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Investigation of BADC installed arctype plastic and net covered greenhouse for production of high value crops in Bangladesh

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Abstract

Climate vulnerable country like Bangladesh is struggling to produce high value crops and to ensure food security. High value crops can ensure food security by reducing poverty and helping farmers to use updated technologies. Greenhouse technology could be potential solution for providing high-value crops year-round. Recently, Bangladesh Agricultural Development Corporation (BADC) installed a greenhouse with modern technologies and facilities to cultivate off-season vegetables and high-value crops at Godhkhali in Jashore for the farmers. The purpose of the study was to investigate the design construction, technical and financial performances of the BADC installed greenhouse for ensuring high-value crops year-round. The relevant data for this study were collected through field visit, experiment, secondary sources, and direct interviews of BADC personnel and greenhouse farmers. The results showed that the solar intensity varied from 40 W m$^-2$ to 150 W m$^-2$ inside the greenhouse from 9.00 AM to 4.00 PM with shed net condition. The maximum temperature was 36°C and minimum was found 26 °C inside greenhouse and the average temperature ranged between 29 °C to 34 °C.The Relative Humidity (RH) was found 75% (maximum) and 46% (minimum). The air velocity was found of 1.3 m s^{-1} (maximum) and 0 m s^{-1} (minimum) inside the greenhouse. Comparing crops' optimum and greenhouse condition, the study has found that the greenhouse has achieved the optimum parameters (solar intensity, temperature, RH) for capsicum and tomato cultivation in November. The payback period for summer tomato and capsicum was found 1.94 years for the rotation cultivation. The benefit-cost ratio was found of 1.83 which indicates the greenhouse is profitable for farmers. The smart greenhouse can be developed by adding a fan, pad cooling system, and sensor-based system which will help to cultivate lettuce leaf, peas, beans, eggplant, cucumber, strawberry and other high-value crops.

Keywords: Temperature, relative humidity, solar radiation, greenhouse, fruits, vegetables

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1 Introduction

Greenhouse is a structure covered by glass sheet or plastic sheet and the structure is to provide controlled environment for cultivation by controlling temperature, relative humidity and solar radiation (Sharma and Jain, 2016). Greenhouse cultivation ensures suitable natural environment for plants to achieve optimum productivity (Benli, 2013). Crop agriculture is constrained in Bangladesh every year by challenges, such as loss of arable land, population growth, climate change, imbalanced use of fertilizers, inefficient water use, pests and diseases, unfair produce prices, and insufficient research investment (Mondal, 2010). Bangladesh has a population of 165.1 million with 1.22% growth rate (BBS, 2022). With the growing population, available agricultural land is decreasing day by day. To meet the excessive food demand of extreme population, more intensive and productive agricultural practices are needed. But, open-field production is hampered by many climatic factors such as humidity, high temperature, rainfall, strong winds, and high disease incidence. Greenhouse may protect the high value crops like capsicum, broccoli, tomato, cabbage, cucumber etc from adverse climatic conditions (Das et al., 2016). High value crops like cucumber, tomato, strawberry, watermelon, okra, capsicum, lettuce can be cultivated in greenhouse to ensure year-round availability in Bangladesh (Awal et al., 2021). The greenhouse area has risen worldwide for growing vegetable crops in recent decades. By the end of the 20th century, the area under protected cultivation was about 275,000 ha (Mishra et al., 2010), whereas in 2018, vegetable cultivation in greenhouse was 5.6 million ha (Qasim et al., 2021). There are now more than 50 countries in the world where greenhouse crop cultivation is done on a commercial scale (Pandey and Pandey, 2015). Cultivation of vegetables has been undertaken around 115 countries in the world (Nimbrayan et al., 2018). In comparison to other countries in the world, Bangladesh lags behind in the construction of greenhouses because of proper government initiative and lack of technical know how. In Bangladesh, there are very few numbers of greenhouses. Most of the greenhouse are situated for research purposes, and those greenhouses are not introduced to the farmers (Saha et al., 2008). Many studies have been conducted on different greenhouse technology like hydroponic greenhouse monitoring (Elegado, 2022) seawater greenhouse with thermodynamic simulation in USA (Sablani et al., 2003), suitable greenhouse technology for different climate through the world like semi-arid (Gundu and Mithun, 2018), hot and humid (Jadhav and Rosentrater, 2017), hot (Kale et al., 2018) and high humid (Kumar, 2018) climate. Cooling greenhouses are developed in Iraq (Aljubury and Ridha, 2017), in Qatar (Ghani et al., 2019) to protect crops from excessive heat in summer. IoT based automated greenhouse was designed and developed to detect and control various climatic factors such as soil moisture, air humidity and light intensity (Jeaunita et al., 2018), to enable the farmer to manage a large farm with minimum manpower (Raja et al., 2018), to save water using rainwater harvester (Jayaty et al., 2018). Several automated plastic greenhouse was developed in India to maintain optimum condition with different technologies like rain sensing roof and temperature sensing automatic vent door mechanism (Karle et al., 2019), PIC microcontroller (Karthikeyan et al., 2017), 89E516RD microcontroller (Kolapkar et al., 2016), RF module (Sharma and Jain, 2016). Sreenivasa et al. (2009) studied on economic feasibility of vegetable production. Lopez-Marin et al. (2019) conducted cost benefit analysis of tomato under different greenhouse covers. Prabhakar et al. (2017) reported on different constraints in adoption of plastic greenhouse technology like environmental, technical, labor related, economic, marketing constraints.

In India, the neighbor country of Bangladesh started commercial utilization of greenhouses from 1988 (Mishra et al., 2010) but now they are capable to meet the demands of both domestic and export markets (Shweta et al., 2014). In Bangladesh, Bangladesh Agricultural Research Institute (BARI) constructed net house for potato seed cultivation for commercial and research purposes, Bangladesh Rural Advancement Committee (BRAC) constructed greenhouse for tissue culture and flower production for research purpose. Paramount Agro farm has constructed two large greenhouses in Gazipur for commercial purpose to produce muskmelon (The Daily Star, August 17, 2017). There were limited protective cultivation practices at farmers level through different NGO initiative which are closed now. In the 2017-2018 fiscal year, Bangladesh Agriculture Development Corporation (BADC) undertook a programme to install seven greenhouses at Godkhali, Jashore, Bangladesh, which is open for the farmers. However, a scientific study is necessary to better understand and maintain the greenhouse production system by controlling greenhouse microclimate. Mean daily temperature and relative humidity has a vital effect on pollen quality, fruit set rates and fruit yield (Harel et al., 2014). All the published studies mentioned above has discussed different modern technologies used in greenhouse worldwide and greenhouse condition in Bangladesh. The BADC installed greenhouse is arctype in nature. Shed net and sprinkler irrigation is used to cool down the greenhouse. There is no scientific study present and no study performed on structure, technical and financial performance of BADC installed greenhouse. Therefore, the study was aimed to understand the design and construction, investigate the technical performance and conduct a financial analysis of BADC installed greenhouse in Bangladesh.

2 Materials and Methods

2.1 Study site

The study was carried out in BADC installed greenhouse at Godkhali, Jashore in Bangladesh. A interview schedule was prepared to collect information about greenhouse construction materials, technologies, and operation costs. Secondary data also were collected from the BADC office records. Based on the secondary data, a 3D model of the greenhouse was drawn using AutoCAD software (Version: AutoCAD 2007, Developer: Autodesk) to know the shape, size, and dimensions of the diverge from the established greenhouse.

2.2 Technical performance evaluation

The technical performance was evaluated by measuring the temperature, relative humidity, solar intensity, and air velocity inside and outside the greenhouse. An RH and Temperature meter (Model: 06100253, Valli Aqua and Process Instruments, Chennai, India), anemometer (Model: RS 212-578 AM-4201, Taiwan), and solar meter (Model-776, DODGE PRODUCTS Houston, Texas) were used to measure temperature, relative humidity, air velocity, and solar intensity in the greenhouse on 17−19 November 2021 and the data points are shown in Fig. 1. The nine points were marked inside the greenhouse by measuring distance and penetrating bamboo sticks to measure temperature and relative humidity. In the same way, three points on the north side and three on the south side were marked just beside the insect net to measure air velocity. Outside the greenhouse, one point was selected to measure temperature and relative humidity, and solar intensity. Each data was collected and recorded at one-hr interval at 0.9 m above from soil surface from 9.00 am to 4.00 pm. During the data collection, there were gladiolus, onion, capsicum seedlings, some plots with irrigation and without irrigation as shown in Fig. 1.

2.3 Economic analysis

The economic analysis was done by calculating the equivalent annual cost, gross income, gross benefit, benefit-cost ratio and payback period. The equivalent annual costs are divided into fixed costs and variable costs. The fixed cost was calculated for GI pipe structures, U.V. polythene sheets, shade net, insect net and water supply system according to their individual lifespan. The cost of the materials were collected from office of Bangladesh Agriculture Development Corporation (BADC), and the lifespan data were collected from BADC engineer who took initiative to install the greenhouse. The straight-line depreciation method was used in the process as it is the simplest method of depreciation calculation. The variable cost was calculated from labor cost, cost of seedlings, manure and fertilizer cost, hormone cost, electricity (for irrigation) cost, repair and maintenance cost for capsicum and summer tomato grown in greenhouse. All the fixed and variable costs were calculated in Tk/year and added to get the equivalent annual cost (EAC) of greenhouse using equation 1 (Rahman et al., 2013):

$$\mathrm{EAC} = \mathrm{FC} + \mathrm{VC} \tag{1}$$

where, EC = equivalent annual cost (Tk yr^{-1}), FC = fixed cost (Tk yr^{-1}), and VC = variable cost (Tk yr^{-1}).

Gross income (GI) was calculated by multiplying the total amount of product with average unit price of the product in harvesting period (Begum et al., 2019). The following formula in equation 2 was used to calculate the Gross income

$$\mathrm{GI} = \sum Q \times P \tag{2}$$

where, GI = gross income (Tk yr^{-1}), Q = quantity of cultivated product, and P = per unit price of the product

The Gross benefit (B_G) is a simple way to measure the relative profitability of a product. Net benefit (B_N) equals total benefit less total cost. The following equations (3 and 4) were used to calculate Gross benefit and Net benefit.

$$\mathrm{B_G} = \mathrm{GI} - \mathrm{VC} \tag{3}$$

$$\mathrm{B_N} = \mathrm{GI} - \mathrm{TC} \tag{4}$$

where, B_G = gross benefit (Tk yr^{-1}), B_N = net benefit (Tk yr^{-1}), and TC = total cost (Tk yr^{-1}).

The benefit-cost ratio (BCR) may be defined as the ratio of benefits to costs (expressed either in the present or annual worth). When the BCR is greater than unity, then it will be economically accepted. This ratio was calculated mathematically by the equation 5 (Sengar and Kothari, 2008):

$$\mathrm{BCR} = \sum_{t=1}^{t=n} \frac{\frac{B_t}{(1+i)^t}}{\frac{C_t}{(1+i)^t}} \tag{5}$$

where, B_t denotes Gross benefit in one year, C_t represents equivalent annual cost in one year, t stands for $1, 2, 3, \ldots, n$, and i is interest rate.

To determine the present worth of benefits, the equivalent worth of all inflows or benefits is discounted to a single present value considering project's life and interest rate. The present worth is an equivalent method of analysis in which a project's cash flows are discounted to a single present value. To determine the present worth of costs, the equivalent worth of all outflows or costs is discounted to a single present value considering the project's life and interest rate.

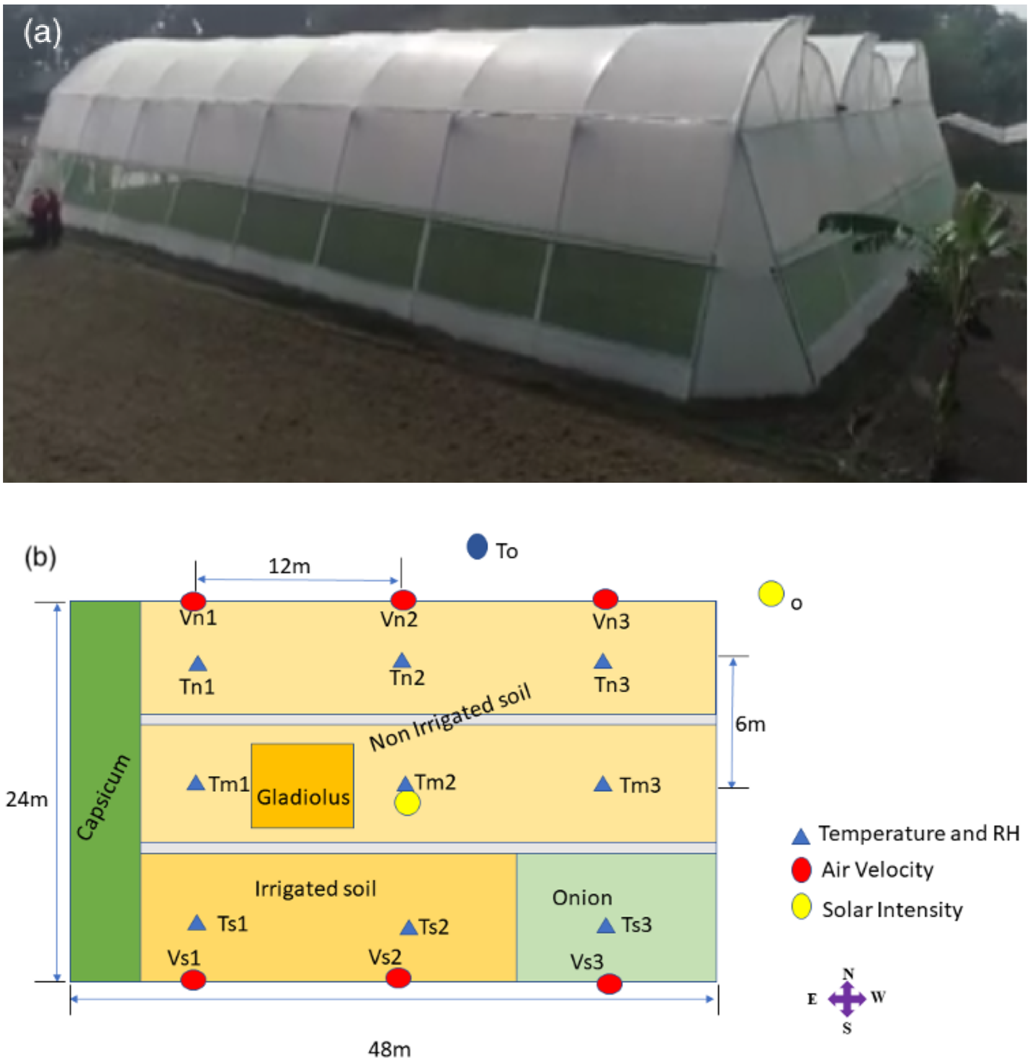

Figure 1. (a) BADC Greenhouse and (b) Data collection points inside and outside of the greenhouse (T means position of temperature sensor, RH denotes position of relative humidity sensor, o represents outside, i means inside, n stands for north side, m is middle and s denotes south side)

The payback refers to the time period within which the costs of investment can be covered by revenues. The payback period can be expressed as equation 6 (Rahman et al., 2013):

$$\text{Payback period} = \frac{\text{Initial investment (Tk)}}{B_N} \quad (6)$$

2.4 Identification of challenges and future prospect

The interview schedule to collect information about greenhouse construction materials, technologies, and operation costs was used to identify the challenges and possible future prospects of BADC greenhouse. Greenhouse farmers and BADC personnel were the respondents of the interview. With the involvement of greenhouse farmers, a SWOT (Strength, Weakness, Opportunities, and Threats) study was conducted to identify the problems and potential.

3 Results and Discussion

3.1 Study of design and construction of greenhouse

The BADC installed arc type plastic and net cover greenhouse (Fig. 2) with the dimension 48 × 24 m^2 where total height of 6 m and 4 m gutter height. The floor type was soil, the main structure was made of GI pipe. There were 52 columns made of GI standpipe and concrete base and 200 µ UV polythene was used as covering material. The leading irrigation system was drip irrigation system. 4-way foggers were used to decrease temperature, increase relative humidity, and provide sprinkler irrigation. Another temperature-decreasing technology was shed net with 50% shading intensity. The ventilation type

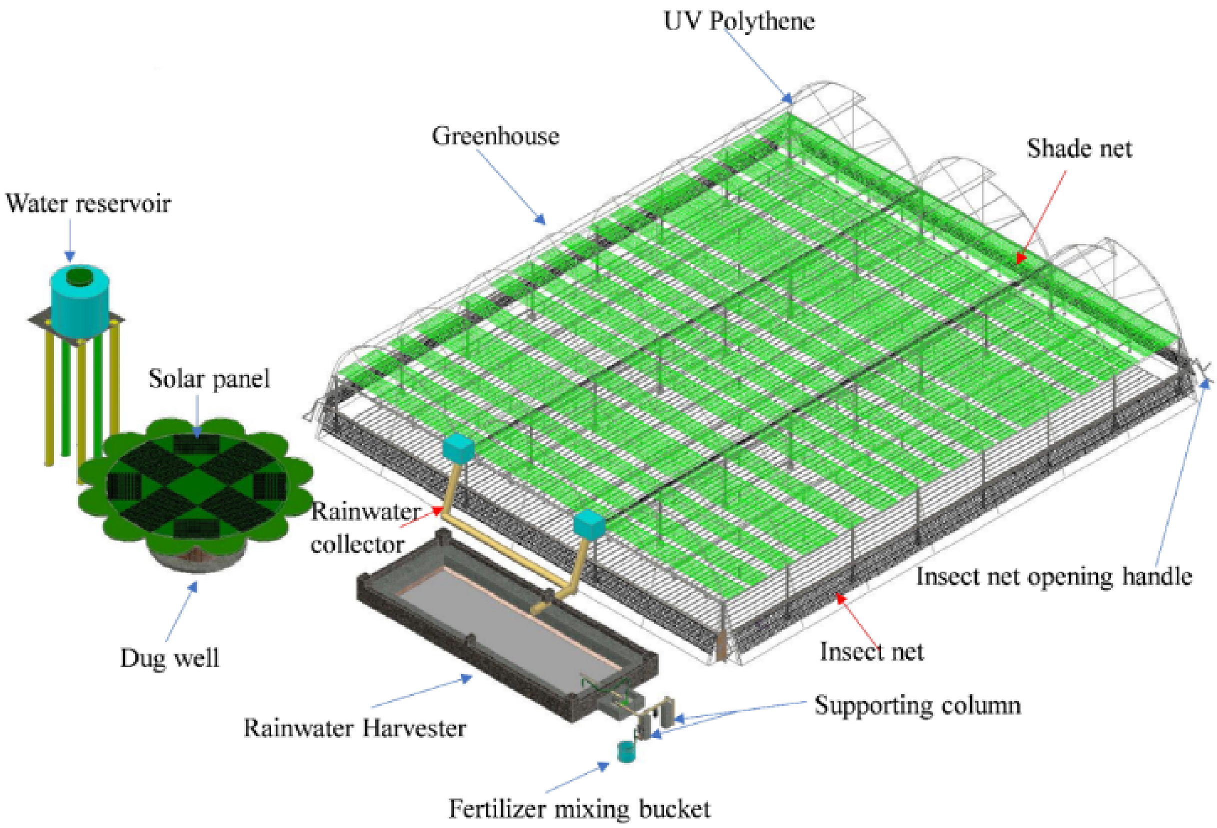

Figure 2. Arc type BADC greenhouse, Godkhali, Jashore, Bangladesh

was natural convection. The rainwater harvester is the main water source of greenhouse (Fig. 3). Precipitation is collected through pipes and stored in rainwater harvester.

In winter, water is supplied from the dug well equipped with solar panel which is constructed mainly for open field. The reservoir can store about 55 m^3 water. The stored water is applied according to need. A pump is directly coupled with motor. The motor-pump has a rated head of 27 m with head range between 22 m to 30 m. The rated power is 2 hp and discharge 3.5 L sec^{-1}. Motor pump draws water from rainwater harvester and supplies to fogger and drip irrigation system (Fig. 3). There are two drip irrigation filter and one washer. The washer is connected below the first filter through which pollutants can be removed. A removable bucket is used to mix fertilizer with water. The water-fertilizer mixture then goes through supply pipe towards underground supply line. There are four valves to control water and water fertilizer mixture. One valve is attached with excess water line, which allows to pump excess water to return to the rainwater harvester. The second valve is closed when fertilizer is mixed with water. The close valve allows the pumped water and fertilizer solution to mix together and go through second filter. The third valve is fogger line valve which is closed during fertilizer application and open in other times. The fourth valve is drip line valve which is opened or closed according to water requirement at root zone. Two concrete pillars 0.9 m n height support filters, supply line, valves and regulators. Farmers cultivated various types of vegetables and flowers in different shades. The products include summer tomato, broccoli, lettuce, brinjal, capsicum, strawberry, summer carrot, Gerbera and Rose.

3.2 Technical performance of BADC greenhouse

The different technical parameters solar radiation, temperature, relative humidity and air velocity distribution with time are shown in (Fig. 4). Solar radiation increased with sun rising and was maximum at mid-day. It was found that temperature rises with rise in solar radiation. Relative humidity decreases with an increase in temperature and wind velocity increased when temperature was high and relative humidity was low (Fig. 4). During the experiment, it was found that solar radiation inside the greenhouse varied from 50 W m^{-2} to 220 W m^{-2} without shade net (Fig. 4a1) when outside varied from 200 W m^{-2} to 650 W m^{-2}. With shade net, the value varied from 40 W m^{-2} to 150 W m^{-2} (Fig. 4a2) when outside varied

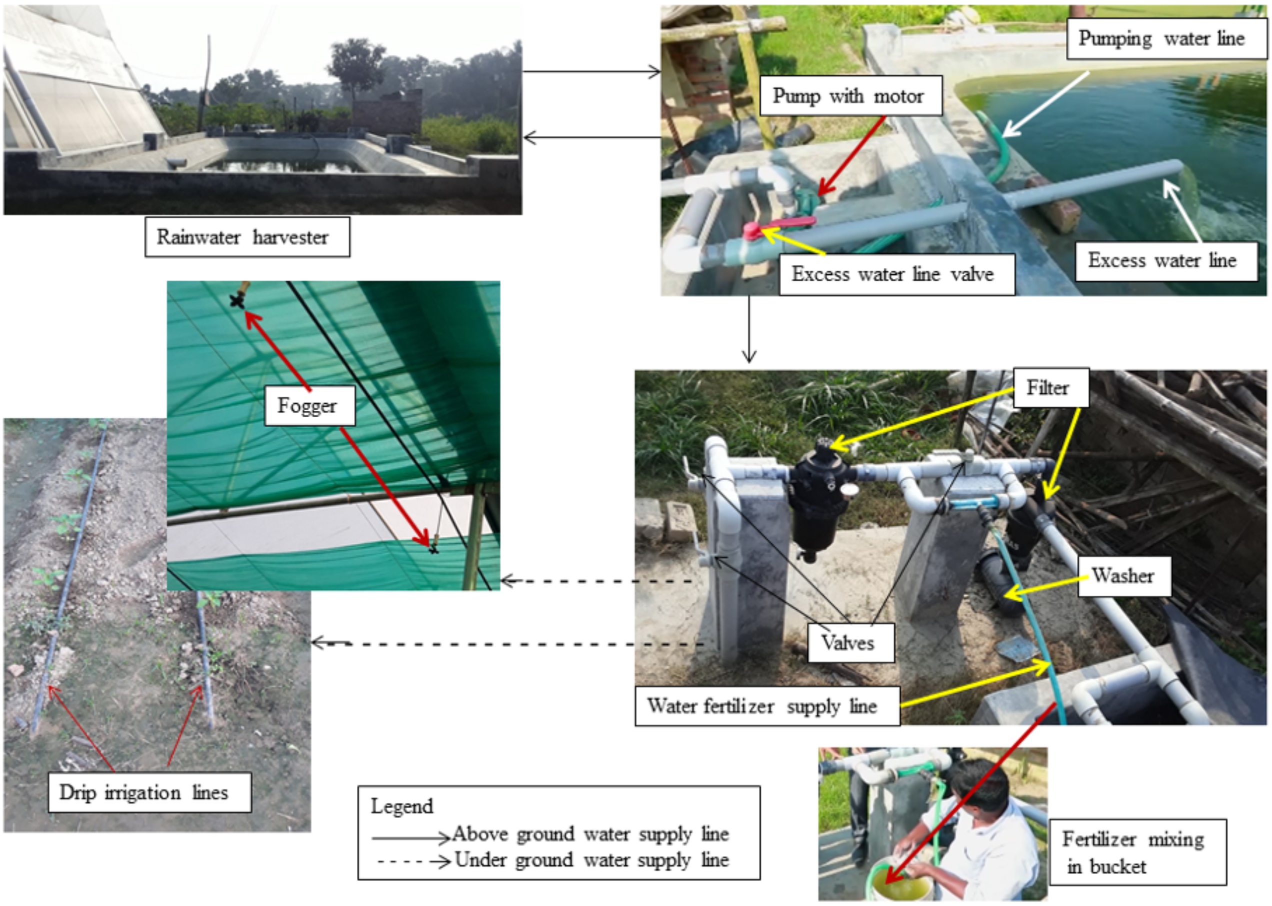

Figure 3. Water storage and supply system of the greenhouse

from 270 W m^{-2} to 790 W m^{-2}. Optimum solar radiation for tomato, strawberry, beans and cucumber is about 43-91 W m^{-2} (Rabbi et al., 2019). Lettuce requires 56.52-63 W m^{-2}, eggplant and peppers 109 W m^{-2} and peas 146 W m^{-2} (Rabbi et al., 2019). Solar intensity inside BADC greenhouse is suitable for cultivating tomato, strawberry, beans, peas, cucumber, lettuce, eggplant and peppers.

During experiment, the maximum inside temperature was found 36 °C and minimum was found 29 °C without shade net (Fig. 4b1, Table 1) when maximum outside temperature was 32 °C and minimum 27 °C. With shade net, the maximum was 34 °C and minimum 26 °C when outside was maximum 32 °C and minimum 25 °C (Fig. 4b2, Table 1). But inside the greenhouse, sometimes there was temperature difference of 1 °C to 3 °C at different points at the same hr. It was found that there was always a temperature difference of 1 °C to 2 °C between north and south side. Most of the time, south side temperature was more though that side was irrigated. The temperature distribution was relatively uniform in the middle section of greenhouse from 12.00 PM to 2.00 PM. Optimum temperature of tomato is up to 30 °C (Shamshiri et al., 2018). Peppers optimum temperature 24-28 °C, eggplant 25-28 °C (Tazawa, 1999). The optimum temperature of lettuce is 20-26 °C (Kang et al., 2013). Optimum temperature for capsicum is 25-30 °C in day and 18-20 °C at night (Pramanik et al., 2020). The study shows that the greenhouse temperature should be further controlled to keep below 30 °C during November for optimum production of capsicum, tomato, peppers, eggplant, lettuce and peas.

Fig. 4c1 and Fig. 4c2 show the relative humidity distribution at different points over time. Without shade net, the maximum RH inside was 64% and the minimum 44% when outside is maximum 68% and minimum 47% (Fig. 4c1, Table 2). With shade net, the maximum was 75% and the minimum 47% when outside was maximum 74% and minimum 46% (Fig. 4c2, Table 2). From 11.00 AM to 3.00 PM on 17 and 18 November, most of the points RH was below 50%. Optimum RH of tomato is 50%-65% (Shamshiri et al., 2018), 50%-60% (Rabbi et al., 2019). Eggplant, peppers, lettuce and peas optimum are above 65% to 80% (Rabbi et al., 2019; Tazawa, 1999). For cucumber, optimum RH is 80%-90% (Rabbi et al., 2019). For better performance of capsicum, RH is 80% when 50%-60% is optimum (Pramanik et al., 2020). The study shows that RH inside the greenhouse is suitable for tomato and capsicum but not for eggplant, peppers, lettuce, peas and cucumber.The maximum time air velocity

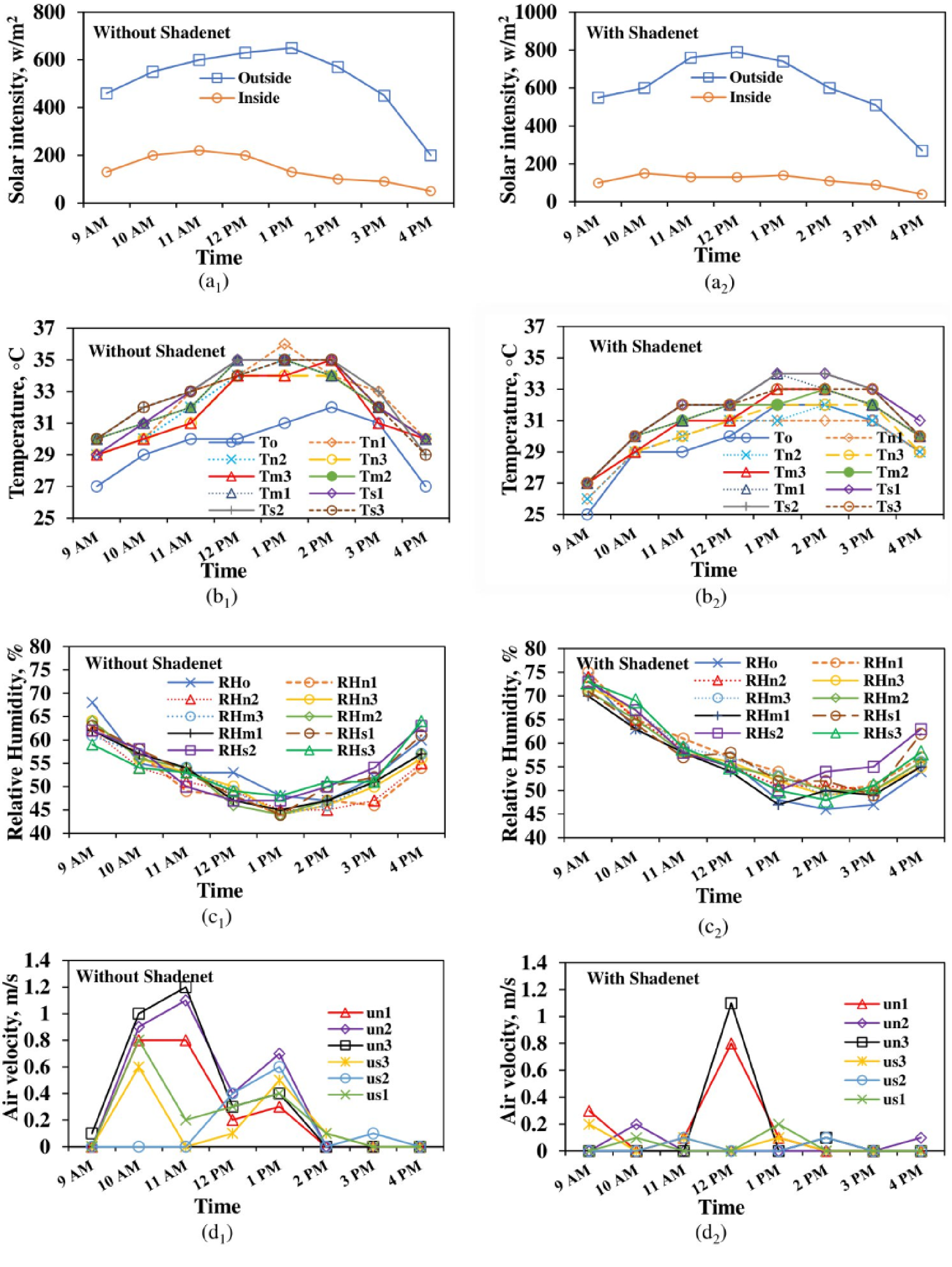

Figure 4. (a) Solar radiation, (b) Temperature, (c) Relative humidity and (d) Air velocity distribution in north and southside of Arch type BADC greenhouse (Subscript 1 for without shade net and subscript 2 for with shade net) in November

Table 1. Temperature (°C) variation in and outside greenhouse with and without shadenet in the month of November

Time	Without shednet				With shednet			
	Amb.	Max. (in)	Min. (in)	Avg.±SD	Amb.	Max. (out)	Min. (out)	Avg.±SD
9:00 AM	27	30	29	29.44±0.53	25	27	26	26.78±0.44
10:00 AM	29	32	30	30.78±0.83	29	30	29	29.55±0.53
11:00 AM	30	33	31	32.22±0.83	29	32	30	31±0.87
12:00 AM	30	35	34	34.44±0.53	30	32	31	31.56±0.53
1:00 PM	31	36	34	34.89±0.6	32	34	31	32.67±1.22
2:00 PM	32	35	34	34.44±0.53	32	34	31	32.78±0.97
3:00 PM	31	33	31	32.11±0.6	31	33	31	32.11±0.78
4:00 PM	27	30	29	29.78±0.44	29	31	29	29.78±0.67

Amb. = ambient, Avg. = average of minimum and maximum temperature

Table 2. Relative humidity(%) variation in and outside greenhouse with and without shadenet in the month of November

Time	Without shednet				With shednet			
	Amb.	Max. (in)	Min. (in)	Avg.±SD	Amb.	Max. (out)	Min. (out)	Avg.±SD
9:00 AM	68	64	59	62.22±1.56	74	75	70	72.44±1.59
10:00 AM	55	58	54	56.33±1.5	63	69	63	65.78±1.86
11:00 AM	53	54	49	52.33±1.87	58	61	57	58.56±1.13
12:00 AM	53	50	46	48.11±1.27	56	58	54	55.78±1.3
1:00 PM	48	48	44	45±1.5	48	54	47	51.33±2.12
2:00 PM	47	51	45	47.67±2.12	46	54	48	50.33±1.80
3:00 PM	52	54	46	50.33±2.45	47	55	49	50.56±1.81
4:00 PM	60	64	54	58.22±3.56	54	63	55	57.56±2.96

Amb. = ambient, Avg. = average of minimum and maximum relative humidity

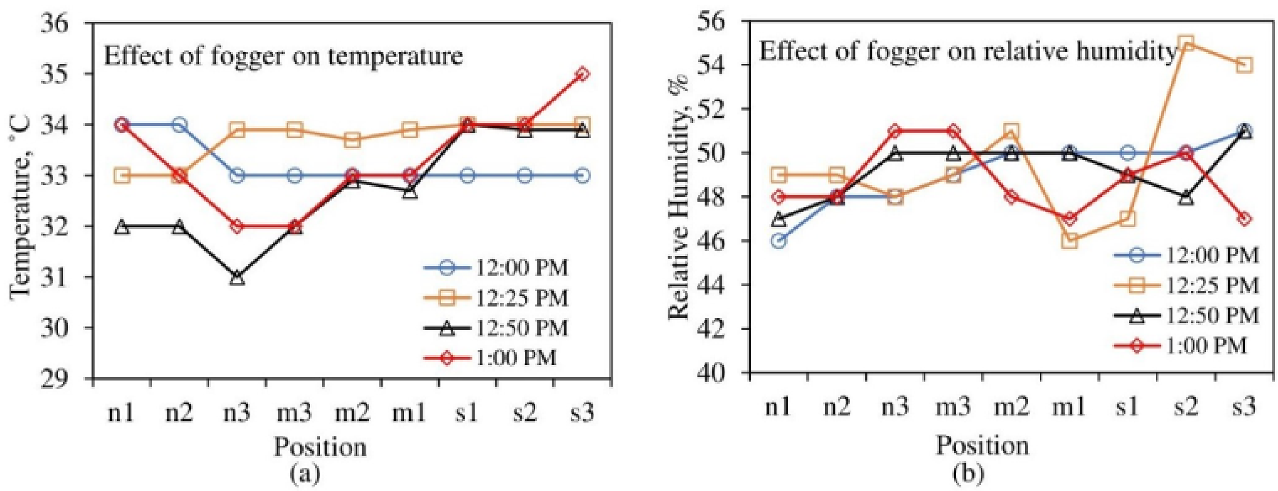

Figure 5. Temperature, (b)Relative humidity distribution at different locations of greenhouse before running foggers (at 12 PM) and after running foggers (after 12 PM) (19 November 2021)

Table 3. Financial analysis of BADC greenhouse

Items	Value
Initial investment	22,99,334 Tk
Total Fixed cost	3,11,213.4 Tk yr^{-1}
Total Variable cost of tomato and capsicum	5,06,000 Tk yr^{-1}
Total income from tomato and capsicum	20,00,000 Tk yr^{-1}
Equivalent annual cost of greenhouse	8,17,213.4 Tk yr^{-1}
Gross benefit of tomato and capsicum	14,94,000 Tk yr^{-1}
Net benefit	11,82,786 Tk yr^{-1}
Payback Period (year)	1.94
B/C ratio	1.83

was 0. But when there was airflow, the air velocity was up to 1.2 m s^{-1} (Fig. 4d1). The northside was responsible for most airflow. In the southside, it didn't exceed 0.8 m s^{-1}. With shade net, the airflow decreased more (Fig. 4d2). During 12.00 PM, there was airflow through n_1 and n_2 on the north side when in t.

3.2.1 Effect of fogger on temperature and relative humidity

On 19 November, at 12.20 PM fogger was run for 2 mins and temperature and relative humidity at 9 different points inside the greenhouse were measured. The data were collected after 5 min, 30 min and 40 min of fogger run. Fig. 5a shows effect of fogger on temperature. Before fogging, the temperature was 33-34 °C, when outside temperature was 31 °C. Five min after fogging, the temperature decreased by 0.2-1 °C. After 30 and 40 min, temperature varied from 32 °C to 34 °C in different points. After 40 minutes, the outside temperature was still 31°C. That means though the foggers can decrease temperature at some extent, it is not sufficient even in November. In mid-day, greenhouse inside temperature is always higher than outside temperature. In summer season, the temperature may be higher and unsuitable for greenhouse plant growth.

Fig. 4b shows effect of fogger on relative humidity. Before fogging, the relative humidity was 46% to 51% at different points, when outside relative humidity was 52%. 5 mins after fogging, the relative humidity was 49% to 55%. After 30 and 40 mins, relative humidity varied from 47% to 51% in different points. After 40 mins, the outside relative humidity was 50%. In November mid-day, the relative humidity could not get nearly standard value. Besides the relative humidity distribution after the fogger run was not uniform (Fig. 4b). Mishra et al. (2010) noticed fog cooling more effective than fan pad system though the effectiveness of natural ventilation and fan pad method varies from climate to climate. In Punjab, India, a polyhouse with a fan-pad system and foggers was developed to maintain a temperature of 20-27 °C and a relative humidity of 75 percent (Kale et al., 2018). The current greenhouse uses fog cooling system. Adding a fan-pad system may increase the cooling efficiency and maintain suitable RH in the greenhouse.

3.3 Financial performance of BADC greenhouse

The initial investment BADC greenhouse was found Tk 22,99,334 (Table 3). The fixed cost of greenhouse was Tk 311,213.4 per year and the variable cost was Tk 5,06,000 per year for tomato and capsicum.

Variable cost may vary according to crop. For capsicum and summer tomato, the greenhouse was profitable with a gross benefit of Tk 14,94,000 per year and net benefit of Tk 11,82,786 per year. The high value crop capsicum plays the large part of benefit. Besides, the tomato from July to November is off-season, providing an average wholesale price of Tk 80 per kg. Cultivating tomato in winter or two season is not beneficial when wholesale price is about Tk 15-20 per kg. The right choice of crop rotation with summer tomato from July to November and capsicum from December to June has made a payback period of 1.94 years and BCR of 1.83, which is quite profitable for a 1152 m^2 sized greenhouse.

3.4 SWOT Analysis of BADC installed greenhouse

A SWOT analysis was performed highlighting possible concerns and prospects of the BADC greenhouse. The analysis included internal factors (strength, weakness) and external factors (opportunities, threats). The findings of the analysis are presented in Table 4.

There are several reasons behind the reluctance of farmers and entrepreneurs like high construction cost, problems in controlling temperature and relative humidity inside greenhouse, competition and problems in marketing due to unawareness of greenhouse products quality among peoples. To manage the cost of the greenhouse, some farmers can cooper-

Table 4. SWOT analysis of BADC installed greenhouse in Bangladesh

Strengths (S)	Weaknesses (W)
1. The greenhouse design is developed in Bangladesh. 2. According to greeenhouse farmers, crop yield and quality is better than open field. 3. Water and pesticide application requirement is very low. 4. According to BADC engineer, more production is possible at small space. 5. Reduction of insect and pest attack. 6. The GI pipe structure has a high longevity.	1. Installation cost is not affordable by general farmers. 2. Foggers get jammed easily and requires regular maintenance. 3. The effect of temperature and humidity control by fogger run only remain for shortly after 30 minutes. 4. Requires artificial phytohormone for optimum growth. 5. The UV polythene sheet should be changed after each five years.
Opportunities (O)	**Threats (T)**
1. The design can be applied in other districts of Bangladesh. 2. Can supply vegetables at Chinese restaurants at high price. 3. Can be used to produce nutritious and high value vegetables which are still not grown locally, but imported from foreign countries. 4. The produced flowers and vegetables can be exported by proper management.	1. Susceptible to damage by strong storm. During the cyclone “Amphan” the greenhouse sheds were greatly damaged. 2. Competition with the open field farmers. 3. The construction materials are not locally available. Those are imported. 4. Risk at marketing Gerbera flowers because the farmers have personal shed houses made with local materials. The quality of those shed house Gerbera and BADC greenhouse Gerbera is not so different. As a result sometimes the farmers doesn’t get expected price. 5. Lack of manpower for regular monitoring and maintenance.

ate themselves. Good quality foggers should be used and maintained properly. Sensor based automation system can solve the problem of proper temperature and relative humidity control. The better quality UV polythene sheet can be used or managed properly the current one to increase its longevity. To prevent the damage from cyclone or heavy storm, the design can be modified or construction materials can be changed, that may be a field for future work. To avoid the competition with open field farmers, separate markets can be started for greenhouse crops, public awareness should be created to understand the benefit of good quality, healthy (produced by using minimum or no pesticide) greenhouse vegetables. Materials can be manufactured locally after taking some policy like constructing more greenhouses. Marketing risk can be reduced by selecting proper crop which have no competition with open field or which are not cultivated in local sheds. Policy can be made to create a list of suitable crops for sustainable greenhouse condition in Bangladesh and encourage the farmers to cultivate those. Some steps can be taken to construct more greenhouse with government funding and preparing farmers to use those.

4 Conclusion

The temperature and relative humidity were not uniform at different points during mid-day. The temperature was found above 30 °C most of the day, even with shednet and fogger. Relative humidity was generally around 50% or below 50% during mid-day. With the fogger, relative humidity was about

55% in mid-day but about 60%-70% before 11.00 AM and after 3.00 PM. The study found that temperature should be lowered and relative humidity should be increased during mid-day for optimum production of capsicum, tomato, eggplant, cucumber, lettuce, strawberry, peas, beans. The solar radiations were within the recommended range for optimum crop production. The technical performance was conducted only in November. It is important to conduct the performance study year-round, especially in summer season. The financial analysis was profitable by cultivating capsicum and tomato from December 2020 to November 2021. The study found 1.94 years payback period and benefit-cost ratio greater than 1. Greenhouse temperature and humidity should be well controlled which was not the case in the present state. Further improvements of greenhouse are needed for controlling temperature and humidity as well as producing high value crops year-round. Ventilation fan can be installed to ensure more temperature and relative humidity control in present condition. In future, sensor-based automation should be applied to ensure optimum temperature and relative humidity.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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