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INNOVATIVE POLYHOUSE FOR PRODUCTION OF BUTTON MUSHROOMS (*Agaricus bisporus*) IN HOT REGIONS

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KEYWORDS

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Heat load

Evaporative cooling

Button mushroom

Temperature

ABSTRACT

An innovative polyhouse was developed for production of button mushrooms in hot region of Punjab. Length, width and ridge height of polyhouse was 15, 4 and 4.27 m, respectively. Floor was kept at 1 m below ground level. Roof was thermally insulated whereas walls were ventilated. Heat load analysis of polyhouse was carried out in the study. Polyhouse was equipped with fan-pad system and foggers to attain cooling through evaporative cooling mechanism. Water required to reduce the inside temperature by 10°C was determined as 1.3 liters. Performance of polyhouse was evaluated in terms of attaining the desirable temperature and humidity conditions. Results indicated that on operating the cooling systems, inside temperature and RH during October were 22-27°C and ≥75%, respectively. These conditions were suitable for *spawn run*. In November polyhouse provided 20-22°C temperature and ≥75% RH. These conditions were suitable for *case run* and *fruiting*. Favorable temperatures and RH were achieved during February and March also. Thus, study demonstrated that, in hot region, button mushroom farming may be started in October month and can be carried out till March using polyhouse developed in study.

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1 Introduction

Button mushrooms (*Agaricus bisporus*) are the fruiting bodies of fungus containing proteins, vitamins, fibers and minerals (Kaur & Rampal, 2017). Protein content of button mushrooms varies from 20 to 35% (d.b.) which is higher than many fruits and vegetables (Thakur, 2014). Commercially produced button mushrooms contain 90% moisture content (w.b.), 3% proteins (w.b.), 5% carbohydrates (w.b.), 1% fats (w.b.) and 1% minerals and vitamins. Consequently, they are the crucial food items concerning human health, nutrition and disease prevention (Chang, 1996). Moreover, mushrooms are acknowledged by FAO as food contributing to protein nutrient in diet of developing countries where most of the population is heavily dependent on cereal/starchy diets (Karthick & Hamsalakshmi, 2017).

On considering the health importance of button mushrooms, their farming was started in India during 1960s in temperate region due to availability of favorable climate in region. Huge amount of agricultural wastes in the form of wheat and paddy straw, availability of suitable strains and farming techniques contributed to growth and diversification of mushrooms in the country (Maheshwari, 2013). Presently, total mushroom production of the country is 4,59,000 MT (Anonymous, 2017). The leading mushroom species produced in the country include button, oyster and paddy straw mushrooms. However, button mushrooms alone contribute almost 90% of total mushroom production of the country (Mehta et al., 2011).

Literature reveals that yield and quality of button mushrooms predominantly depends on environment inside mushroom house. Indeed, button mushrooms are very sensitive to environmental factors (Van Peer et al., 2009). Major environmental factors affecting button mushroom yield and quality are temperature, relative humidity (RH), oxygen and carbon dioxide (CO_2) concentration (Schmidt, 1983; Stamets, 1993; AMGA, 2004; Sarker et al., 2008). Attainment of desirable environment in mushroom house is very crucial. For button mushroom farming, recommended temperature is 22-26°C during *spawn run*, 18-22°C during *case run* and 14-18°C during fruiting. Recommended RH during *spawn* and *case run* is 80-90% and during fruiting it should be 85-95%. Concentration of CO_2 plays a vital role during *spawn run*. It is recommended that CO_2concentration should be maintained at>1500 ppm during *spawn run*. However, it should to be maintained between 800-1000ppm during fruiting period of mushroom (http://agridaksh.iasri.res.in).

Mushroom house provides the major interface between crop environment and ambient environment. It requires suitable arrangements to create desirable microclimate. Number of different small scale and commercial mushroom houses has been developed by various researchers (Kwon et al., 2004; Mabveni, 2004; Reyes et al., 2004; Dhar & Arumuganathan, 2005; Arumuganathan et al., 2010; Schiau, 2013). Variety of square, rectangular, curved, polyethylene covered tunnels with a range of cross-sections and shapes have been studied (Han et al., 2009; Schiau, 2013). However, in India, most of the mushroom farmers still grow button mushrooms in very temporary structures made of locally available materials. These structures lack heating, ventilation and air-conditioning (HVAC) facilities and unable to isolate mushroom environment from atmospheric environment. Some farmers constructed permanent structures with HVAC arrangements. These structures provide all essential requirements to crop but are costly and involve considerable cost of cooling and ventilation. Under such circumstances polyhouse technology, having intermediate cost, adequate life span (10-15 years) and maximum isolation of crop environment from surrounding environment, may be adopted in mushroom farming (Staunton, 1988).

In India, button mushroom farming is largely restricted to temperate region, consisting of Indian states of Himachal Pradesh and Jammu-Kashmir. However, due to large consumer demand, its farming may also be adopted in adjoining states like Punjab and Rajasthan by technological interventions in mushroom houses (Kaur & Rampal, 2017; Kumar et al., 2018). The climate of these states is categorized as hot and semi-arid. Temperature (14-18°C) desired for button mushroom farming is available in hot and semi-arid region from December to February (for 2-3 months) during which one crop is easily grown. However, after March, ambient temperature increases sharply making button mushroom farming difficult in region. Therefore, an innovative mushroom house that can provide desired temperature for more duration (November to March) may prove good in the region for production of 2-3 crops of button mushrooms.

Literature revealed that lot of research has been carried on mushroom production technology, development of mushroom varieties, post-harvest management of mushrooms etc. However, almost no work has been devoted on developing crop specific polyhouse suitable for farming of button mushrooms in hot region. Hence, an attempt was made in present study to develop intermediate cost, durable, completely protected polyhouse for mushroom farming. The main objective of study was to develop polyhouse for button mushroom farming in hot region of northwestern India and to evaluate its performance in terms of attaining desirable temperature and RH inside polyhouse during off-season period *viz*. October, November and March.

2 Materials and Methods

2.1 Experimental site

Experimental site is located in hot and semi-arid region of northwestern India. This region comprises of parts of Punjab, Haryana and Rajasthan. Description of experimental site is presented in Table 1. Mean monthly temperature and RH data was recorded at experimental site prior to study. This data indicated that maximum temperature in May-July reached up to 49°C whereas minimum temperature in December-January dropped to 0°C. Atmospheric RH dropped to 10% during May-June. This data revealed that polyhouse proposed for button mushroom farming should be capable of lowering the temperature by reducing heat gain during October, November and March months. Similarly, it should be able to increase inside temperature to optimum level by preventing heat loss during chilling winter.

2.2 Development of mushroom polyhouse

Crop specific polyhouse was developed according to functional requirement of button mushroom crop. Its roof was insulated and walls were ventilated (Figure1). The details of the structural components of polyhouseare presented below.

- Orientation - east-west direction
- Dimensions - length - 15 m, width - 4 m, ridge height - 4.27 m
- Roof - ridge height from floor: 4.27 m; eve height from floor - 2.13 m. Multi-layer roof composed of iron net (half inch mesh), polythene sheet (0.025 mm thick), jute sheet (3 mm thick), EPF thermocol sheet (8 mm thick) and UV stabilized polythene sheet (0.4 mm thick). Thermal conductivities of all these materials are listed in Table 2.
- Floor - floor material: single layer vertical brick. Floor of polyhouse was kept at 1 m deep below ground level. Aim of

Table 1 Description of the experimental site

Attribute	Description
Location	ICAR-CIPHET, Abohar, Punjab
Latitude	30.17°N
Longitude	74.18° E
Altitude	390 m above the mean sea level
Average annual rainfall	328 mm (200-500 mm)
Monthly Averaged Insolation	5.07kWh/m^2/day
Ground water table	up to 2 m

Table 2 Thermal conductivities of different materials used in roof

Roof material	Thickness (mm)	Thermal conductivity
EPF thermocol	8 mm	0.0245 W/m.K
Jute sheet	3 mm	0.25 W/m.K
UV stabilized black polythene sheet (300 gsm)	0.4 mm	0.45 W/m.K
LDPE Polythene sheet	0.025 mm	0.33 W/m.K

Figure 1Polyhouse developed for button mushroom farming in hot region lowering the floor was to provide extra height to polyhouse with minimized risk of overturning due to strong winds. It was also aimed at achieving more cooling effect through evaporative cooling system.

- Foundation walls - height - 1.22 m, width – 0.2 m
- Walls - Front wall- center height - 4.27 m. Front wall was provided with two 18 inch exhaust fans. Rear wall – center height was- 4.27 m. Side walls - composed of foundation wall (lower half) made of brick - 1.22 m height; and porous wall (upper half) made of insect proof net and UV-stabilized polythene.
- Door - double door frame was used to prevent the entry of insects and pests in to the structure.

2.3 Temperature profile inside polyhouse

After its construction, temperatures at nine different locations inside polyhouse were recorded under no crop load condition. Temperature sensors (PT 100 probes) of datalogger (sixteen channel, make: Intronix India, New Delhi) were installed in a grid of three tiers having three thermometers in a tier at nine locations (Figure 2). Temperatures were recorded at an interval of 30 min. The data was recorded continuously for six months. No cooling was provided to polyhouse during this period.

2.4 Heat load analysis of polyhouse

Heat load analysis was carried out using different equations described by Holman (1989). Heat load was the total heat accounted for increasing inside temperature of polyhouse. Total heat gained (Q_T) inside polyhouse was due to,

- heat inflow from surroundings (Q_S)
- heat generated by compost (Q_C)
- heat generated by workers (Q_W)
- heat generated by data logger, battery etc. (Q_D)

$Q_T = Q_S + Q_C + Q_W + Q_D$

However, amount Q_C ,Q_W and Q_D were very small in comparison to Q_S (Q_C>> Q_C , Q_W, Q_D). Hence only Q_S was considered for heat load analysis during study.

Q_S had two components: heat gained through roof (Q_R) and heat gained through walls (Q_W).Surface areas of roof and wallsexposed to surrounding were determined using Figure 3. Roof surface area (A_R) was calculated as 89.38 m^2 whereas wall surface area (A_W) was 66.23 m^2.

Heat gained through roof (Q_R) was determined using Eq.1.

$$Q_R = U_R A_R \Delta T \quad \text{... (1)}$$

U_R was determined using Eq.2

$$\frac{1}{U_R} = \frac{1}{h_i} + \frac{x_P}{K_P} + \frac{x_J}{K_J} + \frac{x_F}{K_F} + \frac{x_U}{K_U} + \frac{1}{h_o} \quad \text{... (2)}$$

Where, Q_R = heat gained through roof (W)

U_R = overall heat transfer coefficient of roof (W/m^2K) = 2.29

A_R = roof area (m^2)

ΔT = temperature difference of inside and outside of roof (°C)

h= convective heat transfer coefficient of air at low speed ($W/m^2.K$)

X = layer thickness(X_P= polythene, X_J= jute, X_F= foam, X_U= UV stabilized polythene)

K = thermal conductivity of layers (K_P= polythene, K_J= jute, K_{PF}= foam, K_U= UV-stabilized polythene)

Heat gained through wall (Q_W) was determined using Eq.3.

$$Q_W = U_W A_W \Delta T \quad \text{... (3)}$$

U_W was determined using Eq.4

$$\frac{1}{U_W} = \frac{1}{h_i} + \frac{x_U}{K} + \frac{1}{h_o} \quad \text{... (4)}$$

Where, U_W = overall heat transfer coefficient of wall ($W/m^2.K$) = 9.12

A_W = surface area of wall (m^2)

ΔT = temperature difference of inside and outside of wall (°C)

2.5 Cooling of mushroom polyhouse

Two evaporative cooling systems, fogger and fan-fad, were installed to attain desired temperature and RH conditions inside polyhouse.

2.6 Foggers

During *spawn* and *case run* polyhouse should be closed with no air exchange in order to achieve desirable CO_2 concentration (Maheshwari, 2013). Therefore, during this period cooling is possible with foggers only. Fan-pad system would reduce CO_2 concentration and hence may not be advisable. Six overhead foggers having total discharge of 24 liters/h were installed along the ridge line of the polyhouse.

2.7 Fan-pad system

It was useful during fruiting period as air exchange is desirable during *fruiting stage*. The cooling pad was made of khus

(*Chrysopogon zizanioides*) with dimensions as length 3.96 m, height 1.37 m and thickness 3-4 cm. The reason behind selecting khus as padding materials over other organic materials was that air flow through khus pad was higher as compared to wood wool and coconut coir pad (Shekhar et al., 2016). Khus pads were tied to galvanized iron wire mesh to prepare a cooling pad. Two electric exhaust fans with 4 straight blades and 18 inches sweep were used for achieving air exchange in polyhouse.

2.8 Performance evaluation of evaporative cooling systems

Both evaporative cooling systems were operated in polyhouse for predetermined interval of time and their effect on inside temperature, RH and CO_2 concentration was determined. Temperature was measured using infrared temperature meter (MecoIrt 380 infrared thermometer, Spark India System, Gwalior, India), RH was measured using wet and dry bulb hygrometer (Zeal P2501,Zeal, UK) whereas CO_2 concentration was measured with the help of CO_2 concentration meter (KusamMeco KM 6460, Mumbai, India). RH and CO_2 concentration were measured at three locations, close to east wall, at center and close to west wall, and average values were determined. Temperature was measured at various locations along length and height of polyhouse as given below.

Locations of temperature measurement along length

- Lengths (m): 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, 10.5, 12.0, 13.5 15.0 (10 locations)
- Operation time (min): 5, 10, 20, 30, 40, 50, 60

Locations of temperature measurement along height

- Height (m): 0.61, 1.07, 1.52, 1.98, 2.44, 2.90, 3.35, 3.81 (8 locations)
- Operation time (min): 5, 10, 20, 30, 40, 50, 60

2.9 Water requirement for cooling of polyhouse using evaporative cooling systems

Amount of water required to cool polyhouse using evaporative cooling systems was calculated using following equation (Eq. 5).

$$V \times \rho \times C \times \Delta T = \frac{d_m}{d_t} \times \lambda \quad \text{... (5)}$$

Where, V = volume of polyhouse (m^3)

ρ = density of air (kg/m^3)

C = specific heat of air (kJ/kg)

ΔT = temperature difference (°C)

m = mass of water required (kg)

λ = latent heat of water (2257 kJ/kg)

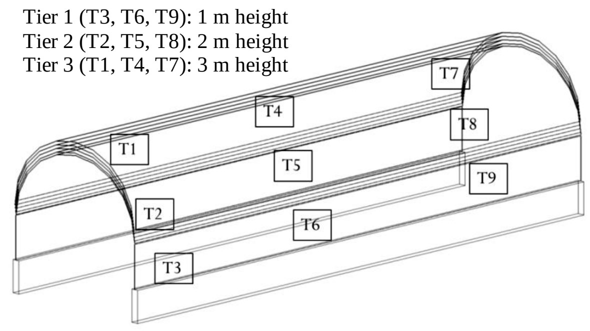
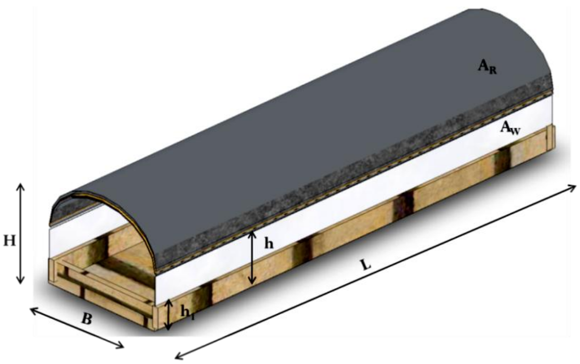


Figure 2 Locations of temperature sensors inside polyhouse



L = 15 m; B = 4 m; H = 4.27 m;
h = 2.36 m; H – h = 1.91 m; h – h_1 = 1.3 m

Figure 3 Surface area exposed to the surrounding

2.10 Performance evaluation of polyhouse

Performance of polyhouse was evaluated in terms of attaining the desired temperature and RH conditions during off-season period. October, November and March months were considered as off-season period. Button mushroom crop was grown in polyhouse as per standard practice (Maheshwari, 2013). Cultivation season was started in October 2016 to mid-March 2017, about 5 to 5.5 months. Two consecutive crops of button mushroom were cultivated during this period. Spawn was obtained from ICAR-Directorate of Mushroom Research, Solan, India whereas compost was prepared at experimental site.

3 Results and Discussion

3.1 Thermal analysis of polyhouse

Temperature at different nine locations inside polyhouse (Figure 2) was recorded under no crop load condition for six consecutive months. It was found that different locations in polyhouse attained different temperatures (Figure 4). The highest temperature (49°C) was recorded at locations in the uppermost tier (T1) and (T4) whereas the lowest temperature (39°C) was found at T9 located in bottom tier. Lower tier showed considerably lower temperatures

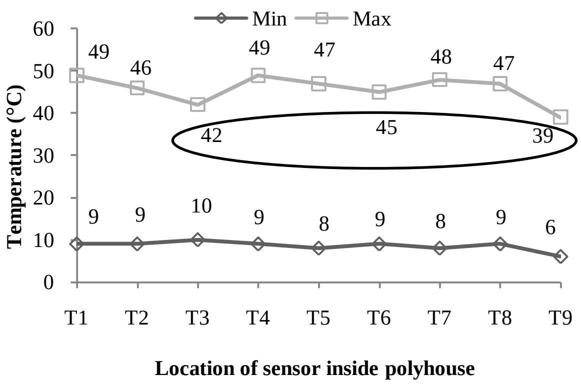


Figure 4 Temperature variation inside polyhouse

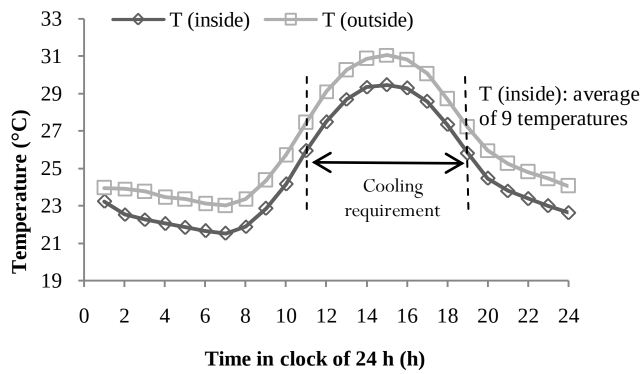


Figure 5 Temperature behavior inside and outside the structure in October month

Table 3 Heat gained by structure during different months

Month	Average Outside temp (°C)	Roof			Wall			Total heat gain (Q_T in W)
		Area (m^2)	Ur (W/m^{2}K)	Q_R(W)	Area (m^2)	U_W(W/m^{2}K)	Q_W(W)	
October	31	89.38	2.29	371.79	66.23	9.12	2479.3	2545.51
November	26	89.38	2.29	638.04	66.23	9.12	1010.3	1648.3
December	16	89.38	2.29	321.2	66.23	9.12	612.3	933.5
January	15	89.38	2.29	293.5	66.23	9.12	692.1	985.4
February	20	89.38	2.29	381.6	66.23	9.12	863.2	1244.8
March	23	89.38	2.29	492.5	66.23	9.12	2132.1	2624.8

as compared to other six locations. It might be due to tall height of the polyhouse and placement of floor below ground level.

Outside temperature and temperatures inside polyhouse at nine different locations (Figure 2) were continuously recorded for 24 h in October month. Average inside temperature was plotted against time and presented in Figure 5. Cooling requirement was understood from this plot. Figure 5 indicates that both inside and outside temperatures were almost constant till 8:00 am in morning. After 8:00 am, they increased till 3:00 pm in the afternoon and again decreased. Results indicated that the polyhouse needed external cooling from 11:00 am in morning to 7:00 pm in evening.

3.2 Heat load in polyhouse

Total heat gained by polyhouse during October to March, growing season of button mushrooms in temperate region, was determined and presented in Table 3. It is evident from Table 3 that heat gained by polyhouse was dependent on outside temperature and varied with month of year. Average outside temperature during October 2016 was observed as 31°C and total heat gained by polyhouse during this month was calculated as 2545.51 W. However, during January 2017, average outside temperature was observed as 15°Cand total heat gained by polyhouse was 985.4 W. Consequently, cooling requirement varied with the month. Maximum cooling was required during March and October whereas almost no cooling was required during December and January.

3.3 Water requirement for evaporative cooling systems

The aim of cooling systems was to lower polyhouse temperature by removing inside heat through evaporative cooling principle. In present study, temperature rise in polyhouse above the desired temperature for mushroom farming was determined as 10°C. Theoretically, water required to reduce inside temperature using evaporative cooling principle was determined as 0.13 liter per °C. Therefore, water required to reduce inside temperature by 10°C was 1.3 liter. However, in practical sense, polyhouse was gaining the heat continuously from the sun. Hence, more water required to attain desired temperature.

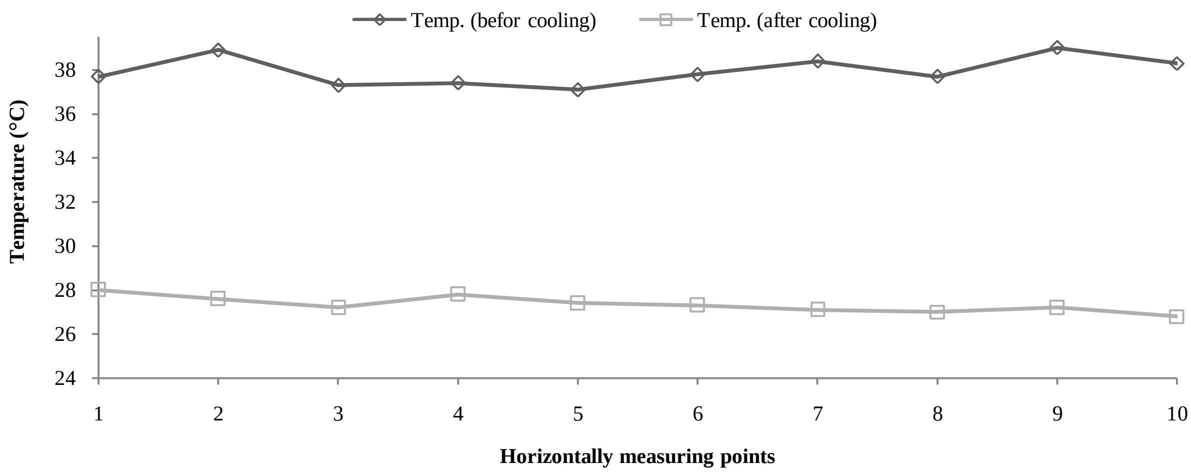


Figure 6 Variation in inside temperature along the length due to fan-pad cooling operation

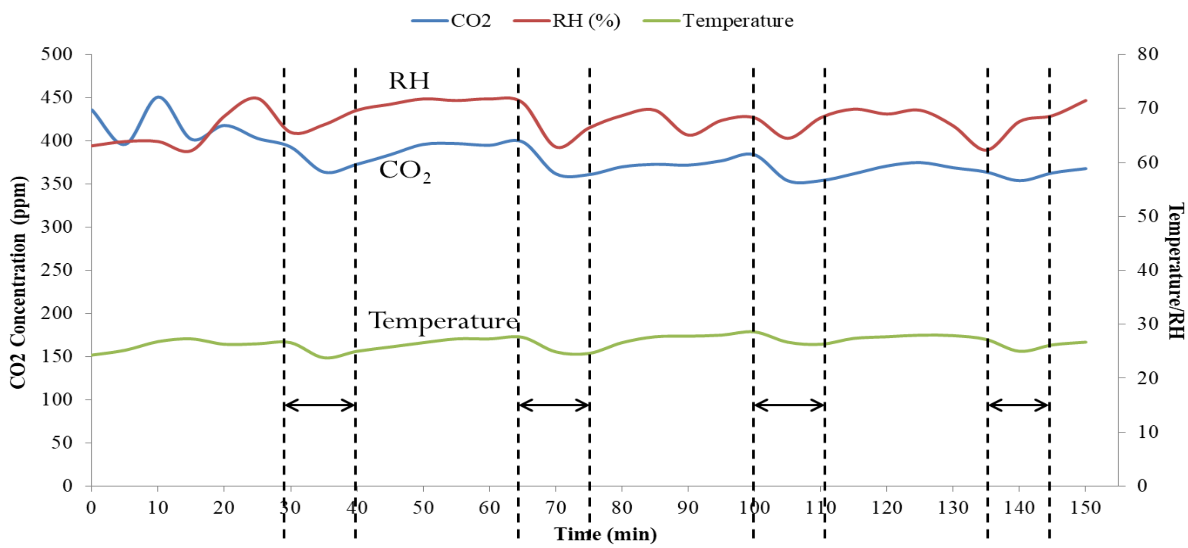


Figure 7 Variation in Temperature, RH and CO_2 concentration due to fan-pad system

3.4 Performance evaluation of evaporative cooling systems

Fan-pad system and foggers were operated independently and their effect on temperature and RH inside polyhouse was determined at different pre-determined locations.

3.5 Effect of fan-pad system on inside temperature and RH

During October-November, fan-pad system was operated for 10-60 min and variation in inside temperature along the length was determined (Figure 6). It was observed that after 60 min of operation, temperatures inside mushroom polyhouse at all 10 locations were almost same. Before cooling, inside temperatures at 10 different locations were 37-39°C and on operating fan-pad system for 60 minutes, these temperatures reduced to 27-28°C i.e. almost 10℃ reduction (Figure 6).

Variation in inside temperature (average of 10 locations) and RH with operating time was also determined in study during October, November and March. Results revealed that initial average inside temperature was 28±2°C and it decreased with time till 30 min of operation. However, after 30 minutes it became almost constant (about 21±2°C) with no further decrease in temperature. Similarly, inside RH was found to be about 76% after 30 min of operation. These conditions were more or less conducive for *spawn run*, *case run* and to some extent *fruiting* of button mushroom.

Fan-pad system draws inside air out and brings fresh air in. Consequently, it reduces CO_2 concentration inside polyhouse. In Figure 7, horizontal arrows indicate that fan-pad system was ON for this period. Figure 7 also shows that temperature and CO_2 concentration inside structure decreased whereas RH increased when cooling was ON. Fan-pad system maintained the inside temperature about 24°C, RH about 70% and CO_2level about 400 ppm. Thus, it could be inferred that although fan-pad system lowered inside temperature, it lowered CO_2level also. Such low concentration of CO_2 is undesirable during *spawn* and *case run*. Hence, fan-pad system should not be operated during this period.

3.6 Effect of fogger system on inside temperature and RH

Fogger system was operated for six different operating times ranging from 10 - 60 min and variation in inside temperature (average of 10 locations inside structure) and RH with operating time was determined. Results indicated that initial inside temperature was 29±2°C and it decreased with time till 20 min of operation. However, after 20 min of operation, it became almost constant (about 22±3°C) with no further decrease in temperature. Similarly, inside RH was found to be about 78% after 20 min of operation. These conditions were found conducive for *spawn run, case run* and to some extent *fruiting stage* of button mushroom.

3.7 Crop production

Two consecutive crops of button mushroom were cultivated in developed polyhouse as per standard practice (Maheshwari, 2013). First crop was spawned in October 2016 whereas second crop was spawned in January 2017. Wheat straw was used to prepare compost. Compost was spawned at the rate of 750 g spawn/quintal of compost and placed in poly bags of 5 kg capacity as well as in plastic crates of 5-6 kg capacity. Results indicated that spawning of button mushroom was possible in October month that allowed starting the mushroom farming one-two months earlier. Similarly, polyhouse provided favorable environment in March also thereby further extending the cultivation season by a month.

Conclusions

The crop cultivation season in hot region of northwestern India is from December – February during which only one crop is grown. The aim of study was to develop crop specific polyhouse that can extend cultivation season and allow growing 2-3 crops. After its construction, thermal analysis of polyhouse was carried out. Polyhouse was provided with two evaporative cooling arrangements. Effect of cooling arrangements on inside temperature and RH was determined. Results indicated that during October, average ambient air temperature was 31°C whereas polyhouse temperature varied from 23-31°Cwhen no cooling provided. On operating evaporative cooling system, inside temperature and RH were changed to 22-27°C and ≥75%, respectively. These conditions were suitable for *spawn run* of button mushroom. Similarly, during November, structure could provide 20-22°C temperature and ≥75%RH. These conditions were found suitable for *case run* and to some extent *fruiting stage* of button mushroom. Similar results were observed in February and March also. Thus study revealed that in hot region, cultivation of button mushroom may be started in October month (one month earlier) and can be carried out till March using developed polyhouse.

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Conflict of interest

The authors declare that the research was conducted in the absence of anycommercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

All authors have made contributions to the work and writing of this manuscript.

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