Han Dynasty) in his book *The Preface of Han Imperial Edict*. The second phase started in 30 BC, when people began heating greenhouses with combustible materials such as firewood. This cultivation technique was detailed in the *Xunli Biography*, another book from the Han Dynasty. Since then, greenhouses had been heated by firewood, coal or oil until the appearance of solar plastic greenhouses (SPGs) in the 1980s, which marked the beginning of the third phase. SPG distinguishes itself from other types of greenhouses by the complete reliance on solar energy for winter production of temperate vegetables. Today, SPGs have been used greatly in China to produce various vegetables, flowers and fruits in cold seasons. The nearly thirty-year history has proved that SPG is a landmark and a revolution in Chinese horticulture. The history and structure of SPG, and its improvements on fundamental structure and cultivation techniques through the years are reviewed.

Keywords: greenhouse history, improvement, vegetables, solar energy
Abbreviations: SPG, solar plastic greenhouse

CONTENTS

INTRODUCTION

The history of protected cultivation of horticultural crops has been over thousands of years in China (Zhang and Zhang 2004). The protected facilities provide a better growing environment that is otherwise unfavorable or impossible for crops to grow. They keep out wind and rain, maintain warm temperatures inside, and protect crops from insect damage. When implemented with a heating device, growing vegetables in cold seasons becomes possible in these facilities (Zhang 1988). In ancient China, the primitive form of "greenhouse" was heated by hot-spring water (Xu 1991), then by coal or firewood, and now usually by propane, electricity or coal, in modern glass greenhouse (Zhou and Wang 2001). China has a large population and low energy resources *per* capita; therefore it is difficult or impossible to produce large-scale out-of-season agricultural produce in a protected environment with petroleum or electricity. The whole world, including developed countries, is facing the same energy shortage as well; so energy dissipation in agricultural production needs to be reduced worldwide.

At the end of the 1980s in China, a special type of greenhouse, the solar plastic greenhouse (SPG) appeared and developed rapidly in the following 20 years. A SPG is

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also called a sunlight house or solar greenhouse. Its advantage is that warm season vegetables can be produced in SPGs with only solar energy in regions that have minimal winter temperatures above -15°C. The cost for construction and maintenance of SPGs and for the crop production in SPGs is much lower than that of a glass greenhouse. The SPG might not look fancy, but it has great potential since it utilizes the energy-saving agricultural production that has become more and more important throughout the world.

HISTORY OF PROTECTED VEGETABLE PRODUCTION IN CHINA

China is one of the earliest countries to plant vegetables in greenhouses in the world. The *Han Book* documented that "To produce shallot and chive during the winter in the Royal Garden, cover them with a roof, heat day and night to keep it warm". This literally shows that "greenhouse" had been used to produce some cold-season vegetables about 2000 years ago (from 206 BC to 23 AD) in China. In the Tang Dynasty (618 AD to 907 AD), melons were produced in greenhouses in February with hot-spring water, as evidenced in Wang Jian's poem *Early Spring* before the Palace: "Used the water of warm-spring, produced the melon in February of winter". In the Ming Dynasty (1368 AD to 1644 AD), Wang Shimao summarized gardening techniques and wrote the book *Comments of Gardening* which described winter production of cucumbers. He documented that "The best cucumbers come from Beijing. They can be planted in "fire-houses". When vines are kept warm with fire, they will be forced to bud, flower and produce fruits at the beginning of February. The cucumber produced will then be served to the Royal families". This record showed that there were gardeners who grew cucumbers in greenhouses about 600 years ago in Beijing and that the techniques and greenhouse were likely to have been more advanced than those in earlier times (Zhu 1984).

The rapid growth of protected vegetable production regarding plant area, species and culture techniques started in 1949, when the People's Republic of China was born (Li 1984; Feng 2003). However, all greenhouses had to be heated to meet the required temperatures for crop growth and development until the invention of SPGs by Chinese farmers in the middle of the 1980s (Zheng *et al*. 1990). SPG was innovated from the structure of traditional glass Yangqi that was used mostly for raising transplants or producing cucumbers (Liu *et al*. 1980). This invention was a breakthrough in the history of greenhouse vegetable cultivation in China because the facility, even though a simple, low-height structure of clay and wood covered with plastics and straw curtains, was able to produce cucumbers without additional heating. After that, various improvements have been made on structures of this plastic greenhouse, as well as on related cultivation techniques for dozens of vegetable crops. With the aid of SPGs, freshly produced vegetables are supplied year around in most regions of China (Li 2004).

It is clear that greenhouses appeared very early in Chinese agricultural history. However, the high expense for producing vegetables in the greenhouse had limited its service only to the Imperial Families in ancient China. The major cost for this out-of-season vegetable production system comes from heating. There have been three types of energy resources for greenhouse vegetable production in China. The first type is geothermal energy, e.g., the hot spring water (Zhang 1988). The use of geothermic energy in China started in 200 BC, as recorded in *The Preface of Han Imperial Edict* (Zhang 1988). This energy source is natural and clean but only available to limited regions. The second type is combustible materials such as firewood, coal, or petroleum, and electricity. The use of firewood or coal started in 30 AD, which is detailed in the *Han Book-Xun Li Biography* and continued until the mid-1980s (Xu 1991). This type of energy is limited and non-regenerative, and often causes various degrees of pollutions. The third type is the solar energy, the most abundant and cleanest resources on earth. China has been widely using solar energy for the production of greenhouse vegetables, flowers and fruits since mid-1980s. The history of the past 30 years has proved that SPG is a landmark, an epochal revolution in Chinese horticulture (Ge 2005).

FUNDAMENTAL STRUCTURE AND OPERATING PRINCIPLE OF SOLAR PLASTIC GREENHOUSE

Fundamental structure

SPGs are heated mainly by solar radiation. In order to maximize absorption of sunlight, almost all SPGs are oriented east to west with a single slope (or arch) facing south. The fundamental structure consists of four main parts (**Fig. 1**).

The walls

A SPG includes the east, north and west side walls for supporting the greenhouse weight and outside pressure. Walls are usually 2.1-2.3 m high and 1-1.5 m thick. These cost-effective thick walls are made from bricks and/or clay so they also serve as heat storage. The thickness of walls usually doubles the maximum thickness of the frozen soil layer in winter for the region (Li and Chen 2004).

The back roof

The back roof, or north roof, angles at 35-45° with a width about 1.7 m and a thickness about 60-80 cm. This roof is for placing the thermal insulation blankets, or curtains or mats, for providing a working space if manual rolling of blankets is applied, and for increasing the inside greenhouse space. It is usually made of corn or sorghum stalks, or straws, which are mixed with clay. This kind of roof is cheap and insulates well, but usually is not durable and could collapse in the rainy season. Farmers tend to make a steel concrete roof that is covered with insulation materials for durability and stability. The back roof is usually supported by steel or concrete posts or columns inside the house (Chen 1994).

The arch struts and support columns

Arch struts, or poles, and support columns are the bearing structures for plastic films, straw curtains, wind pressure, and rain water or snows. Most old SPGs had bamboo arch poles although the most recent ones use steel tubes. Beginner SPG farmers still prefer using bamboo struts because of

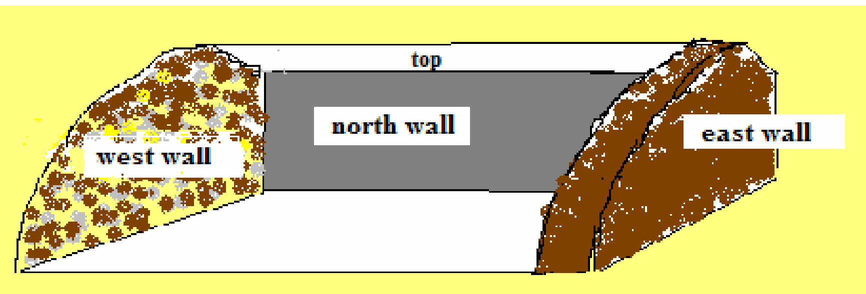

Fig. 1 Framework of a Solar Plastic Greenhouse. Walls made of packed soil or clay or bricks. Top (back roof) made of corn stalks or straws covered with soil. South or front roof covered with polyethylene film.

Fig. 2 A SPG with bamboo arch struts and concrete support columns.

the low cost. Each bamboo strut will need 3-4 support posts, with the number of support posts determined by the span of the greenhouse. These support posts will result in lots of shade and inconvenience of in-house operations (**Fig. 2**). The struts are also less durable than the steel tubes, which frame the greenhouse with the columns that support the back roof. When using arch struts, no support columns other than those supporting the back roof are required; so they are recommended for construction of new SPGs.

The plastic cover and thermal insulation curtains

The front or south slope (roof) of SPG is covered by durable anti-dripping PE films, which can transmit most of the sunlight into the greenhouse. The PE films are changed every year for best light transmission. At night the PE films are covered with another layer, the thermal insulation curtains, also called blankets, mats or claddings. The curtains, which are usually 1.5 m in width and 0.05 m in thickness, block the transduction of heat from the greenhouse to the outside and greatly preserve the heat inside the greenhouse. The length of curtains is correspondent to the span of the greenhouse.

The SPGs vary in size. Years of practice and research have proved that the higher and larger the greenhouse, the more accumulation of heat during daytime. The larger greenhouses usually have less temperature fluctuations and greater buffer capacities than the smaller ones (Liu *et al*. 2007).

The principles

A typical SPG uses only solar energy for vegetable production. Light transmitted into the greenhouse is responsible for maintaining inside temperatures at a certain level and for plant photosynthetic activities. The PE films, thermal insulation layer and thick walls work together to maintain the minimal night temperatures above 10°C, when outside air temperature could be -5°C or lower, which makes it possible for successful production of temperate vegetable in SPGs. The PE film has dual roles, i.e., it transmits short wave radiation into the greenhouse but prevents the outgoing of long wave radiation. During daytime, high energy short wave radiation is transmitted into the greenhouse which elevates the air temperature quickly. The surplus heat will be saved in thick walls and soils, and released through ventilation if the inside air temperature gets too high. The air temperature inside SPG can be 20~30°C higher than that of the outside. At night, heat absorbed and preserved in walls, north roof and soils during daytime will be gradually released to mitigate the descent of the interior temperature. The released heat and the thermal insulation curtains that block night heat transduction, will keep air temperatures above 10°C (Chen 2001).

IMPROVEMENTS ON THE STRUCTURE OF SOLAR PLASTIC GREENHOUSE

Improvement on the fundamental structure

The fundamental structure of SPG has been changed continuously during the past 20 years (Liu *et al*. 2007). The steel framework has gradually replaced the bamboo and wood structure because it is able to increase the height of SPG from 2 m to 3-3.5 m, and the span from 6-7 m to 8-9 m. The typical length has become 60-100 m depending on the landform and location. The columns previously supporting the bamboo arch poles have become unnecessary due to the solid steel framework, which in return make the in-house operation more friendly (**Fig. 3**). These changes in basic structure greatly enlarged the inner space, allowing better transmission of sunlight, heat preserve, and buffering of temperatures.

Improvement on the slope

SPG depends only on solar energy; therefore the maximum sunlight transmission into the house is critical. Since the incident angle determines the light transmission through the PE film cover, the slope of SPG (south roof) that defines the incident angle is very important. Through the years, the south roof has switched to arch shape from plane slope (**Fig. 4**). This arch surface has varied incident angles on different portions, e.g., 30-40° near the ground portion, 60-70° in the middle portion, and almost 80° on the top, which significantly increased the light transmission (Tong and Meng 1999; Wang *et al*. 2002).

Improvement on walls, plastic films and curtains

Maintaining greenhouses beyond the lowest temperature for plant growth at night is the key factor for successful crop production in SPGs. At night, the temperature is maintained by the release of preserved heat in walls and soils, and the insulation of curtains. Walls were built with clay initially, which is cheap and stores heat well; however, it does not

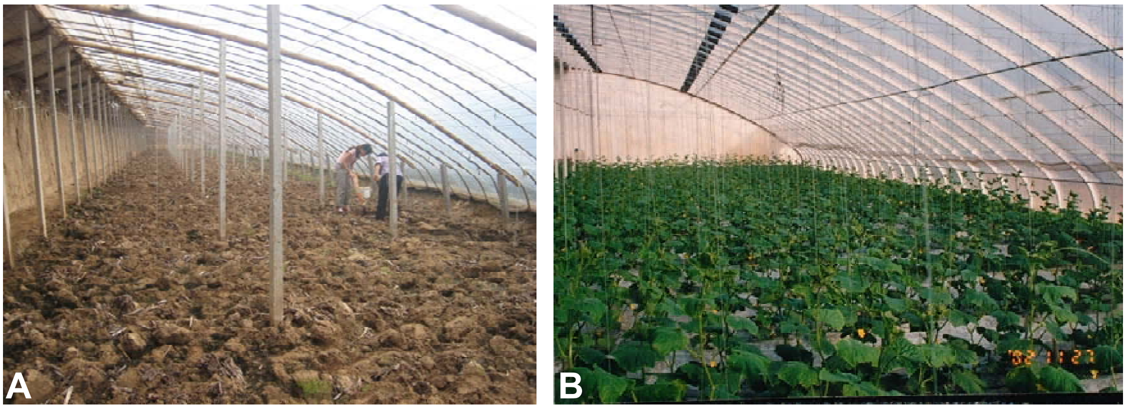

Fig. 3 Improvement on SPG framework. (**A**) bamboo and wood structure with concrete columns; (**B**) solid steel framework without support columns.

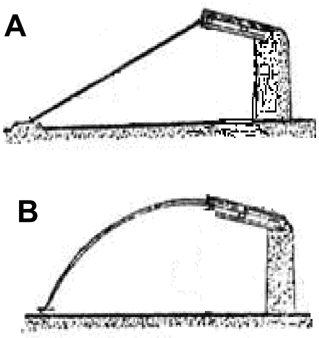

Fig. 4 Improvement on the slope of SPG. (**A**) Plane slope in the past; (**B**) Arch surface now to increase the light transmission.

last long as a permanent construction. Collapse could happen during the rainy seasons. Now most walls are built with bricks plus insulation fillings, a sandwich structure that has brick walls in and outside, with heat preserving and insulating materials such as soil, vermiculite, or perlite filled in between. The thickness of the wall changed from one meter to two meters or more, which costs more but are much more durable than the old type of walls.

The plastic films have been greatly modified. The poly chloro-ethylene films have been switched to anti-dripping PE films which prevent dripping of condensed water vapors on the inner surface of films. The condensed water will flow down to the bottom of south roof instead, which reduces disease incidence. The thermal insulation layer, which was made of straws or corn stalks before, has been replaced with heat storing quilt, which has four layers: the top and bottom layer is made of waterproof materials, then an insulation layer and a heat storing layer. The quilt ($1.5/m^2) costs more than the straw mat ($0.2/m^2), but is much lighter, insulates well, and does not make the PE film dirty (**Fig. 5**).

Mechanical rolling of insulation blankets

In the past, straw mats were manually rolled up in the early morning and released at dusk. The labor cost was at least four hours a day for a 500 m^2 greenhouse (8 m × 63 m). With the later developed rolling machine, only 10 minutes/ day is needed (**Fig. 6**).

THE PROGRESS OF CULTIVATION TECHNIQUES IN SOLAR PLASTIC GREENHOUSE

Vegetable species and varieties

Cucumber is the first warm season vegetable to be cultivated successfully in solar plastic greenhouses. There were no specific varieties for vegetable production in SPGs at that time, which limited the success of production to only a few vegetable species; therefore efforts were made on breeding for plastic greenhouse specific vegetable cultivars. The resulting successful cultivars can grow well under high humidity, low temperatures, and low light environment in SPGs with high yield, disease tolerance or resistance, and easy fruit-set characteristics. These cultivars have covered many kinds of temperate vegetables and fruits such as cucumber, squash, tomato, eggplant, sweet pepper, hot pepper, soybean, balsam pear, nectarine, cherry, strawberry, grape, watermelon, and melon. These special cultivars, together with the continuously improved cultivation techniques that will be discussed later, have increased yields remarkably, for example, cucumber yield increased nearly 5 times, from 45-60 ton/ha to 225-300 ton/ha. Hundreds of these specific greenhouse varieties are commercially available in the markets (Hou and Li 2000).

Fig. 6 Rolling up or releasing the thermal insulation curtains by machine.

Seedling grafting

Seedling grafting is the key technique for successful production of some warm season vegetables in SPGs. The difference between cultivation in SPGs and in regular protected structures is the length of growing period. Vegetables will grow over 250 days in SPGs including more than 90 days in the cold season. These vegetables must have strong roots to vigorously absorb nutrition, resist the winter coldness and combat against diseases and insect pests. Grafting desired scion vegetable seedlings to appropriate rootstocks meet these demands. Almost all transplants of cucumber, melon, and watermelon in SPGs are grafted. Recently, these grafting techniques were also adapted to the production of tomatoes, eggplants, and sweet peppers.

Disease prevention

Disease prevention is very important in SPGs. A disease can spread quickly in the enclosed high humidity environment once it occurs. Many factors should be considered to enhance plant disease resistance, for example, application of large volume of organic matter, crop rotation, removal of

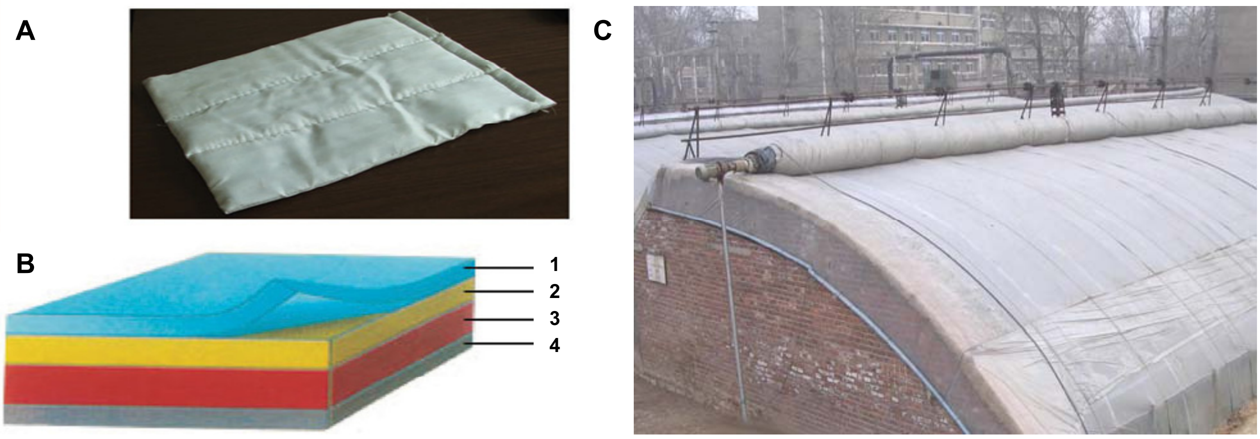

Fig. 5 The thermal insulation quilt: light weight, heat storing and water proof. (**A**) The quilt; (**B**) The structure of the quilt (1 and 4: water proof layer; 2: insulation layer; 3: heat storing layer); (**C**) using quilt on SPGs.

diseased plants/plant parts, rational irrigation and fertilization, and leaf feeding of fertilizers. In a closed space, the humidity and temperature need to and can be controlled properly to avoid disease incidence. For example, cucumber downy mildew can be prevented by scientific management of humidity and temperatures. Humidity can be decreased by covering plastic mulch over the ridge, mulching hays on aisles, and applying drip irrigations; while temperature can be managed at 25-30°C from 08:00-13: 00, at 25-18°C from 14:00-18:00, and at l6-13°C from 19:00-08:00 by rolling up curtains, ventilating, and releasing curtains (Sun *et al*. 2002a, 2002b).

Measures against continuous cloudy, rainy and snowy days

Continuous cloudy and rainy days in winter or early spring can cause serious consequences, or even total failure of vegetable production in SPGs. If cloudy days last over 7-8 days, soil temperature could drop below 10°C, which would cause the roots to rot, leaves to yellow, and eventually the plant to die. The pertinent effective measure against this is to hold irrigation when continuously cloudy days are anticipated. The insulation curtains can be left on most of time although they must be rolled up when short clear weather takes place during those cloudy days. One important practice worth mentioning is that only half curtains should be rolled up when sudden clear sunny days take place after long continuous cloudy days. This will ensure plants have time to adapt to the changing weather, otherwise plants may wilt, even die. In order to maintain appropriate temperatures during rainy or snowy days, the thermal insulation curtains can be left covered for 3 days until the reappearance of desired weather. Some small fruits should be removed to save more nutrition for leaves and roots during long cloudy days (Sun *et al*. 2002a, 2002b; Xing *et al*. 2006).

The solar plastic greenhouse is a miracle in Chinese horticultural history. The achievements of vegetable production in solar plastic greenhouse during the past 20 years in China have proved it. While problems do exist, there is no doubt that solar plastic greenhouse will be used more widely for effective utilization of solar energy, and for better quality and yield of vegetable crops. The existing problems would also trigger innovations that would perfect the structure of greenhouse and cultivation techniques in the future.

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