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PHOTO-SELECTIVE SHADE NETS: A REVOLUTIONARY TOOL FOR CLIMATE-RESILIENT FRUIT CULTIVATION

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ABSTRACT

Fruit crops played a critical role in the world's nutrition, economic development and agricultural sustainability, providing essential vitamins, minerals and antioxidants to the human diet. The world's total production of fruits was about 933.1 mmt, with India ranking as the second-largest fruit-producing country with a total production of 110.21 mmt. However, fruit cultivation was threatened by the effects of climate change and the need to produce safe, high-quality fruits with minimal chemical inputs. The use of protective netting became crucial in modern horticulture to mitigate challenges in fruit cultivation. Although netting was not a new practice, its earliest applications were in fruit crops such as grapes, peaches, apricots, apples and cherries. Photo-selective shade nets were advanced materials made of woven or knitted plastic fibres that created a porous structure allowing air, water and light to pass through. Unlike conventional nets, they were designed with chromophores and light-dispersive elements that selectively filtered solar radiation and converted direct sunlight into diffused light. This spectral manipulation improved canopy light penetration and enhanced light-dependent processes such as photosynthesis. By altering specific wavelengths, these nets could trigger desired physiological responses in plants through photoreceptors such as phytochromes and cryptochromes. And also modified light quality, photo-selective nets provided protection against meteorological hazards (hail, strong winds and heavy rainfall), reduced heat stress and act as barriers against insect vectors and birds. Consequently, they created favourable microclimatic conditions in orchards and protected cultivation systems, improving crop growth, fruit quality and overall production sustainability. This review paper is to provide a comprehensive evaluation of photo-selective shade netting technology as a sustainable and climate-resilient intervention in modern fruit culture.

***Keywords* :** Photo-selective shade nets, Climate-resilient horticulture, Fruit quality.

Introduction

Fruit crops play a vital role in global agriculture, nutrition and economies, providing essential vitamins, minerals and antioxidants that contribute to human health and well-being. They are a key component of balanced diets, helping to prevent chronic diseases and malnutrition. Beyond their nutritional value, fruit crops have significant economic importance, supporting livelihoods through cultivation, processing and trade (Puglisi, 2023). They are also integral to sustainable agricultural systems, promoting biodiversity and soil health. Fruits are utilized in various forms, including fresh consumption, processed products (juices, jams, dried fruits) and as raw materials in industries such as cosmetics and pharmaceuticals. Additionally, fruit crops contribute to environmental sustainability by sequestering carbon and enhancing ecosystem resilience. Their cultivation and utilisation are essential for food security, economic development and ecological balance, making them indispensable to both human societies and the environment. (Anonymous, 2023). The estimated world fruit production is around 933.1 mmt. India stands as the second largest producer of fruits in the world, with production estimated to be 110.21 mt in 2022–23 (Anonymous, 2023; Anonymous, 2024). However, the usage of nets in agriculture is not a novelty. The oldest net applications were in fruit cultivation (grapes, peaches, apricots, apples and cherries) and ornamental plant production (cut flowers) and vegetable production (Briassoulis *et al*., 2007). Photo-selective shade nets are innovative products crafted from interconnected plastic fibres, woven or knitted into a regular porous geometric structure. These nets permit the passage of gases, liquids and light while selectively filtering specific wavelengths of solar radiation (Pandey *et al*., 2023). Beyond their protective role, they are engineered to influence plant growth and development. This advanced technology incorporates various chromophores, light-dispersive elements and reflective components during manufacturing, enabling the nets to screen specific spectral bands of solar radiation and/or convert direct light into diffused light. By manipulating the light spectrum, these nets are designed to trigger targeted physiological responses in plants (Liu *et al*., 2021). Additionally, the scattering of light enhances its penetration into the inner canopy, improving the efficiency of light-dependent processes such as photosynthesis ((Ferreyra *et al*., 2021 and Champaneri and Patel, 2022). Photo-selective shade nets provide a multi-dimensional advantage to horticulture cropping systems (Shahak, 2011 and Jemric *et al*., 2021). These protect crops from meteorological calamities such as hail, high wind and torrential rains, thus reducing damage (Brar *et al*., 2020). These shade nets are also effective for the regulation of solar radiation, which increases crop growth and reduces heat stress (Aoun and Manja, 2020). Additionally, these shade nets act as a physical barrier for virus-transmitting insects and birds, thus reducing pest intensity, These shade nets are highly effective for protected cultivation and nursery crops. These photo-selective shade nets are effective for ground cover, which allows for soil mulching and weeds to be controlled, thus conserving moisture while preventing unwanted root growth . Light quality manipulation also improves horticultural crops quality at harvest and postharvest (Fallik and Illic, 2017). The objective of this review is to evaluate how photo-selective shade nets influence fruit cultivation by analyzing their impact on plant physiology, microclimate modulation and protection against stresses to enhance fruit quality and yield sustainability.

History

The development of photo-selective netting technology emerged from a sixteen year collaboration between Israel's Volcani Centre (ARO) and Polysack Plastics Industries, beginning with foundational research into spectral modifications to optimise plant growth (Oren-Shamir *et al*., 2001). Key steps included designing nets with tailored light-filtering properties, resulting in ChromatiNets® in colours like Red, Yellow and Pearl (Shahak *et al*., 2004a, Shahak, 2008a). Multidisciplinary teams, funded by competitive grants, validated spectral performance in simulated environments and semi-commercial trials (Shahak, 2008a), while long-term studies (3–6 years) ensured robust data across crops such as ornamental foliage, vegetables and fruit trees (Nissim-Levi *et al*., 2008; Shahak *et al*., 2008b).

Industry-academia collaboration addressed challenges like chromophore stability and light scattering, enhancing durability and horticultural benefits (Healey *et al*., 1998; Hemming *et al*., 2008). Research expanded to entomology and phytopathology, revealing pearl and yellow nets reduced pest-borne viral diseases (Ben-Yakir *et al*., 2012) and fungal infections (Fallik *et al*., 2009). Global adoption followed, with trials in Europe, the Americas and China on ornamentals (Leite *et al*., 2008), vegetables (Yan *et al*., 2011) and fruit trees like apples and peaches (Basile *et al*., 2012; Solomakhin and Blanke, 2009), prompting the International Society for Horticultural Science to establish a dedicated sub-working group (Ganelevin, 2008). This innovation underscores the synergy between spectral science and agronomy, driving sustainable agricultural advancements worldwide.

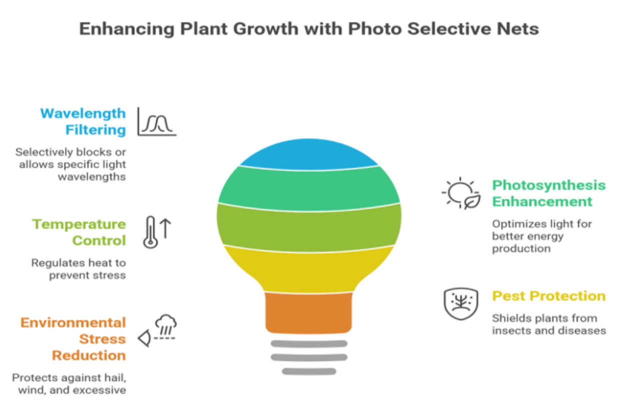

Fig. 1 : Uses of photo-selective nets

Classification of Photo-selective Nets

The photo-selective nets have several advantages and are shown in Figure 1. Photo-selective netting systems are categorised by two primary criteria: light-filtering properties and material composition. Spectral manipulation is achieved through nets tailored for red, blue, green, or far-red wavelengths to modulate plant morphogenesis. Structurally, these nets typically use polyethene or polypropylene, fabricated via knitted or woven techniques to optimise durability and light diffusion (Champaneri and Patel, 2022). The classification of the shade nets is given in Figure 2.

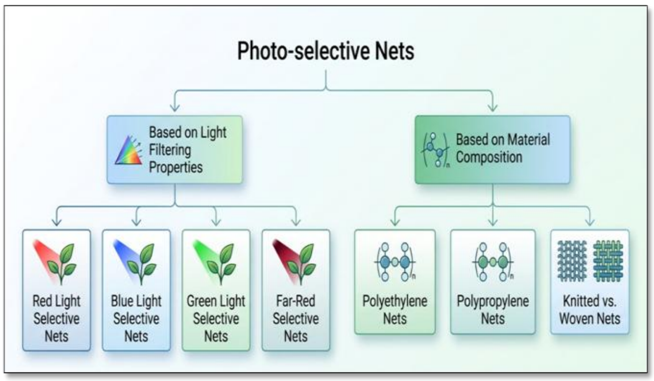

Fig. 2 : Classification of photo-selective nets (Champaneri and Patel, 2022).

Photosynthetic Active Radiation (PAR)

PAR is electromagnetic radiation that can be used as the source of energy for photosynthesis by green plants with a wavelength of 400 to 700 nm. PAR is expressed either in terms of photosynthetic photon flux density (moles $m^{-2}s^{-1}$) or yield photon flux. Since traditional black nets are completely opaque, they do not alter the spectral quality of light; instead, they reduce light intensity without affecting its quality (Arthurs *et al*., 2013; Fallik, 2017). Whereas shade nets are less opaque and scatter light, increasing the amount of diffuse radiation that penetrates the plant canopy. This enhances radiation use efficiency (Stamps, 2009). Coloured shade nets further improve light scattering, which can influence plant growth and development by modifying the spectral composition of light reaching the plants. This alteration in light spectra can enhance photo morphogenetic and physiological responses (Castellano *et al*., 2008; Shahak *et al*., 2009; Fallik, 2017). Stamps (2009) noted that coloured shade nets can be used to alter the red to far-red light ratios detected by phytochromes, adjust the levels of radiation activating blue/ultraviolet- A photoreceptor, modify blue light involved in phototropic responses mediated by phototropins and influence radiation at other wavelengths that impact plant growth and development.

Plant Photoreceptor

Plant photoreceptors are specialised proteins that enable plants to detect and respond to light, which is critical for growth, development and survival. These photoreceptors absorb specific wavelengths of light and trigger signalling pathways that regulate processes like germination, phototropism, flowering and stress responses (Mawphlang and Kharshiing, 2017). Below is an overview of the major plant photoreceptors and their roles.

Phytochromes (Red/Far-Red Light Sensors)

Phytochromes are important plant photoreceptors that perceive red (660 nm) and far-red (730 nm) regions of the light spectrum and play a key role in regulating plant growth and development. Structurally, phytochromes consist of a protein component (apoprotein) linked to a light-absorbing chromophore known as phytochromobilin (Bae and Choi, 2008). These photoreceptors exist in two reversible forms: an inactive Pr form and an active Pfr form. When plants absorb red light, the Pr form is converted into the biologically active Pfr form, whereas exposure to far-red light converts Pfr back to the inactive Pr state (Casal, 2012). The active Pfr form initiates signalling pathways that regulate the expression of light-responsive genes, thereby controlling several physiological processes (Figure 3). Phytochromes are involved in important plant responses such as seed germination, shade avoidance through detection of changes in the red to far-red light ratio, photoperiodic regulation of flowering through genes such as FLOWERING LOCUS T (FT) and synchronisation of circadian rhythms (Liu *et al*., 2021).

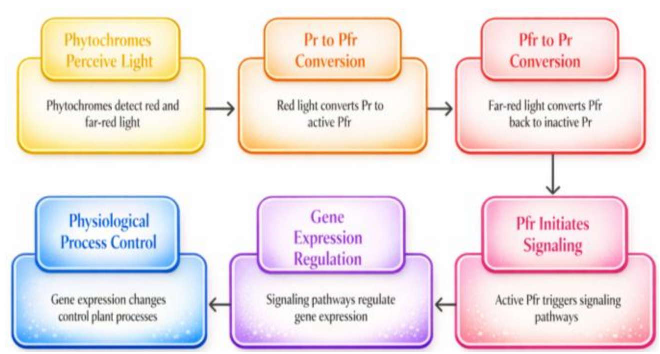

Fig. 3: Phytochromes pathway

Cryptochromes (Blue/UV-A Light Sensors)

Cryptochromes were plant photoreceptors that absorb blue (450 nm) and UV-A (320–400 nm) light. They are flavoproteins that contain flavin adenine dinucleotide (FAD) as the light-absorbing chromophore (Yu *et al*., 2009). After absorbing blue light, cryptochromes activate signalling pathways that regulate several developmental processes in plants. They play an important role in inhibiting hypocotyl elongation in seedlings, regulating photomorphogenesis during de-etiolation and controlling circadian rhythms and flowering time through interactions with genes such as CONSTANS (CO) and FLOWERING LOCUS T (FT) (Wang and Lin, 2020). Cryptochromes are also involved in the regulation of stomata opening and root development, indicating their multifunctional role in blue light signalling in plants.

Phototropins (Blue Light Sensors)

Phototropins are blue light photoreceptors that detect wavelengths in the range of approximately 390–500 nm (Kinoshita *et al*., 2001). Structurally, they contain light-sensing LOV (Light-Oxygen-Voltage) domains and a serine/threonine kinase domain that initiates downstream signalling after light perception (Okajima, 2016). Phototropins regulate several light-mediated physiological responses in plants, including phototropism, where stems and other organs grow directionally toward light. They also control chloroplast movement to optimise light absorption and prevent photodamage under high light conditions. Phototropins regulate stomatal opening through activation of H^+-ATPases in guard cells and contribute to leaf flattening and proper leaf positioning, which enhances photosynthetic efficiency (Kinoshita and Hayashi, 2011).

UVR8 (UV-B Light Sensor)

UV RESISTANCE LOCUS 8 (UVR8) is a specialized plant photoreceptor responsible for sensing UV-B radiation (280–315 nm). Structurally, UVR8 is a β-propeller protein that exists as a homodimer in the absence of UV-B light. Upon exposure to UV-B radiation, the dimer dissociates into active monomers, initiating a signalling cascade that regulates UV-B-responsive genes (Rizzini *et al*., 2011). Activation of UVR8 plays a significant role in plant acclimation to UV-B stress by inducing protective physiological and molecular responses, including DNA repair mechanisms and the production of antioxidant compounds. UVR8 regulates flavonoid biosynthesis, which leads to the accumulation of UV-absorbing pigments that protect plant tissues from radiation damage (Ferreyra *et al*., 2021). It also contributes to the regulation of hypocotyl elongation and photomorphogenic development, thereby influencing plant growth and adaptation under UV-B exposure.

Zeitlupe (ZTL)/F-box Proteins (Blue Light Sensors)

The ZEITLUPE (ZTL) family of photoreceptors regulates circadian rhythms and flowering time in plants. These proteins contain a LOV (Light-Oxygen-Voltage) domain and an F-box domain, which allows them to participate in protein degradation through the ubiquitin pathway (Song *et al*., 2014). They help maintain circadian rhythm by promoting the degradation of clock proteins such as TIMING OF CAB EXPRESSION 1 (TOC1) and also ZTL family proteins influence photoperiodic flowering through interactions with regulatory proteins such as GIGANTEA (GI) (Mas *et al*., 2003; Shim *et al*., 2017).

Plant photoreceptors such as phytochromes, cryptochromes, phototropins and UVR8 play an important role in regulating plant growth, development and stress responses by sensing different wavelengths of light. Photo-selective shade nets modify the quality and intensity of light reaching the plants, which influences photoreceptor activity and related physiological processes. Consequently, the use of photo-selective nets can support improved plant growth, crop quality and stress tolerance in protected cultivation systems.

Role of Photoselective Netting in Fruit Crops

The implementation of photo-selective netting represents a significant advancement in precision fruit culture, providing a non-chemical method to modulate orchard microclimates. By filtering specific wavelengths and diffusing solar radiation, these materials move beyond physical protection to actively regulate plant physiology. The following sections evaluate how spectral manipulation optimizes photosynthesis, vegetative architecture, and fruit quality, as summarized in Table 1.

Photosynthetic Efficiency

Light quantity plays a critical role in determining photosynthetic efficiency (Baraldi *et al*., 1994, Yanez *et al*., 2009). While increasing light levels generally enhances photosynthesis, this positive effect is only observed up to a certain threshold, known as the optimal light level. Beyond this point, further increases in light intensity can lead to photoinhibition or stress, reducing photosynthetic efficiency. Conversely, shading can directly lower photosynthetic intensity when solar radiation is already at or below optimal levels, such as during cloudy days when there is no excess radiation (Pevalek-Kozlina *et al*., 2003, Gindaba *et al*., 2005).

Photosynthetic efficiency is also heavily influenced by light quality, with the red (600–700 nm) and blue (400–500 nm) spectra being the most effective for driving photosynthesis. This is due to their strong absorption by chlorophyll and their role in activating key photoreceptors like phytochromes (red/far-red sensors) and cryptochromes (blue/UV-A sensors). As a result, shading nets can significantly influence photosynthesis by manipulating light quality and quantity. Various studies have demonstrated that red nets enhance photosynthetic efficiency in various fruit species by scattering and enriching the red-light spectrum, which is highly effective for photosynthesis (Shahak *et al*., 2004b, Aoun and Manja, 2020 and Brar *et al*., 2020). Another critical factor is stress mitigation. Shading nets can reduce both light stress (e.g., excessive UV radiation) and temperature stress, thereby improving the photosynthetic efficiency of protected crops (Lobos *et al*., 2013, Shahak *et al*., 2004c, Brar *et al*., 2020). However, the effects of nets can vary depending on the crop species and environmental conditions. In Brazil, Amarante *et al*. (2009) observed a reduction in potential photosynthesis for Royal Gala and Fuji apples grown under black nets, likely due to suboptimal light levels. In contrast, Shahak *et al*. 2004a reported increased photosynthesis in Golden Delicious apples under black nets in Israel, where higher baseline radiation levels may have caused stress that the nets alleviated. These contrasting results highlight the importance of species-specific light requirements and the environmental context in determining the impact of light modification on photosynthesis.

Vegetative Growth

Plant growth is governed by light perception via photoreceptors: phytochromes (red/far-red (R/FR) sensing) and cryptochromes/phototropins (blue/UV-A sensing) (Basile *et al*., 2014, Franklin *et al*., 2008). Nets alter light quality (e.g., R: FR ratios, blue/UV-A levels) and quantity (PAR), triggering photomorphogenic responses. A key mechanism is shadow avoidance, an evolutionary adaptation to low PAR, which drives morphological changes such as elongated shoots/internodes, reduced leaf thickness and enhanced apical dominance (Smith and Whitelam, 1997; Casal, 2012). The R: FR ratio is a critical signal for shadow avoidance, as vegetation shade preferentially absorbs red light, lowering R: FR (Smith and Whitelam, 1997; Casal, 2012). However, plant responses depend on phytochrome equilibrium (Pfr/Ptotal), determined by dynamic interconversion between inactive (Pr) and active (Pfr) phytochrome forms (Pevalek-Kozlina *et al*., 2003). Reduced phytochrome equilibrium and blue light in shaded peach canopies correlated with elongated internodes and fewer lateral shoots (Baraldi *et al*., 1994). Blue light reduction under shade, detected by cryptochromes, typically suppresses shoot elongation and leaf expansion (Butorac *et al*., 1999, Nanya *et al*., 2012). However, natural shade combines low R: FR and blue light, complicating responses. Some studies report shade-induced leaf enlargement in fruit species (Brar *et al*., 2020, Gregoriou *et al*., 2007), suggesting context-dependent outcomes.

Nets as Multifaceted Modulators

Photo-selective nets function as multifunctional tools in crop production systems by influencing several important physiological processes in plants. They regulate carbohydrate production by altering photosynthetically active radiation (PAR) and red-light wavelengths, both of which are essential for efficient photosynthesis and carbohydrate synthesis (Giaccone *et al*., 2012; Fan *et al*., 2013). Nets help to reduce environmental stresses, including excessive water loss and wind damage, thereby improving photosynthetic performance and overall plant growth (Shahak *et al*., 2004b; Basile *et al*., 2014). Furthermore, photo-selective nets can influence source-sink relationships in plants, which may indirectly regulate vegetative growth and ultimately affect crop yield (Giaccone *et al*., 2012).

Fruit Characters

Fruit Size

Fruit size under nets is shaped by a balance of photosynthetic efficiency, carbohydrate allocation and stress responses, with outcomes varying by net type and application timing. Shading can reduce apple size by limiting cell proliferation and expansion (Jackson *et al*., 1997), while post-flowering net use enhances cell elongation, improving size (Shahak *et al*., 2008c). Anti-hail nets intensify fruitlet thinning, reducing carbohydrate competition among sink; this aligns with findings that non-cropping trees maintain 20–45 % higher leaf carbohydrate reserves than cropping trees, highlighting how shading-induced photosynthetic limits accelerate fruit mass decline (Wunsche *et al*., 2005). However, photoselective nets mitigate light scarcity by scattering radiation, preserving photosynthesis. In stress-prone environments, nets enhance photosynthetic efficiency and carbohydrate availability, paradoxically promoting fruit growth. Thus, net effects hinge on resolving the tension between light limitation and stress alleviation, mediated by species-specific responses and environmental context.

Fruit Colour and Pigments

Fruit colour, a key factor in consumer appeal, is primarily governed by anthocyanins pigments responsible for red, blue and purple hues that accumulate during ripening. Nets influence colouration by altering light exposure and temperature: direct sunlight, particularly UV-B and blue wavelengths, stimulates anthocyanin synthesis in apples, pears and stone fruits, while shading under nets often reduces pigmentation by limiting light intensity (Solomakhin, 2010; Savikin *et al*., 2013). Photoselective nets, however, can counteract shading effects by diffusing light to enhance inner-canopy fruit colour (Solomakhin *et al*., 2010), as seen in red nets suppressing undesirable blush in Granny Smith apples (Jemric *et al*., 2021). Temperature also plays a critical role, with anthocyanin synthesis peaking at 15–20 °C but declining above 30 °C; nets in warm regions mitigate heat stress, indirectly boosting pigmentation (Dussi *et al*., 2005; Zoratti *et al*., 2015). Species-specific responses further complicate outcomes: shade tolerant blueberries thrive without direct light (Zoratti *et al*., 2014; Arakawa *et al*., 1985), while red apple cultivars require UV-B exposure and far-red light inhibits their colour development (Arakawa *et al*., 1985; Reay *et al*., 2001). Thus, net effects on fruit colour depend on balancing light quality, temperature modulation and species adaptation, highlighting the interplay between environmental stress alleviation and pigment dynamics (Savikin *et al*., 2013; Zoratti *et al*., 2015).

Fruit Firmness

Fruit firmness, a critical parameter for determining harvest timing and quality, is influenced by nets through their modulation of light conditions and associated physiological effects. Shading under nets often reduces firmness in apples, potentially due to impaired cell wall development, increased water influx into cortical cells and altered cell wall composition leading to elasticity and swelling (Amarante *et al*., 2011). White nets reduced apple firmness by diminishing structural components like cell wall polymers (Amarante *et al*., 2011), while anti-hail nets correlated with softer fruit, possibly due to enhanced natural thinning or microclimate shifts. However, outcomes vary: high shade levels improved blueberry firmness (Lobos *et al*., 2013) and studies on apples, peaches and other species show inconsistent results (Bosco *et al*., 2015, Giaccone *et al*., 2012). These discrepancies may arise from confounding factors like yield, fruit size and harvest maturity. Photoselective nets increased peach size but reduced firmness, reflecting an inverse size-firmness relationship (Shahak *et al*., 2004a). Additionally, varietal traits, particularly ripening timing, mediate net effects, as seen in apple cultivar-specific responses (Amarante *et al*., 2011). Thus, net impacts on firmness depend on interactions between light-mediated structural changes, crop load dynamics and species- or variety-specific physiology.

Table 1: Influence of different photo-selective nets on fruit physical characteristics in fruit crops.

Crop	Net	Country	Weight	Size	Colour	References
Peach cv. Hermosa	White (15%), Red-white (15%), red, blue and pearl	Israel	-	In	In	Shahak *et al*., 2004
Apple cv. Fuji	Red net (20%) (compared to blue, yellow and white)	Italy	In	In	-	Corollaro *et al*., 2015
Pomegranate cv. Mridula	Red (50%) nets	India	In	In	In	Meena *et al*. 2016
Peach	Red nets	Croatia	In	In		Vukovic *et al*., 2016
Peach	Red net (40%), Blue net (40%), Neutral net (12%)	Italy	In	-	In	Schettini *et al*., 2009
Strawberry	Red, blue, no shade net	USA	delay flowering in short-day strawberry transplants			Takeda *et al*., 2010
Apple cv. Fuji	Red shade net, grey shade net, blue shade net, Pearl hail net, red hail net	Italy	leaf photosynthesis (P) and transpiration (E) modified			Bastías *et al*. (2011)

In- Increase

Pest and Disease Infestation

Anti-insect nets, while functionally akin to anti-hail nets, are distinguished by their finer mesh size and specific deployment methods. These nets are positioned over fruit tree canopies and orchard perimeters, forming a physical barrier that obstructs pest movement by inhibiting their flight, thereby curbing infestations (Tasin *et al*., 2008). As ecological awareness and demand for reduced pesticide use rise, such nets offer a sustainable pest management strategy with broad applicability. However, their shading effect reduces solar radiation intensity beneath the nets, which may compromise fruit quality under conventional growing conditions. Traditional black anti-hail nets, noted for their opacity and inability to scatter or modify sunlight, exacerbate this issue (Arthurs *et al*., 2013, Fallik *et al*., 2017). Anti-insect nets, with their denser mesh, amplify shading, further limiting light availability. Beyond their primary function, recent studies highlight their secondary effects: differently colored nets can influence insect behaviour. Optical manipulation of visual cues, particularly through UV exclusion and colour-modified cladding materials, significantly reduced aphid and whitefly infestations and lowered the transmission of non-persistent viruses in protected crops (Ben-Yakir *et al*., 2014). These results from the study indicated that spectral management strategies can be effectively integrated into pest management programs to divert pests, delay virus spread, and achieve reductions in infestation and disease incidence by up to 2–10-fold (Ben-Yakir *et al*., 2014).

Physiological Disorders - Sunburns

The use of protective nets mitigates sunburn, a physiological disorder in apples, table grapes and mandarins caused by excessive solar radiation, leading to browning, necrosis or photooxidative burns. Sunburn results in significant yield losses (10–50 % in regions like Australia and South Africa) when fruit surface temperatures exceed thresholds (46–49 °C for browning; >52 °C for necrosis). As fruit surfaces can be 12–15 °C warmer than ambient air, even moderate air temperatures (e.g., 35 °C) risk surpassing these thresholds. Nets reduce surface temperatures by 2.6–5.7 °C, as demonstrated by studies: under grey anti-hail nets, only 9% of apples exceeded 46 °C on clear days (vs. 45% uncovered) and 32% on cloudy days (vs. 79%) (McCaskill *et al*., 2016). Coloured nets (pearl, blue, red) and white nylon nets similarly lowered temperatures (Lee *et al*., 2015).

Mechanisms include shading-induced cooling and modulation of photosynthetically active radiation (PAR) and UV exposure. While necrosis arises solely from high temperatures, browning requires UV-B radiation and photo-oxidative burns depend on visible light (Racsko *et al*., 2012). Nets may also reduce sunburn risk under climate change by limiting PAR. Additionally, nets enhance relative humidity and soil moisture, alleviating water stress linked to sunburn incidence (Racsko *et al*., 2012). Thus, nets offer multi-faceted protection, lowering temperatures, filtering harmful radiation and improving microclimatic conditions to safeguard fruit quality and yields.

Conclusions

Photo-selective shade nets offered more than cover; they functioned as tools for climate-resilient horticulture by modulating solar radiation. Our review showed that these nets reduced fruit surface temperatures by up to 5.7 °C, which mitigated sunburn and heat stress while improving photosynthetic efficiency and fruit quality. The modified spectral environment under coloured nets also disrupted pest behaviour, reducing pesticide dependence. Although scalable for adaptation, the industry's next step was to develop species-specific spectral management to maximize performance across horticultural systems.

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Conflicts of Interest

The authors declare no conflicts of interest.

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