The Pharma Innovation Journal 2022; SP-11(12): 1042-1048

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(12): 1042-1048

www.thepharmajournal.com
Received: 17-09-2022
Accepted: 20-10-2022

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Comprehensive review on Naturally Ventilated Greenhouse

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Abstract
In a greenhouse, plants are shielded from a variety of climatic factors such as wind, cold, precipitation, intense radiation, extreme heat, insects and diseases. Greenhouses are extensively used to grow ornamental crops, which need proper ventilation, especially in the summer. The primary purpose of a greenhouse is to improve plant development conditions while reducing dependency on environmental factors. Greenhouse heating is done by conduction, convection and radiation. The greenhouse's natural ventilation system is essential for controlling the climate. Bamboo greenhouse, mulching and hydroponic system these are also forms of protected cultivation. Designing a greenhouse requires careful consideration of the regional climate and geographical latitude. High quality material for greenhouse construction ensures the longer life of structure. Folding roof greenhouse works well in snowy conditions. Intense agriculture that uses readily available resources, recycles data, and maintains productivity in the greenhouse is greenhouse automation. It is a very authentic, efficient, and modern form of agriculture. In addition to saving time and labour-intensive manual work, wireless devices provide accurate data when compared to conventional agriculture. When the outside climate is suitable, open-roof greenhouses provide a natural habitat for plant growth and when the outside climate is unsuitable (Too hot or too cold) artificial environment are provided. An open roof greenhouse shield plants from low night-time temperature and higher day temperatures without using a mechanical fan for ventilation. The distribution of air temperature and relative humidity has a significant impact on uniform development of crops in a greenhouse.

Keywords: Ventilation, environmental factors, mechanism, open roof, folding roof, retractable roof, automation, temperature, relative humidity, productivity

Introduction
The earliest record of producing crops by using protected structures are dates back to 14 to 37 CE in Rome. In the 17th and 18th centuries, structures called Orangeries were used in France to protect fruit trees from cold temperatures [11]. Agriculture production inside the protected structures started from 19th century in Netherlands and 20th century in France. In that simple glass structures used which provides climate protection and mainly used for growth of ornamental plants. But after the end of 2nd world war the technology of greenhouse construction accelerated, especially in Western Europe cold countries [1]. Now a days, various automation techniques (sensors) and operating mechanisms are used in the greenhouse. Such as open roof mechanism [28], retractable roof mechanism [67], folding roof mechanism [28] and automatic curtain rolling mechanism [65].
Greenhouses are framed or inflated structures covered with transparent or translucent material large enough to grow crops under partial or full controlled environmental conditions. Greenhouse protects the plants from various climatic conditions such as wind, cold, precipitation, excessive radiation, extreme temperature, insects and diseases and creates an ideal micro climate (sufficient sunlight, temperature, humidity) around the plants [1, 5, 14]. Greenhouses are widely used for the production of ornamental crops; vegetable crops and flowers and these crops requires adequate ventilation particularly during summer season [2].
Greenhouse is classified into five types according to shape, utility, construction, covering material and cost of construction. In shape they are classified as lean-to type, even span type, uneven span type, quonset type, saw tooth type and ridge and furrow type. By utility they are classified as active heating and active cooling. According to construction there are three types such as wooden framed, truss framed, and pipe framed. According to covering material they are classified as glass, plastic film and rigid panel.

By cost of construction there are three types such as high cost, medium cost and low cost [1].

The structural components of greenhouse are side wall, curtain wall, eaves, rafter, truss, purlin, ridge, side posts, column, bottom chord, gutters and fixtures [1]. Polyhouse partially allows sun rays reach to crop taken in polyhouse and also increases production by creating Green House effect using the carbon dioxide release by crop during night [6]. Warm species plants are grown in greenhouse and absolute minimum temperature should be 0 ℃ to avoid risk of killing plants because of frost. The absolute maximum temperature for plants should not be higher than 35 ℃ to 45℃ [7]. Greenhouse heating is done by conduction, convection and radiation [14]. Airflow present in the greenhouse is highly turbulent [8]. The cost of growing a crop in greenhouses is greater than growing it in the field. Hence, for greenhouses to remain competitive, they have to be able to reduce the cost of production and to increase crop yields. Energy costs typically account for 15 to 40 per cent of plant production costs [10].

The greenhouse effect is the term used to describe the role the atmosphere plays in insulating and warming the earth surface. The atmosphere is largely transparent to incoming solar radiations when these radiations strike the earth surface, some of it is absorbed; thereby, warming the earth's surface. The surface of the earth emits some of this energy back out in the form of infrared radiation. As this infrared radiation travels through the atmosphere, atmospheric gases such as carbon dioxide, methane and water vapor absorb much of it. Without the greenhouse effect, the earth would be a frozen planet with an average temperature of about 18 ℃ [69].

Protected cultivation

Greenhouse cultivation involves growing crops inside structures covered with a transparent material that protects from extreme weather and unfavourable climatic conditions. In addition to greenhouses, there are other forms of protected cultivation, including row covers, low and high tunnels and net houses [11]. It protects crop from overheating as well as from super cooling and helps to keep out pests. But irrigation is one of the important operations in protected cultivation system because water is the main element for surviving the plants [12]. Vegetables production in protected cultivation offers distinct advantages of quality, productivity and favourable market price to the growers. Therefore, vegetable growers could substantially increase their income by growing off-season vegetables at any season in protected structures [13].

The bamboo greenhouses also constructed in the protected cultivation. The use of bamboo instead of G.I pipes reduces the initial cost of construction of protected cultivation structure. Mulching is one of the forms of protected cultivation that minimizes the growth of weed and decreases the dispersion of soil by rain drops, also reduces the erosion of soil. There are two types of mulches such as organic mulches and non-organic mulches. Mulching helps to improve the soil temperature, soil moisture content, soil structures and organic properties of soil. For clay soil recommended mulching depth is less than 50 mm and for sandy or loamy soil it is recommended as 76-100 mm [66]. A closed greenhouse system design maintains air temperature and humidity for enhancing the plant growth and increases crop yield [15]. Movable shading system allows to adjust the intensity of incoming solar radiations according to crop requirement. This shading can be done by special mobile cloths which are partially reflected and installed inside the greenhouse [16]. Quantity of direct solar radiation intercepted by row canopy mainly depends on row orientation, planting density and geometric structure [17].

Hydroponics system is also part of the protected cultivation. In that system crops are grown in soilless media. The various root media are used for growing purpose such as cocopeat, rockwool, sand. The nutrients to the plants are given by liquid media. The chances of soil borne diseases are decreased in soilless media. Also, it gives more yield in less space as compared to open field. Mostly maize are grown in hydroponic fodder system. 7-8 days are required to complete growing of fodder in hydroponic system and this fodder can sustain in any situation, climate change and drought condition [76].

Design and construction of Greenhouse

The local climatic conditions and geographical latitude are important consideration in design of greenhouse [22]. While constructing the greenhouse select qualitative material so that it ensures the longer life of structure [24]. Variations should be made in greenhouse according to the various climatic zones and microclimatic factors also considered while design of greenhouse such as light, temperature, relative humidity etc. India has several wind zones according to the Indian Standard Code Design (IS 875: 2003) [23]. Greenhouses can be built in a variety of designs with a range of floor areas, from less than 280 square meter to huge gutter-connected ranges of more than an acre. Typically, single greenhouses are 28 to 37 meter long and 6 to 10 meter wide. The slope of a naturally ventilated roof must be between 1:4 and 1:2. The frames of greenhouse should be constructed by using various materials such as GI pipes, wooden frames, bamboo frames and concrete poles. Also, various glazing materials are used such as polycarbonate, plastic film, glass, FRP panel [20]. Depending on the size of the greenhouse, all of the structural elements in the greenhouse are placed 1.2–2.4 meter apart. Purlins joined by a cross tie are used in areas subject to strong winds to offer additional support. Vertical supports are provided by side posts and columns, with typical high points of 0.3 to 3 meter [21].

Indian farmers prefer tiny, naturally ventilated greenhouse buildings in the saw-tooth shape that are between 200 and 4000 square meters in size, according to an on-farm survey done as part of the study. As a structure's height rises, the tensile stresses on purlins decrease. In comparison to bottom purlins, the top purlins carry the ridgeline's maximum compressive pressures. Length-width ratio should be 80:20 or 75:25, with side heights between 3 and 5 meters and the central height between 3 and 9 meters [23]. The entrances are protected with insect-proof screens to physically keep pests out of the greenhouse. Closed and semi closed greenhouses are to increase the CO_2 level inside the greenhouse which causes reduces the pesticide application and saves energy [18].

Natural ventilation in greenhouse

Natural ventilation is important for controlling the greenhouse climate and equipped with continuous lateral windows [25]. The exchange rate of air between interior and exterior of greenhouse is known as rate of ventilation [26]. Climate management in greenhouse depends on its natural ventilation system [3]. Ventilation provides ideal environment for crops which brings about remarkable economic and social benefits [3, 4, 9]. The mean flow of sensible heat in naturally ventilated greenhouse is estimated between 55 per cent and 80 per cent

of the total flux, so that the turbulent flow does not exceed 45 per cent of the total. Characterisation and measurement of the air flow involved in greenhouse natural ventilation is usually done by classical tracer gas methods. In natural ventilation system air exchange efficiency of about 60 per cent [25]. Proper ventilation systems are needed for completing the dual objectives such as good natural air exchange rate and good protection against insect attack. The new roll up roof vents performed effectively while maintaining a good ventilation rate [27].

Bamboo: Woody material for Greenhouse

There are over 1600 species of wood that are used for various purposes. Wood is a biological raw material with high economic importance such as in the construction, furniture and packing industry. Global production of wood is estimated as 3912 million m^3 in 2020 of which fuel wood 1928 million m^3 and roundwood 1984 million m^3. The log house is also one of the types of attraction to the tourist to come for agrotourism. For constructing the Log house locally available wood and light weight wood are used. The Ain wood is preferred as one of the most important types of wood among the most commonly used type of woods. Because the compression stress of Ain wood is 1.3×10^7 kN/m^2 which is higher than compressive stress of commonly used Teak wood i.e., 5×10^4 ken/m^2. Therefore, Ain wood can be used as a construction material for log house [74].

Bamboo is an important resource in India and there are 125 species of bamboo growing in the country [73]. The annual production of bamboo in India is 3.2 million tonnes against the potential availability of 4.6 million tonnes with an average production of 0.33 tonnes/ha [70]. Bamboo plays an important role as woody raw material for the construction of bamboo greenhouses. But bamboos are not durable against wood-degrading organisms. Biological degradation affects the usage, strength utility and value of bamboo. The attack of fungus and beetles harms the bamboo hence chemical treatment is necessary, when bamboo is used as a structural member and where safety is of major concern [72, 73]. In konkan region four species of bamboo are available such as Manvel, Kalak, Mes and Manga and their scientific names are Dendrocalamus strictus, Bambusa bamboo's, Dendrocalamus stocksii and Dendrocalamus ritchy respectively. These bamboos are treated with hot and cold process, vaccum/pressure process, diffusion Boucherie process, boric acid borax treatment, copper chrome boron treatment, cashew nutshell liquid treatment. The Mes and Kalak variety of bamboo mostly prefers for construction of greenhouse. Preservation of bamboo improves their life and improves the safety of the structure. The Universal Testing Machine are used for measurement of tensile and compressive strength of bamboo during storage period of time [70, 72]. Bamboo used without chemical needs frequent replacement which would be time consuming and involves costly labours [73].

The agro tourism is very important for rural communities as well as urban areas. It can provide several advantages like income, employment, natural resource conservation, recreation and education. The material required for construction of bamboo house should be readily available and accessible. The bamboo-based house has a very low weight so the foundation can be minimized. Bamboo can tolerate high values of deformation in the elastic range i.e., possesses high elasticity. The properly constructed bamboo house should be ductile. Therefore, they are being able to sway back and forth during an earthquake [73].

Cladding material in the Greenhouse

The plants cannot distinguish the difference between direct light and diffused light. Diffused light is the direct light that reaches plants in an indirect path. Photosynthesis will equally occur when same light intensity is provided to the plants. The maximum light intensity in clear polyfilm ranges between 35500 lux to 58000 lux. In diffused polyfilm, the maximum light intensity ranges between 49000 to 64000 lux. The minimum light intensity in clear polyfilm and diffused polyfilm is 6500 lux to 8075 lux and 7822 lux to 9800 lux respectively. The humidity in diffused and clear polyfilm 74 % to 91 % and 85.6 % to 92 % respectively. But minimum humidity in diffused film ranges between 67 % to 83 % and in clear film ranges between 68 % to 84 %. The number of flower and number of leaves in diffused polyfilm is more than the clear polyfoil [71].

Mechanisms used in Greenhouse

Folding roof in greenhouse works well in snowy climates. During cold weather they can be tightly closed. Most designs of this mechanism use standard vent hardware. In that some panels hinge at the gutter and open upward. Also, opening is done almost 100 per cent in folding roof greenhouse. If they slide sideways on Teflon bearings opening is done about 85 per cent. Retractable roof structures consist of a steel frame, flexible glazing and cable support. Flat roof designs are used where there is little rain or snow [28]. Spraying mechanism avoids human interference in the polyhouse which prevents infection to the farmers and there is uniform spraying of pesticides to the plants [5].

For operating the mechanism there are two types of drive systems are used such as cable drive system and rack and pinion drive system [29]. The main advantage of this system is that it reduces the manual work and there is no need of any training to the farmers about operating this system [5]. Greenhouse curtains are also known as screen, thermal blankets and night curtains and they are available from many years and there are many varieties of curtains are available as per crop need. In that 70 to 80 per cent heating occurs at night. Some growers can save 30 to 50 per cent of their heating electricity cost [29].

Automation in Greenhouse

Innovations in greenhouse engineering are the technical developments in the controlled environment agriculture. In that crops are protected from external unfavourable climate conditions and pests. Also, modify the indoor climate to create a suitable environment for crop growth and production [30]. Greenhouse automation is highly authentic, effective, and contemporary intensive agriculture, that utilize the accessible sources, recycles the data and maintains productivity in the greenhouse [37]. Various sensing techniques are commercially available for measuring the status of the aerial climate in the greenhouse, the conditions in the root zone or the status of the plants and it includes sensing techniques for covering solar radiation, soil moisture content sensing, sensing light interception by the canopy, soft sensor to measure the ventilation rate in greenhouse and fruit firmness sensing [15, 30-36]. Sensors for smart and precision agriculture includes environmental, power supply and nutrient solution sensor. The properties of nutrient solution sensor are determined by sensors. The most common properties measured in the

nutrient solution are temperature, dissolved oxygen, total dissolved solids (TDS) and potential of hydrogen (pH) values [41-42].

Wireless systems give accurate data as compared to old methods also it saves time and labour intensive manually [38]. In any production environment, especially in agronomy, Internet of Things devices enable efficient planning and resource allocation, providing economic benefits and increasing competitiveness in the market [39-40]. In rainy season moisture gets accumulated on the sheet of the polyhouse due to which specific number of sunrays may not enter so roof top mechanism is used which is signalled by rain sensor module then the roof top opens and closes when it rains [5]. The automatic curtain control system maintains optimum temperature and relative humidity which is essential for the favourable growth of crop inside the greenhouse. When the inside temperature goes below or beyond the limit value of temperature then microcontroller operates the relays and opens or closes the curtains [65]. The Argus system controls all mechanical systems and provides a record. The data obtained from greenhouse is organized and summarized accurately to analyse dependent and independent variables of process [43].

Retractable roof mechanism in Greenhouse

In contemporary retractable roof structures, structural design and movement technology are based on the use of structural movement systems and their constituent parts. Four alternative closing situations such as 25 per cent, 50 per cent, 75 per cent and 100 per cent are included in the design and analysis. A retractable roof can be moved or folded so that it opens or closes completely or in part. A very good design of mechanism is required because it takes up a lot of space and uses more materials during construction [44]. Retractable roof protects from extreme weather conditions such as strong wind, snow, hail, high or low temperature. Crops get benefit of suitable environment and improves productivity [67]. In innovative structures, covering panels or membranes are joined to a foldable lattice of beams connected by cylindrical connections. There is essentially no limit to the geometry of these structures, which fold toward their edge [45].

Open roof mechanism in Greenhouse

Open-roof greenhouses offer a natural habitat for plant growth when the outside climate is appropriate and an artificial environment when the outside climate is too hot or cold. Opening the roof over the plants increases light intensity, which can help to control the growth habit, flowering and crop timing [28]. Open roof greenhouse design differs significantly from traditional, mechanical or naturally ventilated greenhouse [46]. Open roof mechanism covers and uncovers the roof sheet mechanically and reduces the time required for shade covering and uncovering. This saves time and increases the profit in production [6]. The amount of opening of roof is determined by computer control system and when roof sections fully opened 66 per cent of total greenhouse floor area is opened. Generally, indoor temperature deviation from the set point 18.3 ºC or 65ºF [46-47]. The open-roof greenhouse can provide plant air temperature close to outside temperature during the day and protect from cool night air temperatures. A computer simulation model for natural ventilation in open-roof greenhouses was created to forecast the ventilation performance. Based on weather and structural factors, such as internal net radiation, wind speed and the height and size of the roof openings, the model forecasts ventilation rate and the temperature variations between inside and outside. Using thermal buoyancy and wind forces the ventilation rate was determined [46].

Effect of roof opening

Microclimatic conditions in greenhouse are related to the characteristics of greenhouse such as size, shape, orientation, covering material, shading, cooling, heating, ventilation and influencing the crop yield and quality [48]. Vent configuration in the greenhouse effects on the greenhouse microclimate pattern and distribution of internal temperature and relative humidity. When dehumidification process occurs, open roof helps to decrease greenhouse dehumidification time [3]. The E-W row canopy provided a higher standardized daily canopy irradiance than the N-S row canopy at 35°N, but the reverse results were reported at 45°N and 55°N throughout the winter months, i.e., the major seasons of greenhouse production. At 35°N, the normalized daily canopy irradiance of an E-W direction revealed greater values in the winter and lower values in the spring and summer compared to a N-S orientation. However, regardless of the season, the normalized daily canopy irradiance of the N-S orientation at 45°N and 55° N produced greater values than that of the E-W orientation [17].

Covering is important to break the dormancy of the fruits and protect them from rain, hail and frost, however uncovering is advantageous to boost photosynthetic impact and when spraying is desired [49]. Particularly natural or hybrid ventilation instead of air conditioning can significantly lowers primary energy use [50]. Tracer-gas measurements and CFD simulation were used to examine the impact of a net-covered windbreak on a greenhouse's leakage [51]. Difference in the greenhouse internal environment varied with the period [52]. It was suggested that whenever the screen had a simple geometry, the mean dimensions and their standard deviations should be supplied, together with the thread diameters and the distances between neighbouring threads in both the warp and weft orientations. Additionally, screen porosity or the ratio of open area to total area, needs to be computed and reported [53].

Temperature and Relative Humidity effect in naturally ventilated Greenhouse

Relative humidity is the primary environmental component that regulates dust mite populations [54]. The uniformity of plant development and crop productivity in a greenhouse is largely influenced by the dispersion of air temperature and relative humidity [55]. The entered solar radiation in the greenhouse is the principal source of sensible heat which increases the T_{in} and causes its variations within the greenhouse. The distribution of the T_{in} and RH_{in} is significantly improved by shading [56-57]. As a result, the T_{in} and RH_{in} typically vary the most during noon [58-59]. To increase the homogeneity of the T_{in} and RH_{in}, evaporative cooling or ventilation is preferred [60-61]. Around noon, a peak in solar radiation coincided with the maximum spatial variation in the T_{in} and RH_{in}. T_{in} and RH_{in} distributions in the vertical direction and along greenhouse sidewalls were also found to be significantly higher than distributions along pad-fan directions [57]. The effectiveness of windbreaks in lowering mean wind speed has been assessed using computational fluid dynamics (CFD) models [62-63]. Surface evaporation inside the greenhouse, solar radiation and ambient temperature are a few examples of the natural factors

that contribute to temperature and, to a lesser extent, RH changes during observation time [64].

Capsicum can be grown in polyhouse and in open fields. But successful plant growth occurs in polyhouse under irrigated condition. For optimum growth of capsicum, a frost-free period of about 130-150 days with 15-35 ℃ temperature is required. Beyond that limit the vegetative growth period reduces and results in poor fruit set as well as severe fruit drop. High relative humidity is good for crop growth, fruit set and increases crop yield [75].

Conclusions

Agriculture production in protected structures starts from 19th century in various countries. During 19th century simple glass structures was used for cultivation of crops, but now a day's various materials, automations, mechanisms and types are used in greenhouse. Greenhouse protects the plants from various climatic conditions and provides ideal environment for plant growth. Hydroponic system is one of the type of protected cultivation. Mulching is involved in protected cultivation and there are two types of mulches such as organic mulches and non-organic mulches. During construction of greenhouse local climatic factors are considered. In India various wind zone occurs, therefore Indian Standard Codes are referred during construction of greenhouse. Greenhouses are built in a range of 280 to 4000 m^2. High quality material increases the life of structure. Natural ventilation controls the climate and air exchange efficiency is about 0.6. Bamboo is used for construction of greenhouse and bamboo houses. But before construction bamboos are treated with various treatments to avoid damage due to wood degrading organisms and for increase the life of structure. Bamboo houses and log houses are important part of agritourism. It helps to increase livelihood, income and employment. For covering of greenhouse various cladding materials are used such as polycarbonate, polyethylene, polythene. In greenhouse various mechanisms are used such as folding roof, retractable roof and open roof and this mechanism operates on the two types of drive system namely cable drive system and rack and pinion drive system. Retractable roof opens in various percentage, and it is opened according to requirement. In open roof greenhouse, when roofs are completely opened then it opens about 66 per cent of greenhouse floor area. Sensors are used in automation system in greenhouse, and it sense the temperature, relative humidity, soil moisture and many factors. The temperature and relative humidity in greenhouse affected on uniform growth of plant and productivity of crop.

Financial Assistance:

The authors hereby acknowledge that the financial assistance for the study was rendered by ASPEE Agricultural Research and Development Foundation, Mumbai.

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