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Passive Cooling of Natural Ventilated Polyhouse During Summer using IR Reflective Film

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ABSTRACT

The high temperature (soil and air) and light intensity are major challenge in utilizing the natural ventilated polyhouse (PH) during summer season. There is urgent need to develop passive cooling system to address the challenge so that natural ventilated PH can be utilized for round the year cultivation. The IR reflective film have novel property in addressing the challenge, so it is utilized to develop natural ventilated PH to passively cool it during summer season. The efficacy of IR reflective film in cooling the natural ventilated PH is compared with open field and clear film by measuring the microclimate parameters and crop growth parameters. The increase in maximum temperature under clear film PH and IR reflective film PH are 6.2°C and 1.5°C respectively in comparison to open field. The IR reflective film is more suitable than clear film in reducing the temperature during summer season. The increase in yield under IR reflective film PH is 7.6% more than clear film PH due to suitable microclimate conditions under IR reflective film PH.

Keywords Temperature, Clear film, IR reflective film, Microclimate, Passive cooling, Polyhouse.

INTRODUCTION

The productivity and quality of any produce is influenced by the genetic characteristics of the cultivar, agronomical and microclimate management. Under open field cultivation, we can best manage agronomical management and there is no control on microclimate around the plant (Rai 2020).

Polyhouse (PH) is an agro technology wherein the microclimate around the plant is controlled fully, partially or modified to protect the crop from adverse microclimate parameters. The primary reason for using polyhouse is protection from low temperature in addition to other secondary benefits such as control of light intensity, relative humidity, carbon dioxide and protection from high wind speed, heavy rainfall, hailstorm and insects and diseases (Sánchez-Hermosilla *et al.* 2013, Manonmani *et al.* 2018, Gurav *et al.* 2022, He *et al.* 2023).

The major challenge in round the year utilization of polyhouse is high temperature and light intensity during summer season when both the temperature and light intensity is very high in open field condition

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(Rai 2009). The greenhouse effect in polyhouse is due to two different effects i.e. (i) A confinement effect, resulting from the decrease in the air exchanges with the outside environment, and (ii) An effect caused by the existence of a cover characterized by its low transparency to far infrared radiation (emitted by the crop, the soil and the inner greenhouse elements), but its high transparency to sunlight (Baudoin *et al.* 2013). Due to greenhouse effect, the temperature inside the polyhouse will be always more than the open field temperature.

To reduce the temperature of polyhouse during summer season so that it can be utilized round the year, the passive and active cooling system can be utilized (Davies and Zaragoza 2019, Nikolaou *et al.* 2019). The challenges of using active cooling system are high fixed cost and operating cost, energy cost, operational challenges and higher carbon footprint (Ghoulem *et al*. 2019, Ntinas *et al.* 2020). The common passive cooling technologies used are natural ventilation and heat prevention [shading and (radiation filters (NIR-reflective film cover and fluid roof covers)] (Sethi and Sharma 2007, García *et al.* 2011). The natural ventilated polyhouse can reduce temperature by 1.3–3.6°C but cooling effect inside natural ventilated polyhouse is influenced by external environmental factors (Mistriotis *et al.* 1997, McCartney and Lefsrud 2018). The shadenet can also reduce inside maximum temperature of natural ventilated polyhouse by 3–5°C (Hatem *et al.* 2008). The major challenge for cooling of polyhouse using natural ventilation and natural ventilation with shadenet is that the temperature inside the polyhouse is always more than open field temperature. Apart from high temperature inside the polyhouse other issue is low light intensity when shadenet is used for cooling (Rai 2018, Rai 2020).

The NIR is the main source of heat load that should be removed from the polyhouse to prevent the overheating during summer season. The IR-reflective film has special property in which shading and reflection are the fundamental concepts in the reduction of high sunlight intensity which as a result reduce the cooling requirements without affecting the plant growth inside the polyhouse (Soussi *et al.* 2022). Abdel-Ghany *et al.* (2001) reported that the naturally ventilated polyhouse covered with IR-reflective film can maintain the inside air temperature equal to open field temperature but major focus should be given on improving the property of film to reflect more NIR and increase the transmission rate of PAR.

The IR-reflective film is very promising technology in reducing the inside temperature of natural ventilated polyhouse passively. Keeping above challenges during summer season and opportunity to apply IR-reflecitve film, this study was conducted to evaluate the performance of IR-reflective film in reducing the temperature during summer for natural ventilated polyhouse.

MATERIALS AND METHODS

The experiment was conducted at research farm (longitude: 85.318°E, latitude: 23.448°N) of the AICRP on Plastic Engineering in Agriculture Structure and Environment Management (PEASEM), Department of Agricultural Engineering, Birsa Agricultural University, Kanke, Ranchi, Jharkhand during 2021-2023.

For experiment two natural ventilated polyhouses with cladding materials of clear film and IR reflective film were constructed and different materials used were i.e. bamboo, aluminium profile and spring lock, GI wire, coal tar, waste plastic, nail, cladding materials- [IR reflective blue film (200 micron), UV stabilized clear film and UV stabilized insect net proof material (40 mesh)]. The specification of both the polyhouses are, length: 12 m, width: 6 m, side height: 2 m and central height: 3 m (Inside door:- width: 1 m, height: 2.2 m) and compartment for double door structure: width: 2 m, length : 2 m and height: 2.2 m (outside door:- width: 1 m, height: 2.2 m). The side slope is 23.7^{o} and ventilation area is 44% of floor area.

Tomato crop were taken and in-line drip irrigation was used for irrigation and fertigation with proper RDF of 111:67:133 kg/ha. At the time of transplanting 100% doses of DAP, 20% of urea and 20% of MOP was given as basal dose. Rest of the doses of urea and MOP were given through fertigation.

The minimum and maximum temperature in

open field and both the polyhouses were measured using minimum and maximum thermometer (ZEAL: UK, range: -40°C to 50°C, least count: 1°C). The dry bulb and wet bulb temperature in open field and both the polyhouses were recorded using dry bulb (db) and wet bulb (wb) hygrometer (ZEAL: UK, range: -5°C to 50°C, least count: 1°C), and data were recorded at 7 am and 2 pm daily. The relative humidity (RH) was calculated from psychometric chart using dry bulb (db) and wet bulb (wb) temperature for temperature recorded at 7 am and 2 pm. The light intensity in open field and both the polyhouses were recorded using lux meter (Lutron: Tiwan, range: 0-200 klux, least count: 0.01 lux, accuracy: ±3%) and data were recorded at 7 am and 2 pm daily. The soil temperature in open field and both the polyhouses were recorded daily at 7 am and 2 pm with the help of soil thermometer at the depth of 5 cm.

RESULTS AND DISCUSSION

Microclimate parameters

The range of weekly mean temperature (minimum and maximum) and light intensity and their mean during summer season [7th meteorological week (12 Feb) to 19th meteorological week (13 May)] under open field and polyhouses are given in Table 1. The mean of minimum temperature under open field, clear film PH and IR reflective film PH are 14.3°C, 15.2°C and 15.2°C respectively. The increase in minimum temperature under both the polyhouse in comparison to open field is around 1°C. It is reported that there is 1-3°C increase in minimum temperature under polyhouse depending upon the design of polyhouse (Rai 2018).

The mean of maximum temperature under open field, clear film PH and IR reflective film PH are 40.7°C, 46.9°C and 42.2°C respectively. The increase in maximum temperature under clear film PH and IR reflective film PH are 6.2°C and 1.5°C respectively in comparison to open field. Normally the increase in maximum temperature under clear film PH is around 5-10°C in comparison to open field due to confinement and greenhouse effect (Rai 2018). The increase in temperature under IR reflective film PH is 1.5°C which is lower than clear film PH. Due to inherent property of IR reflective film in reflective/absorbing IR portion of solar radiation, the heat load

Table 1. Average temperature and light intensity during summer (7th meteorological week to 19th meteorological week) under open field and polyhouses.

Conditions	Minimum temp (°C)			Maximum temp (°C)			Light intensity (lux) at 7 am				Light intensity (lux) at 2 pm			
	Range		Mean	Range		Mean	Range		Mean	%T	Range		Mean	%T
Open field	4.6	23.0	14.3	31.0	48.0	40.7	29750.0	46013.0	38455.0	-	55740.5	83741.7	73713.4	-
Clear film PH	6.1	25.5	15.2	37.8	50.0	46.9	11750.0	28719.0	18294.2	47.5	28091.5	52361.7	41607.1	56.4
IR reflective film PH	5.7	25.5	15.2	32.8	50.0	42.2	6740.0	21326.0	11616.3	30.2	19692.5	29609.5	25866.4	35.1

Table 2. Average relative humidity and soil temperature during summer [7th meteorological week (12 Feb) to 19th meteorological week (13 May)] under open field and polyhouses.

Conditions	Relative humidity (%) at 7 am			Relative humidity (%) at 2 pm			Soil temp (°C) at 7 am			Soil temp (°C) at 2 pm		
	Range		Mean	Range		Mean	Range		Mean	Range		Mean
Open field	34.9	60.7	49.0	12.0	33.5	25.1	14.1	28.7	22.1	20.4	38.0	29.9
Clear film PH	50.2	72.7	63.0	23.7	63.1	39.6	17.5	26.0	22.0	19.1	34.0	26.8
IR reflective film PH	41.6	79.9	66.3	24.3	58.0	36.7	14.9	27.8	21.8	19.8	36.0	27.6

Table 3. Average temperature and light intensity during winter season (46th meteorological week to 06th meteorological week) under open field and polyhouses.

Conditions	Minimum temp (°C)			Maximum temp (°C)			Light intensity (lux) at 7 am				Light intensity (lux) at 2 pm			
	Range		Mean	Range		Mean	Range		Mean	%T	Range		Mean	%T
Open field	3.3	11.5	7.1	26.2	34.5	30.0	5882.0	34256.7	23896.0	-	31707.0	90091.7	63704.0	-
Clear film PH	5.0	12.1	8.0	34.0	42.8	37.9	4258.5	19258.6	12903.1	53.9	19422.6	58142.6	38472.5	60.4
IR reflective film PH	4.4	11.9	7.8	23.3	35.6	30.7	3031.0	12057.4	7839.8	32.8	11174.0	34010.0	22248.8	34.9

under PH is removed which prevents the overheating of PH (Abdel-Ghany *et al*. 2012).

The percent light intensity transmission (%T) at 7 am and 2 pm under clear film PH and IR reflective film PH in comparison to open field are 47.5 and 30.2 and 56.4 and 35.1 respectively. The %T under clear film varies between 47.5 to 56.4 which is lower than 30.2 to 35.1 found under IR reflective film PH. The %T under clear film varies between 40 to 86% which depends upon quality of film, aging of film, dust particles on film (Rai 2018). The %T under IR reflective film is lower in comparison to clear film due to IR reflective pigments (Impron *et al.* 2008).

The range of weekly mean relative humidity and soil temperature and their mean during summer season at 7 am and 2 pm under open field and polyhouses are given in Table 2. The relative humidity at 7 am and 2 pm under clear film PH and IR reflective film PH in comparison to open field are 63.0 and 66.3 and 39.6 and 36.7 respectively. The relative humidity both under clear film PH and IR reflective film PH is higher than open field due to evapo-transpiration (Liu *et al.* 2020).

The soil temperature at 7 AM and 2 PM under clear film PH and IR reflective film PH in comparison to open field are 22.0°C and 21.8°C and 26.8°C and 27.6°C respectively. The soil temperature at 7 AM both under clear film PH and IR reflective film PH is similar to open field temperature. The decrease in temperature at 2 PM both under clear film PH and IR reflective film PH 3.1°C and 2.3°C in comparison to open field. Due to silver-black mulch, there is reflection of light, hence, there is marginal decrease in temperature under both the polyhouses (Rai *et al.* 2017).

The range of weekly mean temperature (minimum and maximum) and light intensity and their mean during winter season [46th meteorological week (12 Nov) to 06th meteorological week (11 Feb)] under open field and polyhouses are given in Table 3. There is 1°C increase in temperature under both polyhouses in comparison to open field as found during summer season. There is decrease in temperature under both the polyhouses in comparison to open field as reported during summer season. The clear film is more suitable than IR reflective film during winter season because it is desirable to increase the temperature during winter

Table 4. Average relative humidity and soil temperature during winter season (46th meteorological week to 06th meteorological week) under open field and polyhouses.

Conditions	Relative humidity (%) at 7 am			Relative humidity (%) at 2 pm			Soil temp (°C) at 7 am			Soil temp (°C) at 2 pm		
	Range		Mean	Range		Mean	Range		Mean	Range		Mean
Open field	67.1	96.1	81.8	31.6	57.9	47.1	11.1	18.0	14.3	18.8	24.5	20.6
Clear film PH	70.1	90.2	77.8	20.9	50.5	33.0	12.7	18.4	15.6	17.7	23.5	20.1
IR reflective film PH	70.8	91.3	82.0	21.2	54.1	36.4	15.1	19.9	17.6	19.1	24.1	21.9

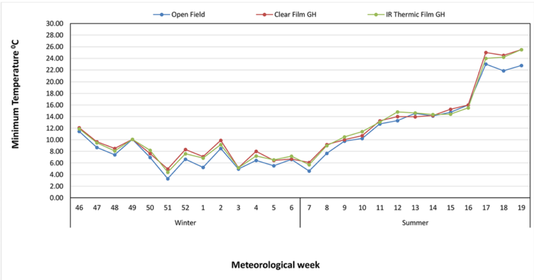

Fig. 1. Variation of minimum temperature with meteorological week of winter and summer season.

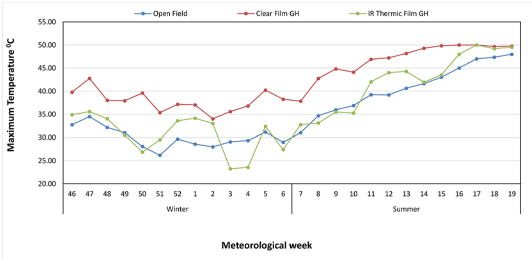

Fig. 2. Variation of maximum temperature with meteorological week of winter and summer season.

season depending upon open field condition. The % T for both the polyhouses has similar trend as recorded during summer season. It is desirable to reduce the light intensity during summer season under polyhouses which is more than required for cultivating crops but during winter season light intensity is under desirable range for cultivating crops (Rai 2018).

The range of weekly mean relative humidity and soil temperature and their mean during winter season [46th meteorological week (12 Nov) to 06th meteorological week (11 Feb)] at 7 am and 2 pm under open field and polyhouses are given in Table 4. There is increase in temperature under both the polyhouses due to this reason there is decrease in relative humidity both at 7 am and 2 pm in comparison open field (Rai and Ansari 2018). The similar observation is found for soil temperature at 7 am and 2 pm for both the polyhouses in comparison to open field as reported during summer season.

The variation of minimum temperature with meteorological week of winter [46th meteorological week (12 Nov) to 06th meteorological week (11 Feb)] and summer season [7th meteorological week (12 Feb) to 19th meteorological week (13 May)] is shown in Fig. 1.

The variation of maximum temperature with meteorological week of winter [46th meteorological week (12 Nov) to 06th meteorological week (11 Feb)] and summer season [7th meteorological week (12 Feb) to 19th meteorological week (13 May)] is shown in Fig. 2.

Crop growth parameters

The crop growth parameters (plant height, stem girth, no. of nodes/plants, total no. of fruits/plants, productivity) of tomato cultivated under open field, clear film PH and IR reflective film PH for non mulch and mulch condition is given in Table 5. It is clear from Table 5 that under mulch condition the crop growth parameter is better than non mulch condition for open field and both the polyhouses. The growth under mulch condition is better than non mulch condition due to conducive soil moisture, availability of oxygen in root zone, control of weed (Rai *et al.* 2017). The productivity of tomato under mulch condition is

Table 5. Crop growth parameters of tomato.

Sl. No.	Parameters	Open field		Clear film PH		IR reflective film PH	
		Non mulch	Mulch	Non mulch	Mulch	Non mulch	Mulch
1	Plant height (cm)	45.5	51.2	71.0	68.8	80.7	88.7
2	Stem girth (mm)	9.35	9.75	9.4	10.5	10.1	11.7
3	No. of nodes/ plant	66.3	77.8	70.0	86.8	69.7	128.7
4	Total no. of fruits/ plant	39	48	55	70	68	87
5	Productivity (t/ha)	30.3	37.2	64.4	71.5	68.6	76.9

found to be 37.2 t/ha, 71.5 t/ha, 76.9 t/ha respectively for open field, clear film PH and IR reflective film PH. The increase in yield under IR reflective film PH is 7.6% more than clear film PH due to suitable microclimate conditions under IR reflective film PH.

CONCLUSION

The major challenge in round the year utilization of natural ventilated PH is high temperature (soil and air) and light intensity during summer season. There is urgent need to address the challenge so that natural ventilated PH can be utilized profitably and sustainably. The cooling of natural ventilated PH during summer season can be done using active and passive cooling system. Due to lower fixed cost and operating cost, passive cooling using IR reflective film is tested for its efficacy in comparison to clear film PH. The increase in maximum temperature under clear film PH and IR reflective film PH are 6.2°C and 1.5°C respectively in comparison to open field. The %T under IR reflective film PH varies between 30.2 to 35.1 which is lower than 47.5 to 56.4 found under clear film PH. The IR reflective film addresses the challenges of high air temperature and light intensity during summer season and the productivity of tomato is 76.9 t/ha better than 71.5 t/ha for clear film PH. The performance of IR reflective film during winter season and its cost per unit are major challenge in comparison to clear film. Though IR reflective film is working better than clear film during summer but there is need to work on other efficient cooling systems (only passive or passive with active) which is more economical and efficient which can address the challenge.

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