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Photo Selective Shade Net: An Effective Tool to Reduce the Impact of Global Warming and Pesticide Residues in Vegetable Production: A Review

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ABSTRACT

Photo selective shade net is a product made of plastic fibers connected together with each other, forming a regular porous structure and allowing gases, liquid and light to pass through. It has a capacity to selectively filter the intercepted solar radiation, in addition to their protective function. Vegetables are considered as protective food which are highly perishable in nature. High temperature due to global warming, climate change and excessive use of chemicals are some of the burning issues of vegetable production. Photo selective shade net can be a partial solution for these problems. Vegetable crops grown under different photo selective shade net shows productive responses thus by application of various Photo selective shade nets we can improve the quality as well as production of vegetable crops.

Key words: Climate change, Global warming, Pest management, Properties of photo selective shade net, Vegetable crop production.

Vegetables are known as protective food as they supply essential nutrients, vitamins and minerals to the human body and are the best resource for overcoming micronutrient deficiencies. These crops, considered as perishable commodities, are important ingredients in human diet. ICMR (Indian Council of Medical Research) recommends 300 g vegetable consumption/capita/day (Champaneri *et al.*, 2021). Classification for vegetable consumption/capita/day is shown in Fig 1.

Apart from the health improvements, production of vegetable improves the economy of a country as these are very good source of income and employment. The contribution of vegetables remained highest (59-60%) in horticulture crop production over the last five years in India. India ranks second in vegetable production in the world after China. Area, production and productivity of various horticultural crops in India (Anonymous, 2018) are given in Table 1 and production share of India is illustrated in Fig 2.

Global warming affects production of various crops in horticulture. Production is suffered due to erratic rainfall, hail storm, increase in temperature and high intensity of solar radiation because of the climate change (Meena, 2013). Mean annual temperature of India has been increased by 0.46°C over a period of last 111 years due to the increased amount of greenhouse gases like CO_2 and CH_4 in atmosphere as well as global average surface temperature is expected to rise from 1.1°C to 6.4°C by the last decade of 21st century. This abnormal temperature increase leads to problems like change in timing and amount of rainfall, water availability, wind patterns, droughts, heat waves, flood storms, forest fires and hastens rate of ozone depletion (Minaxi *et al.,* 2011; Kumar, 2012).

Vegetables are generally sensitive to environmental extremes. High temperature and limited soil moisture are the major causes of low yields as they greatly affect several physiological and biochemical processes like reduced photo synthetic activity, altered metabolism and enzymatic activity, thermal injury to the tissues, reduced pollination and fruit set *etc.,* which will be further magnified by climate change (Koundinya *et al.,* 2014). Fruit colour is not in favorable marketable condition when the plants are exposed to high temperature. The optimum temperature for development of lycopene pigment in tomato is 25-30°C. Above 27°C temperature degradation of lycopene starts and it is completely destroyed at 40°C. Pollination and fruit set in tomato also is adversely affected above 25°C temperature (Kalloo *et al.,* 2001). Higher temperature is also responsible for abnormal pollen production, abnormal development of the female reproductive tissues, hormonal imbalances, lower levels of carbohydrates and lack of pollination which leads to poor reproductive performance of tomatoes (Peet *et al.,* 1997). Increase in temperature leads to increased fecundity and earlier completion of life cycle in some group of insects

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with short life cycles such as aphids and diamond back moth, which can help to produce more generations per year than their usual rate (FAO, 2008). Disease outbreak is heavier in high temperature stress conditions. Rising temperature also increase the incidence of cracking in tomato crop (Marr and Jirak, 1990). With 2°C temperature increase, insects might experience one to five additional life cycles per season which increases the mealy bug population in tomato crop (Adil *et al.,* 2003). Growth and yield parameters *i.e.* plant height, fresh weight, number of fruits per plant and fruit yield of tomato crop were adversely affected by stress of water and temperature (De Silva and Gunawardena, 2016).

Pesticide residue refers to the chemicals or metabolic products of the pesticides that may remain in food grains, vegetables and fruits after they are applied to crops. Many of these chemical residues, especially derivatives of chlorinated pesticides, exhibit bioaccumulation which could build up to harmful levels in the body as well as in the environment (Sachs *et al.,* 2010). At present, vegetable production is also characterized by a strong dependence on chemical plant protection with its all inherent environmental and health hazard, both for the growers and consumers (Grewal *et al.,* 2017). Excess consumption of pesticides leads to variety of human health hazards, *i.e.* damage to central nervous systems, cancer, allergies, hypersensitivities, reproductive disorders and disruption of the immune system (Mishra *et al.,* 2014). By considering these disadvantages of chemicals in recent times, organic

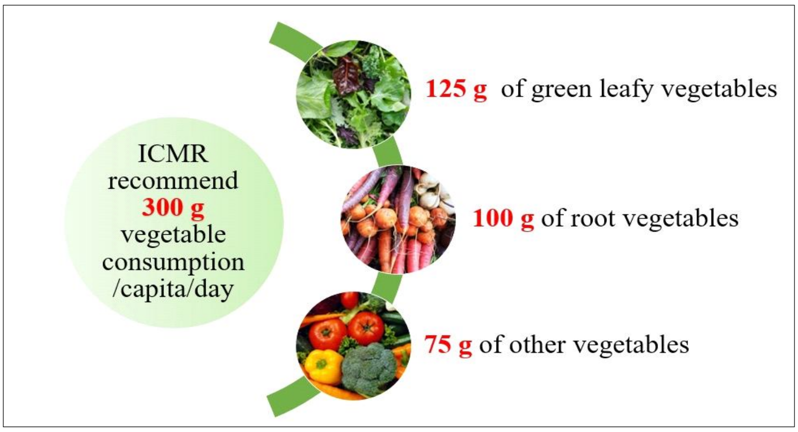

Fig 1: Vegetable consumption/capita/day recommended by ICMR.

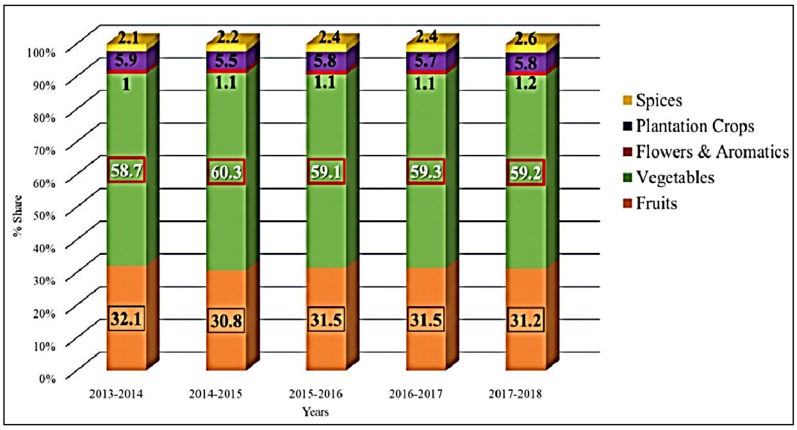

Fig 2: Production share of various vegetable crops.

Table 1: Area, production and productivity of various horticultural crops in India.

Crops	2016-2017			2017-2018		
	Area ('000 Ha)	Production ('000 MT)	Productivity (MT/Ha)	Area ('000 Ha)	Production ('000 MT)	Productivity (MT/Ha)
Fruits	6,373	92,918	14.58	6,506	97,358	14.96
Vegetables	10,238	1,78,172	17.40	10,259	1,84,394	17.97
Flowers, aromatics and medicinal crops	970	3,364	3.47	1,044	3,651	3.49
Plantation crops	3,598	17,972	4.99	3,744	18,082	4.83
Spices	3,671	8,122	2.21	3,878	8,124	2.09

vegetable produce has higher pick in demand due to awareness of people about health (Champaneri *et al.,* 2020).

Striking a balance between all season availability of high quality vegetables with minimum environmental impact and still to remain economically competitive in this time of globalization, is a major challenge for the modern technology of vegetable production. Photo selective shade nets can be considered as an impactful solution to resolve above given problems as well as to gain higher vegetable production with superior quality. Photo selective shade nets does not provide full pest control, but it can be incorporated into integrated pest management strategies (Ben-Yakir *et al.,* 2012).

Photo selective shade nets

Photo selective shade nets are product made of plastic fibers connected together with each other, in a woven or knitted way forming a regular porous geometric structure and allowing gases, liquid and light to pass through. It has the capacity to selectively filter intercepted solar radiation, in addition to their protective function. This technology is based on plastic net products into which various chromophores, light dispersive and reflective elements are introduced during manufacturing. These nets are designed to screen various spectral bands of the solar radiation and/or transform direct light into scattered light. The spectral manipulation is aiming at specifically promoting desired physiological responses, while the light scattering improves the penetration of the spectrally-modified light into the inner plant canopy, thus increasing the efficiency of light-dependent processes.

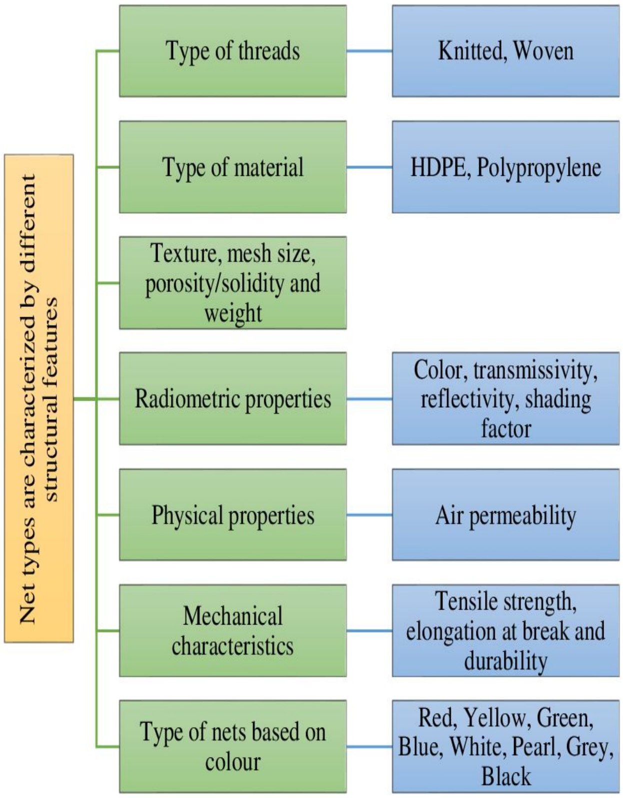

Fig 3: Classification of photo selective shade nets.

Additional aspects of this technology relate to photo selective effects on plant, pests and diseases (Shahak, 2011). Various applications of photo selective shade nets are given below (Castellano and Russo, 2008) and classification of nets based on various properties is given in Fig 3.

- Protection against various meteorological hazards.
- Solar radiation manipulation.
- Protection against virus vector insects and birds.
- For protected cultivation and garden centers in order to create walking areas.
- For soil mulching against weeds and as a barrier for roots, *etc.*

Shading effect

Shading effect of photo-selective nets can lower the inner temperature under the nets with a higher shade factor leading to decreased radiation exposure. Radiation of sun is partially reflected or absorbed by the shade nets. The part of the radiation that was not reflected or absorbed by the shade nets is transmitted *via* the nets. A negative correlation exists between weight or density of the shade nets and the light transmittance. Lower density of shading gives greater total light transmittance through the nets (Abdel -Ghany *et al.,* 2014).

The shading intensities of photo-selective nets affect the photosynthetic active radiation (PAR) under the nets (Lobos *et al.,* 2013). The PAR is described as the spectral range of solar radiation from 400 to 700 nm, the energy range that photosynthetic organisms are able to use in the biosynthetic process of photosynthesis. PAR measurement is important in agriculture in order to evaluate the growth of the plant and it is recorded in the field using a light quantum sensor (Rosati and Dejong, 2003). The PAR measured inside the nets includes the PAR that passed directly *via* the pores of the nets and the diffused PAR (Al-Helal *et al.,* 2010; Mõttus, *et al.,* 2012). The PAR under the photo-selective nets differs according to the shading intensity. PAR transmitted under the 25-28% shade nets was 63%, whereas under the 40-45% shading, only 37% of the PAR was transmitted (Elad *et al.,* 2007). Temperature under 25% shading were lower and the relative humidity was higher due to the knitting pattern. A densely knitted pattern of the threads in 40% shade nets was reported to slightly increase the temperature and negatively affect ventilation (Tinyane *et al.,* 2013).

Spectral radiation

Spectral photon irradiance can be altered by the color and shading intensity of the photo selective nets (Lobos *et al.,* 2012; Dodd *et al.,* 2005). Different colors of a specific photo -selective net are due to the absorption and reflection of light caused by the reflective fibers added to the net. The light dispersive and pigmented material of the chromatic additives and the reflective fibers selectively filter solar radiation to promote specific wavelengths of light inside the nets (Zelanski and Fisher, 2009). Photo-selective shade netting has been developed to improve the percentage transmittance of PAR and allow the modification of the spectral light composition with different light scattering properties (Fletcher *et al.,* 2005).

Photo-selective nets are manufactured in the following two color groups: colored - Colour Nets (red, yellow, green and blue) and neutral - Colour Nets (pearl, white and gray), absorbing spectral bands shorter or longer than the visible range (Rajapakse and Shahak, 2007). Transmission and absorption of various spectral bands under blue, red, yellow, white and pearl colour shade nets is portrayed in Fig 4 (a, b, c, d and e). Transmission and reflection of solar radiation according to shading percentage is demonstrated in Fig 5 (a, b, c and d).

Mechanism of light on plant

Red and far red light

Plant growth and development within the canopy can be modified by shifting the levels of red and far red light and by shifting the spectral distribution. Plants that were exposed to far red radiation showed longer internode length, light green in colour, had thin leaf blades and reduced branching compared with the plants exposed to the red region (Kasperbauer, 1970). Red: Far red light ratio can affect photosynthesis and the biomass production (Li *et al.,* 2000).

Blue and UV light

Cryptochromes and phototropins are known as B or Ultraviolet-A (400-320 nm) absorbing photo receptors (Cashmore *et al.,* 1999; Ninu *et al.,* 1999). Blue light stimulates the transcription of cryptochrome CRY1 genes and the CRY1 protein in the *Arabidopsis thaliana* plant is responsible for the inhibition of hypocotyl elongation, cotyledon expansion and root elongation (Wu and Spalding, 2007; Lin *et al.,* 1998). Ultraviolet-A radiation was responsible for the improvement of higher leaf chlorophyll content and photosynthetic activity. Supplementation of Ultraviolet-A radiation affected the leaf anatomy by

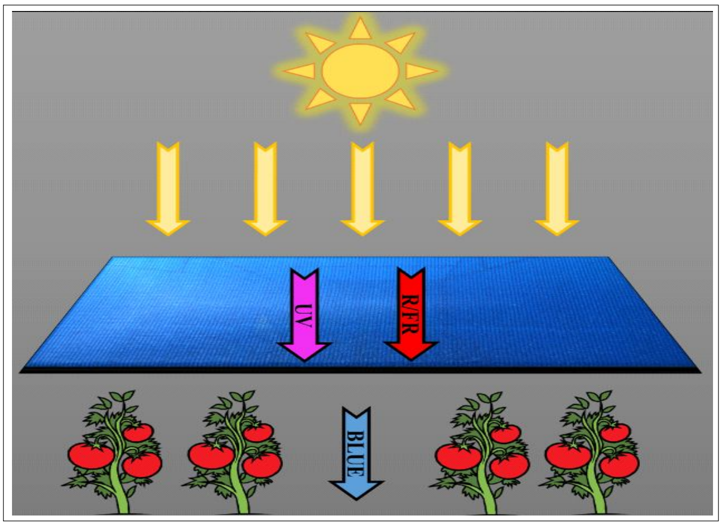

Fig 4 (a): Blue shade net absorbs ultraviolet (UV) (100-400 nm), red (R) (640-680 nm) and far red (FR) (690-750 nm) spectral regions, while enriches blue (B) (420-460 nm) spectral regions.

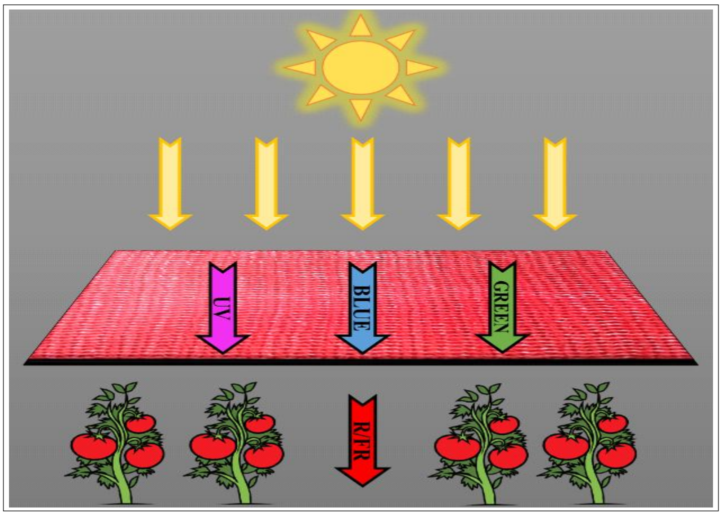

Fig 4 (b): Red shade net absorbs ultraviolet (UV), blue (B) and green (G) (495-570 nm) spectral regions and enriches the red (R) and far red (FR) spectral regions.

increasing the thickness of the palisade parenchyma and abaxial epidermis of the leaves, while the spongy mesophyll and adaxial epidermis were not affected (Victório *et al.,* 2017; Verdaguer *et al.,* 2017). Ultraviolet-B (280-315 nm) influences the activation of signal transduction pathways, which result in changes in gene expression for inducing photo morphogenesis, reduction of biomass, leaf area and stem extension (Huche-Thelier *et al.,* 2016, Tilbrook *et al.,* 2013).

Effects of photo selective shade nets on vegetable crops

Yield improvement

Under red net leaf greenness, leaf area and leaf dry weight increased due to the interaction of higher photosynthetic photon flux density (PPFD) and red light. Pearl and aluminized nets were transmitted the second largest flows of red light and blue light, respectively. These light levels favored the photosynthesis that led to increase the biomass production, which generally implies a greater area of phloem, more efficient transport and greater reserve capacity of assimilates for later use in the fruit filling (Murica *et al.,* 2016). On the basis of these facts, some research works are presented here in the aspects of yield improvement under photo selective shade net in vegetable crops.

Tafoya *et al.* (2018) observed environment created by the photo selective shade nets significantly affects the growth of cucumber plants and recorded higher average fruit weight under aluminized shade net (303.2±5.5 g/fruit) and No. of fruit (30.1±2.5 fruits/plant) as well as fruit yield (88.7±8.3 t/ha) under pearl shade net. Poornima *et al.* (2017) found Mean

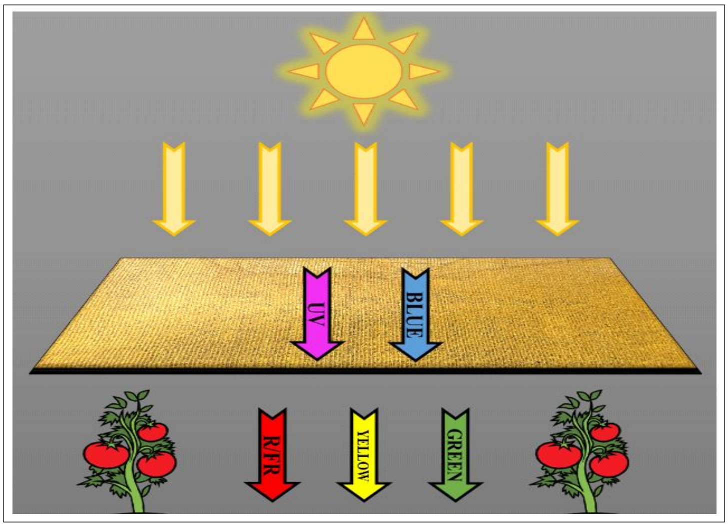

Fig 4 (c): Yellow shade net reduces ultraviolet (UV) and blue (B) wavelengths and enriches green (G), yellow (Y), red (R) and far red (FR) wavelengths.

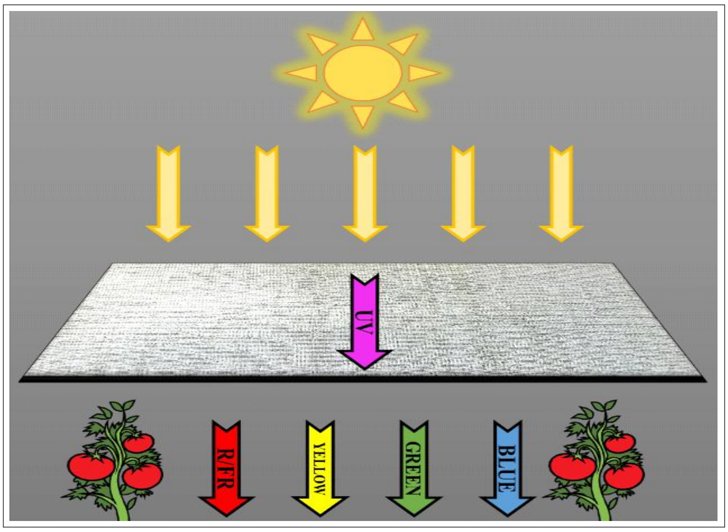

Fig 4 (d): White shade net absorbs ultraviolet (UV) wavelength and enriches blue (B), green (G), yellow (Y), red (R) and far red (FR) wavelengths.

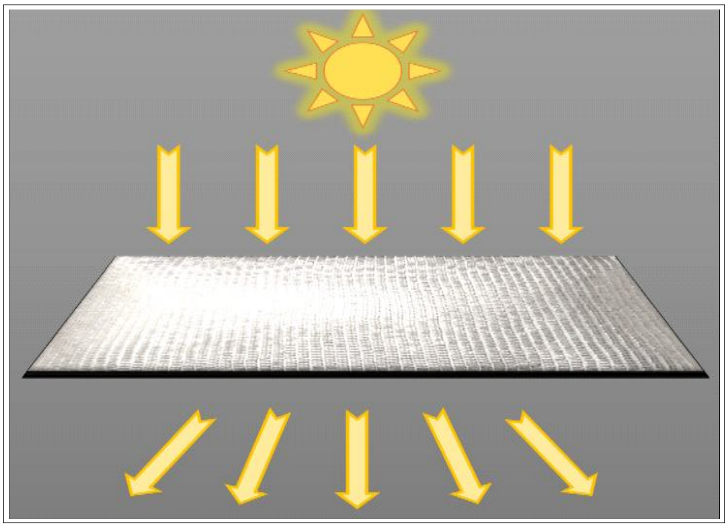

Fig 4 (e): Pearl shade nets do not enrich or absorbs different wavelengths. They designed to scatter the to a greater extent than other types of colored shade nets mentioned above.

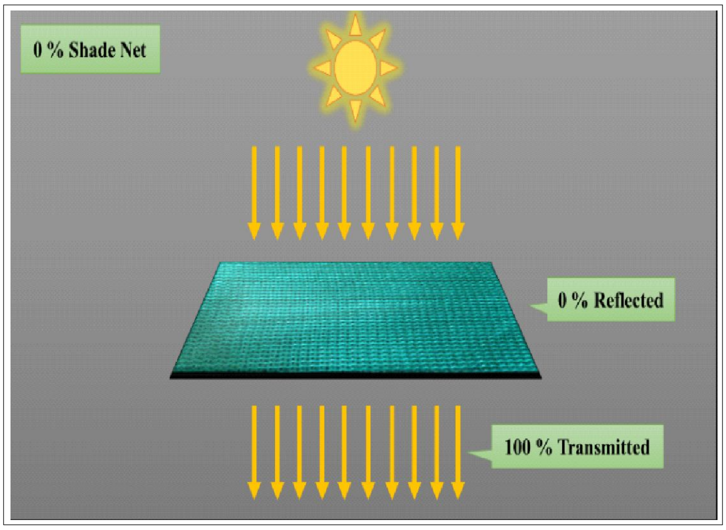

Fig 5 (a): 0% shade net transmits 100% light rays towards the plants while reflects 0% light rays from net surface.

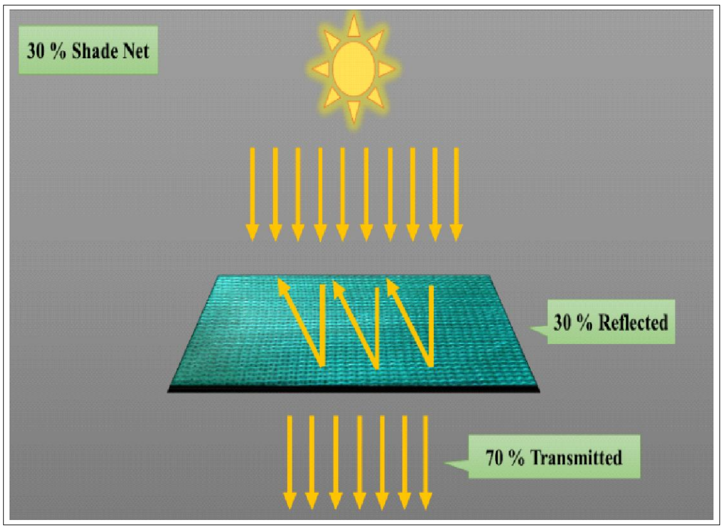

Fig 5 (b): 30% shade net transmits 70% light rays towards the plants while reflects 30% light rays from net surface.

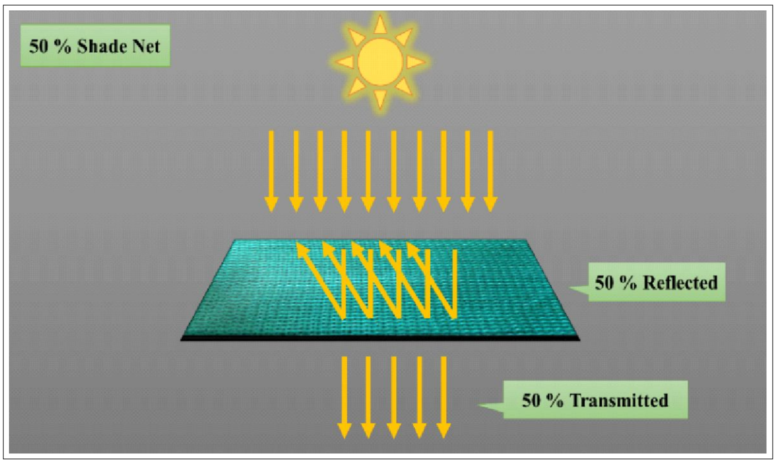

Fig 5 (c): 50% shade net transmits 50% light rays towards the plants while reflects 50% light rays from net surface.

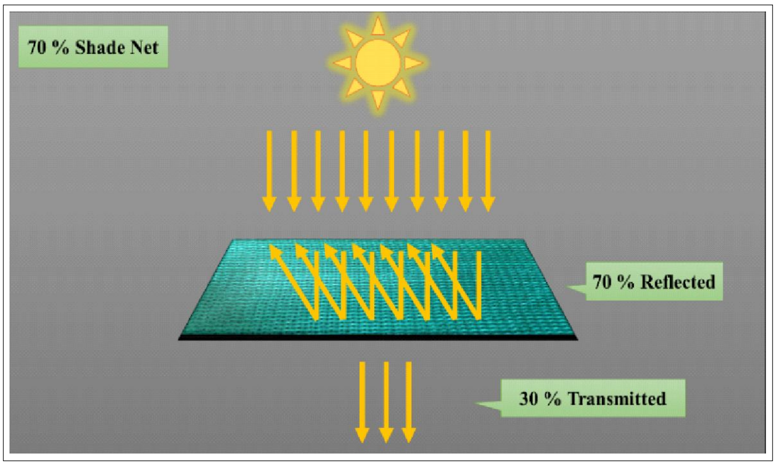

Fig 5 (d): 70% shade net transmits 30% light rays towards the plants while reflects 70% light rays from net surface.

air temperature and mean relative humidity under photo selective net is more favorable in compared to open field for cucumber crop and recorded the highest diameter of fruit (3.61 cm), length of fruit (15.18 cm), weight of fruit (207.14 g), no. of fruits per vine (12.68) and yield per plot (1.52 kg/7.8 m^2) in cucumber. Patil and Bhagat (2014) recorded highest diameter of fruit (4.19 cm), fruit weight (170.87 g), no. of fruit per vine (8.32 fruits) and yield (27.32 t/ha) under 75% shading. Nishimura *et al.* (2012) observed photo-selective light films modify the light spectrum to obtain a higher R:FR ratio and recorded an improvement of fruit yield (39.1%) and fruit number (44.6%) in cucumber (*Cucumis sativus*) produced under photo-selective films.

Red spectrum improved the yield in lettuce (Son and Oh, 2013). However, with regard to three leafy loose lettuce varieties, Aquarell (green), Ashbrook (green) and Exbury (red), cultivation under photo-selective pearl and yellow nets with 40% shading improved the fresh leaf mass and percentage of marketable yield at harvest (Ntsoane *et al.*, 2016). Ilić *et al.* (2017) observed that plants grown in the shade tend to have a larger leaf area because cells expand more under low light intensities in order to receive light for photosynthesis. Lower light intensities increase the stem elongation, leaf blade area and leaf area index. They measured the highest LAI (3.1), head weight (331 g/plant), head diameter (22.6 cm) and leaf no. (42) under pearl shade net while highest stem-core length (9.7 mm) and early maturity (34 days) were recorded under red shade net. They also found superior quality head under color shade net as compared to open field.

Under red colour shade net higher chlorophyll content and higher PPFD and red light interaction was observed. Due to these facts, Ombodi *et al.* (2015) in sweet pepper cultivars observed highest yield (7.13 kg/m^2) in Kárpia F_1 and (8.21 kg/m^2) in Karpex F_1 under red shade net 49. Nagy *et al.* (2017) recorded the highest yield in two hybrid pepper cultivars *i.e.* Star Flame (2.9 kg/m^2) and Fire Flame (3.2 kg/m^2) under white shade net. Shahak (2008) in pepper crop found the highest fruit yield 127.6 t/ha, 136.1 t/ha and 128.3 t/ha in cultivars Caliber, Anna and Triple Star, respectively under red shade net.

In comparison to open field under red colour shade net, Desai (2015) found low temperature and he also measured the maximum photosynthesis in fenugreek (25.44 µmol CO_2 $m^{-2}s^{-1}$), coriander (25.69 µmol CO_2 $m^{-2}s^{-1}$) and garlic

(26.26 µmol CO_2 $m^{-2}s^{-1}$) which leads to highest plant height in fenugreek (25.59 cm), coriander (20.62 cm) and garlic (28.08 cm). He also observed maximum no. of leaves in fenugreek (28.47), coriander (29.30) and garlic (4.75) as well as noted the highest fresh biomass yield in fenugreek (135.25 kg/100 m^2), coriander (58.19 kg/100 m^2) and garlic (59.47 kg/100 m^2) under red colour shade net.

Pest management

Net covers have been reported to be an effective physical barrier excluding a wide range of lepidopteron pests from growing plants (Gogo *et al.,* 2014). Nets have properties to filter the ultraviolet radiation (280-400 nm) interfering with the vision of insect pests and hence their ability to see and discern the host plants (Shahak *et al.,* 2004). The elimination of the ultraviolet portion of the light spectrum interferes with ultraviolet vision of insects and which affects their behavior related with movement, host location ability and their population parameters which leads to lowering their population under agro-net covers (Diaz and Fereres, 2007). Reduced number of silver leaf whitefly and aphids observed under the yellow net cover can be attributed to the pigments contained under this net cover that attracts whiteflies and aphids. So, crops grown under these nets could potentially be at a lower risk of pest infestation (Antignus and Ben-Yakir, 2004). According to Ben-Yakir *et al.* (2012) the optical property and light reflection of yellow net cover makes whiteflies and aphids land and stay arrested on it for an extended period of time without penetrating through the net. Shahak, (2008) observed that blue net cover also contains pigments known to attract thrips so, growing tomato under blue net cover could potentially be at lower risk of thrips infestation. Caroline *et al.* (2017) in tomato, noticed highest no. of fruits (53) from which 36.80 fruits were marketable as well as highest yield (24,938.87 kg/ha) from which 17,830.68 kg/ha fruits were marketable under white color shade net. He also counted the lowest pest population at 84 days after transplanting in silver leaf white fly (0.94 no./plant), aphid (1.21 no./plant) and thrips (0.51 no./plant) under yellow, white and blue color shade net, respectively. Ngelenzi *et al.* (2018) in French bean, recorded the lowest aphid population *i.e.* 0 no./plant (21 days after planting), 0 no./plant (35 days after planting), 1.94 no./plant (49 days after planting) and 5.19 no./plant (63 days after planting) as well as the lowest white fly population *i.e.* 0.42 no./plant (21 days after planting), 0.38 no./plant (35 days after planting), 0.20 no./plant (49 days after planting) and 3.33 no./plant (63 days after planting) under yellow shade net. Elad *et al.* (2007) observed that production of sweet peppers under the blue-sliver, green and red shade nets helped reduce the incidence of powdery mildew in the leaves caused by *Leveillula taurica* compared to the plant grown in the open field. He also concluded that the light qualities under the different colored shade nets or due to an indirect effect on improving the host (plant) defense mechanism reduced powdery mildew incidence in the sweet pepper leaves. Along with this, the shade net production improved the yield, compared with the open field production, by increasing the average fruit weight of a single fruit.

Physiological disorders management

A high light intensity can lead to disorders in development and appearance of tomato fruit (Dorais *et al.,* 2001). Sunscald injury and uneven ripening are caused by direct effects of light on fruit. Sunscald injury of tomato fruit increased with irradiance and air temperature and their combined effects (Adegoroye and Jolliffe, 1987). Peet and Willits (1995) observed that sun scald is a common form of heat injury and also found a linear increase of fruit cracking at the upper clusters of tomato fruit with high solar irradiance and fruit temperature. Lorenzo *et al.* (2013) observed the benefit of shade on quality of tomato fruit due to less blossom end rot and cracked skin. Possible cause of the decrease of cracked fruit by shading is a decreased fruit temperature by the shading treatments. Sun scald was eliminated under shading while tomato cracking, blossom end rot and puffiness were reduced to about 50% than that under open field. Milenkovic *et al.* (2012) registered the highest marketable yield (87%), lowest cracking (5%) and no sun scalding under 40% pearl color shade as well as the highest marketable yield (81%), lowest cracking (6%) and no sun scalding under 50% pearl color shade net as compared to other color shade nets and open field in tomato. High temperatures with high solar radiation leads to increased incidence of leaf disorder in lettuce. Rib discoloration, tip burn and bolting were observed less under colour shade net in compared to open field condition due to optimum temperature and radiation (Ilic *et al.,* 2017).

CONCLUSION

By considering the above given facts, it can be concluded that temperature is comparatively lower under photo selective shade nets so we can utilize this technique to overcome the problems of high temperature due to climate change and global warming. Photosynthetic rate, plant growth parameter as well as yield was high under various photo selective shade nets in vegetable crops. Along with this, pest incidence and occurrence of physiological disorders observed were far reduced compared to open field under photo selective nets which leads to lower consumption of chemicals in vegetable production. So we can avoid or reduce the use of excessive chemicals thus eliminating the health related issues. Thus we can conclude that, for better quality, higher yield, less pest incidence as well as to reduce adverse effects of high temperature in vegetable production photo selective net can be an effective solution.

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