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Review

Sustainable Food Production: Innovative Netting Concepts and Their Mode of Action on Fruit Crops

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Abstract: Net application in agriculture has a long history. Nets were usually used for the protection of plants against different hazards (hail, wind, birds, pests, excessive sun radiation) and, lately, from insects (nets with smaller mesh size). In recent years, photoselective netting technology has emerged, which adds desired plant responses caused by light quality changes to their basic protective properties. A combination of anti-insect and photoselective net technology (anti-insect photoselective nets) may present a notable contribution to the sustainable food production concept. Notable positive effects of this eco-friendly approach on agroecosystems are mainly achievable due to its non-pesticide pest protection of cultivated plants and, at the same time, promotion of special beneficial morphological and physiological plant responses. Although netting has been extensively studied over the last decade, there is a pronounced lack of publications and analyses that deal with their mode of action on fruit trees, which is especially true for new netting concepts. A better understanding of such mechanisms can lead to improved development and/or utilization of this technology and enhanced generation of value-added products. This review was based on a revision of the literature regarding netting in agriculture, with emphasis on fruit cultivation, and the following databases were used: Web of Science, ScienceDirect, Scopus, and Google Scholar. Although this study aims to comprehend a majority of fruit species, it narrows down to those usually net-protected and, hence, studied, such as apple, peach or nectarine, kiwifruit, blueberry, etc. Nets mainly differ in their mesh size and color, which are the parameters that mostly determine their capacity for light quantity and quality modification. Such light modifications, directly or indirectly (e.g., change in microclimate), initiate different fruit tree responses (in some cases, mechanisms) through which the final effect is realized on their vegetative and generative traits. For instance, some of them include a shade avoidance mechanism (initiated by changes in red to a far-red ratio, blue light levels, etc.), source–sink relationship, and carbohydrate availability (actualized by changes in photosynthesis efficiency, vegetative and generative growth, etc.), plant stress response (actualized by microclimate changes), etc. In most cases, these responses are interconnected, which contributes to the complexity of this topic and emphasizes the importance of a better understanding of it.

Keywords: photoselective nets; light quality; light quantity; sustainability; sustainable food production; value-added; fruit quality; vegetative growth

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1. Introduction

The use of nets is considered an indispensable measure in the cultivation of many fruit species. Nowadays, this is especially true, as modern agriculture is experiencing a need to protect crops from their cultivation environment due to global climate changes and their resulting extreme climatic events. Furthermore, urbanization processes are thrusting agriculture towards less amenable environments, and, on the other hand, there is a need to meet rising market demands for better product quality, reduced chemical applications, food safety, and sustainability of the production processes [1]. 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) [2].

Plastic nets present a product made of plastic threads (usually made of high-density polyethylene) connected in a woven or knitted way, forming a regular porous geometric structure and allowing fluids (gases and liquids) to pass through [3]. The main reason for using nets is the protection of cultivated plant species from various natural disasters, such as hail, heavy rain, snow, wind, excessive solar radiation, birds [2–8], and, more recently, insects (anti-insect nets) [9–12]. Anti-insect nets are similar to anti-hail nets, but they differ from anti-hail nets in mesh size and mode of application [10]. Thus, they overlay a fruit tree canopy and the edge parts of the orchard, thus creating a physical barrier that disrupts the propagation of pests by preventing their flight [12]. Their mechanism of action can be seen in Figure 1. As consumer awareness regarding pesticide usage and ecology grows, this environmentally friendly pest control method has huge potential applications. However, each net creates a certain amount of shade and, therefore, reduces the intensity of available solar radiation to plants grown below them. In normal growing conditions, this can potentially harm some fruit quality traits. This is especially true for the traditionally used black anti-hail net, which, according to Arthurs et al. [13] and Ilić and Fallik [14], is completely opaque and, therefore, does not scatter or modify solar radiation. Due to the smaller mesh size and consequently greater shading, anti-insect nets can potentiate this negative effect on radiation. At the beginning of this millennium, a new technology concept was developed in Israel to improve the utilization of solar radiation for cultivated crops, with standard protection against various disasters [6,15,16]. This approach was initially developed for ornamental plant species, and the main goal was to develop a "smart shade" that would surpass the traditionally used black net [16]. The technology is based on the incorporation of various chromophores and light-dispersive and -reflective elements into plastic nets during production [17]. This technology aims to stimulate the desired photomorphogenic or physiological plant responses by spectral manipulation and to enhance the penetration of light into the inner part of the canopy by light scattering [1,17]. Relative enrichment in the intercepted light by productive components of the spectrum and reduction in the less productive ones allow for better and more productive utilization of the solar energy by horticultural crops [18]. In addition to the promotion of desired plant responses, according to Shahak et al. [1], some insects variously respond to the differently colored nets. In Figure 2 can be seen an example of a predator (*Asilidae* sp.) preying on an insect possibly attracted by the yellow net color. Initially, this technology was named "colored nets"; however, afterward, the term "photoselective nets" was standardly used [6,17]. Considering that not all colored net products look colored to the human eyes, this terminology is used, as well as the fact that it derives from technology that deals with light quality modification in its broadest sense, including the filtration of spectral bands in the UV, visible, FR, and beyond as well as light scattering [17]. For example, photoselective nets can be divided into two groups: "colored photoselective nets", which include red, yellow, green, and blue nets and which are "visibly colored", and "neutral photoselective nets", which include pearl, white, and gray nets [1,17].

Figure 1. Anti-insect nets physically prevent insects bigger than the net mesh size from entering the orchard.

Figure 2. An example of a predator (*Asilidae* sp.) preying on an insect possibly attracted by the yellow net color.

A combination of these two technologies (anti-insect photoselective nets) presents a notable contribution to the sustainable food production concept, since this approach has the potential for a notable positive impact on agroe cosystems due to its non-pesticide pest protection of cultivated plants and, at the same time, promotion of special beneficial morphological and physiological plant responses. Although, lately, netting has been extensively studied, there is a pronounced lack of publications and analyses that deal with their mode of action on fruit trees, which is especially true for new netting concepts. A better comprehension of such mechanisms can lead to improved development and/or utilization of this technology and, therefore, enhancement of production sustainability, productivity (in quantity and quality terms), and profitability, with the consequent generation of value-added products. Thus, the goal of this review is to explain the mechanisms by which they achieve such impacts. To enable easier comprehension of various mechanisms of the effects of nets on different vegetative and generative fruit tree traits, the net impact is described in detail with respect to light and microclimate manipulation.

2. Methods

This review was based on a revision of the literature regarding (a) netting in agriculture, (b) the application of nets in fruit cultivation, (c) new netting concepts (photoselective nets and anti-insect nets), and (d) the physiology of fruit trees with regard to light impact. The following databases were used: Web of Science, ScienceDirect, Scopus, and Google Scholar. There was no selected timeline, but priority was given to more recent studies. The main search terms included keywords and/or their combination: netting, anti-hail nets, photoselective nets, anti-insect nets, fruit quality, light manipulation, light quantity manipulation, light quality manipulation, fruit tree physiology, vegetative growth, bioactive compounds, shading, etc. The literature search included all access types of articles published or accepted for publication in indexed peer-reviewed journals as well as conference proceedings and master's and doctoral theses. The types of searched publications included research and review articles, articles in press, books, and book chapters. Specifically, one technical sheet was included from an official manufacturer's website.

3. Light Manipulation

The influence of nets on the quality and quantity of solar radiation is of prime importance, due to its crucial role in plant life. In general, the radiation spectrum relevant to plants ranges from 280 to 800 nm, which includes UV-B (280–320 nm), UV-A/B (300–400 nm), photosynthetically active radiation (PAR, 400–700 nm), and far-red radiation (TC, 700–800 nm) [19]. Primarily, light manipulation nets influence the vegetative and generative traits of plants cultivated underneath them. To explain the effect of nets on light manipulation, basic net characteristics must be described. Agriculture nets are primarily produced from high-density polyethylene, which has good UV stability if certain additives are added to it [3,20]. Nets consist of single threads that are connected in such a way that they form a regular porous geometric structure, the mesh [3]. Therefore, solar radiation can come into contact with the threads and be affected by their properties or pass unchanged through the meshes (the space between threads) (Figure 3). Manipulation of solar radiation by nets depends on the net type. Due to their opacity properties, traditionally used black nets (Figure 4) only reduce light quantity [6,13–15,17]; transparent nets scatter light but do not spectrally modify it [17], while photoselective nets reduce the light quantity, scatter it, and spectrally manipulate it [6,15,17,21]. Therefore, photoselective nets create a mixture of natural (non-modified) light that passes through meshes and diffused (spectrally modified) light that is scattered by threads [6,22]. In low-shading nets (shading around 20%), most of the light (approximately 80% of sunlight) is not modified, in contrast to the rest, which is [18]. The examples of implemented red, green, and blue photoselective nets in Croatian orchards can be seen in Figures 5–7 (respectively).

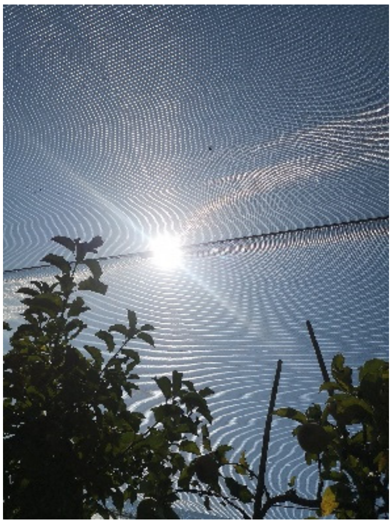

Figure 3. Light modified by net application.

Figure 4. Traditionally used black net in an apple orchard in Međimurje County, Croatia.

Figure 5. First orchard with implemented photoselective red net technology in Republic of Croatia, near Zadar; the application of LIFE.SUSAFRUIT project results.

Figure 6. An example of an apple orchard located in Croatia, near Ivanić Grad, that experimented with the application of a green anti-hail net.

Figure 7. An example of an apple orchard located in Međimurje County, Croatia that experimented with the application of a blue anti-hail net.

Light quantity reduction primarily depends on net texture (thickness of threads and mesh size) and its light-scattering properties, e.g., net color. It is defined by the producer of each net. However, in production conditions, certain deviations are possible in relation to producer-defined values [23–25]. Since photoselective nets contain partially transparent threads, differences in shadiness are related to the light manipulation ability (thread color) in addition to the effect of the "true shadow" caused by the light interference of the threads [13,26]. This means that differently colored photoselective nets with the same mesh size will not possess the same shading factor. Thus, in relation to black nets, higher thread counts are needed to create the same shade factor, which results in smaller holes and less open area [13]. Therefore, when trying to determine the effect of net color on certain parameters, two approaches are possible. One is to use nets with the same mesh size (which will probably result in different shading factors between nets), and the other is to use nets with the same shading factor but, hence, different mesh sizes.

In a few studies with the same mesh size between studied nets, it was reported that black nets more notably reduced PAR (photosynthetically active radiation) or photosynthetic photon flux density compared to a white nets [26–28]. Contrary to this, in a different study, the black net showed the smallest PAR reduction [29]. In a few studies where nets with the same shading factor were comparable, similar differences could be found [13,30,31]. Although, as mentioned above, some authors reported that, among tested nets, the black net reduced PAR intensity the most, this was not the case in studies conducted by [6,15]. Oren-Shamir et al. [15] attributed the slightly higher effect of shading in photoselective nets compared to neutral nets (including black) to dust retention due to higher weave density. In studies where mesh size or shading factor varied between nets, the following was reported. Solomakhin and Blanke [32] observed a negative correlation between the number of black fibers in nets and light permeability, and Lobos et al. [5] reported that, in three different shading levels, black nets more significantly reduced PAR intensity than the white net. Similarly, Blanke [33] reported that, among tested nets, the black net reduced PAR intensity the most. According to Agrintech [34], with the same mesh size (2.4 mm × 4.8 mm), the following PAR shading percentages were stated: pearl, 13–16%; yellow, 13–18%; blue, 15%; red, 17–21%; and gray net, 20%. In a study conducted by Arthurs et al. [13] where all nets had the same nominal shade factor (50%), the observed PAR values were reduced the most under black nets (55% to 60%) and least under red nets (41% to 51%), with blue (51% to 57%) and pearl (52% to 54%) nets intermediate. Retamales et al. [31] reported that there were no notable differences in PAR levels between white (35 and 50% shading), gray (35 and 50% shading), and red (35% shading) nets, with the exception of the red net with 50% shading, where a notable reduction occurred. According to the aforementioned, it is evident that the ability of nets to scatter radiation presents an important factor in light quantity manipulation. Diffuse light is a broad term and includes all non-direct light [16], and the capacity of each net to scatter radiation is also determined by its texture [18]. The light rays that pass through and are selectively filtered by the colored plastic threads come out of the threads in a fully diffused mode [18]. In a few studies, it was reported that the proportion of diffuse light was higher under photoselective nets than under a black net or in natural conditions [6,15,16]. Light scattering represents an important part of the technology of photoselective nets, since it improves the penetration of this spectrally modified light into the inner canopy, thus amplifying the photoselective effect [6,16,18]. In addition, radiation utilization efficiency increases when the diffuse component of direct radiation is increased in the shadow [35]. Therefore, plants cultivated under colored nets with a shading factor of 30% in reality "see" more light than those under black nets with the same shading factor [6]. Photoselective nets scatter less ultraviolet (UV) than photosynthetically active radiation due to the absorption of UV light by pigments embedded in their threads [15]. When it comes to light scattering, PAR is most often discussed, due to its crucial role in plant development. According to the available literature, it can be summarized that the pearl net has the highest and gray net the lowest light-scattering potential, while other nets (white, yellow, blue, green, red) are in between [6,15,16,21]. Regarding the light-scattering possibilities in the UV section, there are uneven reports. According to Oren-Shamir et al. [15], green nets notably increased light scattering of UV spectra in comparison to other nets (black, gray, red, blue, aluminet). Shahak et al. [16] reported that only the application of a pearl net caused notable UV scattering (in comparison to gray, red, blue, red-blue, and white nets), while Basile et al. [21] reported a lack of significant difference between tested nets (gray, red, blue, white).

The impact of photoselective nets on light quality is probably smaller than on light quantity [25]. It is important to additionally emphasize that photoselective nets modify only the fraction of sunlight rays that pass through the plastic threads, while the rays passing through the holes of the net remain unchanged, i.e., identical to the spectral and direct/diffuse composition of the natural sunlight prevailing at any particular time of the day/season [18]. Thus, light quality modifications are realized mainly in diffused light [6,21]. The possibility of each net manipulating light quality is defined by the pigments that are embedded in the plastic material [18]. In addition, it can be assumed that the extent of light spectral manipulation also depends on all of the parameters affecting the contact net–light surface (mesh size or weave density, thickness and shape of the threads, dust accumulation, etc.). The blue net has a broad transmission peak in the blue-green region (400–540 nm), while it absorbs UV and red spectra [6,15,25]. The green net has a broad transmission peak at 520 nm as well as gradual transmittance in the far-red (FR) [15], while Blanke [36] reports that, under this net, transmission of spectra above 500 nm increased by 3%. Unlike blue and green nets, the red and yellow nets operate as cut-off filters, absorbing light below a specific wavelength range while transmitting light thereafter [18]. Oren-Shamir et al. [15] reported that the red net had the highest transmittance beyond 590 nm and a minor peak around 400 nm; Shahak et al. [6] reported that it transmitted from 590 nm onwards, and Bastías et al. [37] reported that it peaked in light transmission at all wavelengths above 620 nm. Blanke [36] stated that light spectrum transmission above 570 nm increased by 2–5%, and Zoratti et al. [25] reported a lack of blue spectrum or UV-A radiation under this net. The yellow net transmits light from 500 nm onwards [6]. While the red net transmits light above 580 nm (only the red + FR spectra), the yellow net transmits light above 515 nm, i.e., allowing the passage of green and yellow spectra along with the red and FR spectra [18]. Three neutral nets (black, gray, and aluminet) do not modify light in the visible spectrum [15], but the gray net absorbs infrared radiation more efficiently than other colored nets [6]. Although, in two studies [6,17], it is stated that the white net absorbs UV radiation, Zoratti et al. [25] reported a higher presence of the UV-A spectrum below this net than in natural conditions.

With the exception of the stated light quality manipulations in many studies, these effects are represented as a ratio between different radiation spectra, due to easier interpretation and their importance in the morphogenetic plant reactions. Due to their high number and differences in results between studies, only the red to far-red ratio (R:FR) will be mentioned, since it has a crucial role in plant morphogenesis (Table 1). This ratio is often used to quantify the spectral distribution of photon fluxes of red and dark red wavelengths [38]. Such conflicts between studies in terms of the overall net light manipulation ability can be contributed to the different agroecological conditions, net properties (other than color), and experiment methodologies.

Table 1. Effect of applied nets on R:FR ratio (↑—increase, ↓—decrease, m.d.—minimal differences).

Netting	Source	R:FR Ratio	
		Diffuse Light	Total Light
Black	[6]	↓ *	m.d.
Blue	[6,21]	↓	
	[16]	small ↑	
	[6,15,16,21,25]		m.d.
Green	[15]		↓
Gray	[6,16,21]	↓	
	[6,15,16,21]		m.d.
Pearl	[6,16]	↓ (mostly highest)	↓ (mostly highest)
	[25]		m.d.
Red	[6,16,21]	↓	
	[6,15,16,21]		↓
	[25]		m.d.
White	[21]	↓	m.d. **
Yellow	[6,18]	↓	↓

* minimally in comparison to other nets; ** similar to the blue and gray nets, with the exception of the red net.

At the end of this chapter, a few additional factors must be mentioned that can play an important role in net light manipulation possibilities. Net durability, in terms of the changes that occur in them during aging, which can affect their long-term capacity to successfully bear the load and transfer it to the supporting structure [2] as well as their characteristics regarding manipulation of light quantity and quality [6,39]. According to Briassoulis et al. [2], the most critical property affected by the aging of nets (tensile strength) drops down to one-third of its initial value after 10 years of exposure under the conditions of the Netherlands. The authors [2] state that it should be expected that, under south European climatic conditions with much higher UV radiation, the weathering effects would be more dramatic. The durability of black nets is greater than transparent nets due to the carbon black additive that is added to those nets (which also acts as a UV-stabilizer) [3], while photoselective nets have been developed and tested to be stable for 5–8 years under field conditions [6]. The tendency of the nets to fade after prolonged exposure to the sun, the accumulation of dust on their threads, and agrochemicals are the main reasons why, with the length of use of the nets, there are changes in their manipulation of light [6,33,39]. Blanke [36] stated that the aging of colored polyethylene nets with narrow meshes caused an annual reduction in PAR transmission of 2%, independent of wavelength. Additionally, over time, nets transmit less UV radiation than PAR [33]. The reduction in PAR transmittance due to dust accumulation in Israel varied from 5–6% to 18–19% (greater dust impact on a more transparent thread) [6]. The authors [6] stated that washing dust from nets could solve this problem; however, this is not practical to carry out. In addition, during the installation of the nets, or later due to temperature changes, stretching of the nets may occur [6], which can also cause a reduction in their light manipulation capabilities.

4. Microclimate Conditions

The possibility of the net's impact on the microclimate (humidity, temperature, wind speed, etc.) is of increasing importance due to the consequences of climate change. The use of photoselective nets is an increasingly popular technology for various cultivated species due to their potential beneficial effect on the alleviation of environmental stresses caused by heat, cold, and drought [5,22]. Generally, in the majority of studies, daily temperatures were reduced under nets in comparison to natural conditions, while in some no difference was recorded (Table 2). Kalcsits et al. [40] stated that the use of sensors without radiation shields in some previous studies may have confounded the effects of the reduction in light from netting on air temperature. As mentioned in the previous chapter, to assess the effect of net color on certain traits, it is important to have a uniform mesh size or shading factor; however, neither solution is optimal. For example, Arthurs et al. [13] used nets with the same shading factor; however, because of that, the black net had a larger mesh size and, hence, achieved lower wind reduction. These factors are stated in Table 2. Kalcsits et al. [40] reported that, although the in-canopy air temperatures were not significantly different under the blue and red netting, they were significantly lower under pearl netting compared to the control. Zoratti et al. [25] also observed that, during the sun exposure time, the temperature was reduced under pearl, red, and black nets (nets had different shading factors). Interestingly, in two studies [25,29], it was reported that the blue net tended to increase the average or maximum temperature (respectively), but this phenomenon was not confirmed in other studies [6,16,19,41]. Larger temperature differences are recorded during clear and sunny days, and smaller ones during cloudy ones [42], consistent with higher temperatures [40]. This means that the most pronounced effect of nets on temperature reduction is during summer or in warm areas. No net effect on night temperatures was recorded in a few studies [4,6,7], while McCaskill et al. [24] reported minimal reduction under nets (0.2 °C); García-Sánchez et al. [43] reported a small reduction in December but not in August, and Zoratti et al. [25] jumbled results (depending on net type). It was also reported that the application of nets could reduce soil temperature, especially during hot periods (sometimes more than 1.5 °C) [40]. Generally, the application of nets enhances relative humidity (Table 2). It is also important to mention that the application of nets enhanced soil moisture content in an irrigated apple orchard [40,44], while Retamales et al. [31] reported minimal differences in a blueberry orchard. Corvalán et al. [45] reported that, under a pearl net, the average soil water content was higher than in open-field conditions, as well as under a red net. The application of nets also notably reduces wind speed (Table 2).

The mechanism of the net's influence on the microclimate is not complex, and, according to Shahak et al. [6], can be achieved by shading, reducing wind speed, and selective filtration of radiation (photoselective nets). Shading and the possibility of selective filtration are net properties defined by producers during production. Wind speed reduction is achieved by nets' mechanical resistance and by their ability to prevent the formation of wind speed gradients (when applied only horizontally) [6]. Radiation reduction achieved by net usage can consequently affect air, plant, and soil temperature and relative humidity ([46] according to [47]). The reduction in wind speed and strength can affect the microclimate under nets due to the reduction in air mixing [6,48]. Similarly, Iglesias and Alegre [42] stated that nets could modify air temperature through radiation interception, or a "shading effect" (decrease in temperature), and prevention of air circulation, or a "greenhouse effect" (increase in temperature). In addition to the aforementioned, some nets can have an impact on temperature by reducing heat loss during the night in such a way that they block the transmission of near-infrared radiation (NIR), which, according to Bastias [19], is characteristic of the gray net. Relative humidity is usually higher below the nets as a result of water vapor created by the transpiration of the protected plants and reduced air mixing with drier air outside of the nets, even when temperatures below the nets are higher than outside them ([46] according to [47,49]). However, all nets do not have the same impact on the microclimate below them, as this is feature-dependent. Blanke [33] stated that the influence of nets on the temperature, intensity, and quality of light depends on the following net characteristics: color, thickness, number of longitudinal and transverse threads, and mesh size. Regarding differences in soil water content, Corvalán et al. [45] assumed that differences could be due to different evaporation because of varying ambient conditions under the nets or because of changes in transpiration rates as a result of plant vigor differences. They concluded that, in their case, it was due to different ambient conditions created by the use of nets. It must at least be remarked that the effect of nets on microclimate traits will also depend on overall climatic conditions. For example, in a three-year study, Bosco et al. [50] attributed a significant increase in air humidity under the black net in only one year to the lower incidence of solar radiation during that year compared to the other years, whereas coverage showed a significant effect. In another example, [42] noted that larger temperature differences between nets and open-field conditions were recorded on bright and sunny days and lesser ones on cloudy days. According to the aforementioned results, it is evident that the impact of nets on environmental factors is not only achieved through the impact of solar radiation but derives from the interaction of several different factors. However, it can be stated that, with the selection of nets with smaller mesh sizes and higher shading factors, the effect on the microclimate will be greater.

Table 2. Effect of applied nets on microclimate (↑—increase, ↓—decrease, m.d.—minimal differences, ic.r.—inconsistent results, T-max—maximum temperature, H-min—minimal humidity, i.c.—inside the canopy, a.c.—above the canopy).

Country	Source	Protected Plant	Netting	Air Temperature	Relative Humidity	Wind Speed
Australia	[7]	apple	anti-hail	↓1–3 °C	↑10–15%	↓up to 50%
	[24]	apple	gray quad (10% shading)	↓0.5 °C	↑1.8 (afternoon) and 3.8% (during night)	↓22–24% (i.c.—upper part)
Brasil	[50]	apple	black net (mesh size 4 mm × 7 mm)	m.d. (i.c.)	ic.r. (i.c.)	↓30% (top of canopy)
Chile	[45]	grapevine	red and pearl (20% shading)	m.d.	m.d.	
Germany	[51]	apple	white and red-black (mesh size 3 mm × 9 mm and 2.5 mm × 6.5 mm, respectively)	↓0.5 °C	↑1–3%	
	[32]	apple	white, white-red, red-black, and green-black (12, 14, 18, and 20% shading within PAR, respectively)	↓1.3 °C	↑2–5%	
Italy	[41]	kiwifruit	blue, red, and gray (26.9, 22.8, and 27.3%, shading within PAR, respectively)	↓0.1–0.9 °C		
			white (20.4% shading within PAR)	m.d.		
Israel	[49]	pepper	black (25–28% shade), black, dark-green, blue-silver, green-silver (40–45% shade)	↓3–4 °C	↑20–35%	
	[16]	apple	red, blue, gray, and pearl net (30% shade) and white and red-white net (15% shade)	↓3–6 °C (T-max) (i.c.)		
	[6]	apple, grape, etc.	red, yellow, blue, gray, black, and pearl net (30% shading)	↓1–5 °C (T-max) (i.c.)	↑3–10% (H-min) (i.c.)	m.d. (a.c.) or ↓ (2 m a.c.)
	[52]	mandarin	red, yellow, white, and transparent (25, 24, 18, and 13% shading, respectively)	m.d. or ↓up to 1 °C (T-max)	↑	↓70% (a.c.)
						↓85–90% (i.c.)
Peru	[31]	blueberry	white, red, gray, and black (35 and 50% shading)	m.d.	m.d.	
Serbia	[53]	highbush blueberry	gray (mesh size 2.8 mm × 8 mm)	↓1.5 °C, 2.4 °C (T-max)	↑1%, 4% (H-min)	
Slovenia	[29]	apple	red, gray, blue, green, and black (mesh size 8 mm × 4 mm)	m.d.	m.d.	↓47–72%
South Africa	[39]	avocado	crystal (30% shading)		↓1–5%	↓

Table 2. *Cont.*

Country	Source	Protected Plant	Netting	Air Temperature	Relative Humidity	Wind Speed
Spain	[42]	apple	black and crystal (mesh size 3 × 7.4 mm)	↓3 °C (T-max) (i.c.)	↑ (i.c.)	
	[43,54]	lemon	aluminet (50% transmittance of incident light)	↓6 °C (T-max)		
	[55]	apricot	mosquito (10% interior shading)			↓20%
Taiwan	[56]	mandarin	white nylon (20% shading)	↓3.8–5 °C		
USA	[13]	/	red, blue, and pearl (50% shading)	↑(T-max)	m.d.	↓
			black (50% shading)	↓0.1–0.9 °C (T-max)	m.d.	↓
	[40]	apple	pearl, blue, and red (20 to 23% shading)	m.d. (a.c.), ↓0.1–0.9 °C (i.c.—pearl net) and m.d. (i.c.—other nets)	↑0.5–1.1% (a.c.), ↑1–4% (i.c.),	↓40% (a.c.)
	[44]	apple	white (30% shading)	↓1 °C		

5. Vegetative Growth

The impact of net application on vegetative growth was studied in: apple [19,27,28,57–60], peach and nectarine [8,16,61], blueberry [31], kiwifruit [41,62], avocado [39], grapevine [45], lemon [43,54], and mandarin [52] and in nursery production [63]. In the majority of these studies, the effect of nets on vegetative growth was positive (enhanced values of some parameters). The exceptions are blue netting in a study conducted by [19] and red netting in [59].

The growth and development of plants are highly regulated by light, and plants can sense the intensity, spectral composition, and direction of light and react accordingly through the photosynthetic system and photomorphogenic processes [41]. Nets, by light manipulation, achieve their effect on plant vegetative growth, and plant morphogenesis is the main mechanism through which this effect is conducted. Light signals are perceived by specialized information-transducing photoreceptors which include the red and FR light-absorbing phytochromes and the blue/UV-A light-absorbing cryptochromes and phototropins [64]. The shadow avoidance mechanism is mentioned as a probable photomorphogenic mechanism through which nets achieve their effect on the vegetative parameters of fruit species grown under them [8,19,41]. The shadow avoidance mechanism is the most important competitive strategy possessed by plants, developed as an evolutionary response to the reduction in PAR below the saturation level, which can seriously impair plant status [65,66]. Outcomes of the shadow avoidance mechanism, among many others, include increased shoot growth, increased length of internodes, leaf elongation, reduction in leaf thickness, shoot growth at the expense of leaf development, enhanced apical dominance, etc. [65]. Signals that trigger the shadow avoidance mechanism include qualitative light changes, as stated by Casal [66]; reduction in R:FR values perceived by phytochromes; reduction in red and FR irradiation perceived by phytochromes; reduction in blue–UV-A irradiation perceived by cryptochromes; and reduction in blue and green light ratios perceived by cryptochromes. According to Smith and Whitelam [65], the R:FR ratio is considered to be one of the main environmental signals affecting the initiation of the shadow avoidance mechanism. In the natural environment, R:FR reduction occurs in conditions of shading by other vegetation due to the optical properties of green leaf mass, which absorbs more red spectrum than far-red [66]. The impact of this ratio on vegetative growth parameters of fruit species was recorded [67–69]. However, considering only the R:FR value, the plant's response cannot be accurately assumed, because it is conditioned by phytochromes that perceive changes in the specified spectrum. According to Pevalek-Kozlina [70], phytochromes can exist in two alternative forms—the form that maximally absorbs red light (inactive form) and the form that maximally absorbs far-red light (P_{fr}) (active form)—which can reversibly pass into one another. Therefore, instead of R:FR, another model has been proposed as a good indicator of the plant's presumed photomorphogenic response to a specific light spectrum—phytochrome equilibrium (Φc): the equilibrium state of the biologically active P_{fr} form relative to total phytochromes (P_{fr}/P_{total}) ([71] according to [72–75]). The equilibrium between these two forms changes dynamically with the composition of the light spectrum within the range of 300 to 800 nm and is strongly correlated with R:FR values ([38] according to [72,76]). In the lower part of the peach canopy, Baraldi et al. [77] recorded a reduction in Φc as well as in the amount of blue light. Such conditions, in the aforementioned study, stimulated a significant increase in the length of the internodes compared to the conditions in the middle and upper parts of the canopy. Moreover, the number of lateral shoots doubled in the upper part of the canopy compared to the lower part of the canopy. The shaded leaves had a smaller surface area, fresh and dry mass, a parenchymal cell thickness, and a smaller number of stomata [77]. Although Baraldi et al. [77] noted a reduced leaf size in the shade, in other studies leaves of various fruit species grown under shade had enhanced growth [63,78,79]. Eye visible effects of a red net on peach shoots can be seen in Figure 8. Lately, the role of blue light in photomorphogenesis has been increasingly investigated. In the natural environment, a reduction in blue light occurs in the conditions of shading by other vegetation together with a change in R:FR values. A lower content of blue light was recorded in the sunny part of a walnut canopy than in the shaded part [80]. Although phytochromes also absorb in the blue part of the spectrum, most of the effect of blue light is attributed to the action of a special photoreceptor cryptochrome [70]. According to numerous studies [81–84], it can be stated that blue light inhibits shoot etiolation and reduces internode length and leaf expansion. Since the reduction in Φc and the reduction in blue light are simultaneously present in the conditions of natural shade, it can be concluded that all of the above responses represent a coordinated response of the plant to shade avoidance. However, according to Oren-Shamir et al. [15], the shade avoidance mechanism is not responsible for changes in vegetative growth under all nets. In some studies, it was assumed that PAR intensity was also involved in plant morphogenesis [19,63,85]. Since light quality and quantity manipulation by nets (modification of R:FR light, manipulation of blue light, and PAR reduction) was described in detail in Section 3, it can be assumed that all aforementioned in this chapter present mechanisms through which nets achieve their effect on plant vegetative growth.

Figure 8. Eye visible differences (leaf size and color) of peach shoots grown under red net (right shoot) and in open-field conditions (left shoot) in Croatia, near Zadar.

Carbohydrates are the next important parameter, since they are necessary for vegetative growth [86]. Nets can potentially achieve their effect on carbohydrate availability by their manipulation of light quantity (shading causes carbohydrate limitation) and quality (red light is most important for carbohydrate synthesis), microclimate manipulation (reduction in stressful conditions will cause an increase in photosynthetic efficiency and, hence, carbohydrate availability), and by changes in the source–sink relationship (yield effect) [8,42,81,87,88]. Additionally, a reduction in all stressful conditions (light, water, wind) can have a positive effect on vegetative growth [16,41,42,52,63,89].

6. Photosynthesis Efficiency

The effect of net application on the photosynthetic efficiency of fruit trees was reported in many studies [6,19,25,27,28,60,63,90]. The outcomes of net application on plant photosynthetic efficiency are not consistent, due to numerous factors that can interfere, e.g., plant species and variety (shade tolerance ability), agroecological conditions, net properties (shading factor, color . . .), etc.

Light quantity is strongly related to photosynthesis efficiency [77,91]. However, an increase in light quantity will positively affect photosynthesis only until the optimal light levels are achieved, meaning that shading can directly reduce the photosynthetic intensity in leaves when sun radiation levels are optimal or below optimal (when there is no excess radiation, as during cloudy days) [70,92]. Photosynthetic efficiency is also directly related to light quality, and the red and then blue spectrum of light is the most efficient [81,93,94]. Therefore, nets can achieve their effect on plant photosynthesis efficiency by light manipulation (Section 3). A positive effect of the red net on the photosynthetic efficiency of different fruit species cultivated underneath it was highlighted in a few studies [6,60,63], which could simply be attributed to its ability to scatter the red light spectrum (Section 3). Another closely related factor is stress, where nets can mitigate light and temperature stress (Section 4) and, therefore, increase the photosynthetic efficiency of protected fruit species [5,6,63]. For example, in Brazil, Amarante et al. [27,28] reported a reduction in potential photosynthesis of 'Royal Gala' and 'Fuji' apples cultivated under a black net, while, in Israel, Shahak et al. [6] reported an enhancement of photosynthesis levels of 'Golden Delicious' apples also cultivated under a black net. It must be mentioned that fruit species differ greatly with respect to their light requirements; thus, light modification imposed by nets will diversely affect their photosynthetic efficiency.

7. Production Parameters

The effect of net application on various production parameters (differentiation of generative buds, return flowering, number of generative shoots, yield, yield density, yield efficiency) of different fruit species was extensively researched, and results were not consistent. In a smaller number of studies, this effect was not significant [8,42,59–61], while in others it was fully or only partly significant (depending on parameter, net type, variety, and year) [5,16,19,21,22,31,43,52,62,90,95,96]. All of these productive parameters are interconnected, and the modification of one parameter will consequently cause a change in other parameters. Thus, the possibility of nets affecting the most important of them will be described.

The differentiation of generative buds is a very complex process, and the factors on which it depends are not yet fully understood. It is assumed that the interaction of specific physiological and environmental conditions ensures an appropriate balance of endogenous hormones that cause the initiation of generative bud differentiation [97]. Koutinas et al. [98] assumed the existence of a versatile relationship between genetic control, hormone balance, and the presence of a sufficient amount of assimilates in the whole plant, i.e., in the generative buds that are being formed. Given that ecological conditions can affect the initiation and development of generative buds [97,98], this is the first factor to be considered. Of all ecological factors, light should be the first mentioned, due to its crucial role in the aforementioned process and the well-documented possibility of nets manipulating its quantity and quality (Section 3). Basile et al. [62] attributed the negative impact of net application on the number of flowers per kiwifruit shoot to shading. In two studies [5,25], it was noted that a high shading percentage harmed the initiation of generative blueberry buds. Yanez et al. [99] reported that there was a certain critical level of PAR required for the differentiation of generative buds of *Vaccinium ashei*. Therefore, the shading properties of nets can be responsible for the reduction in generative bud differentiation if the amount of PAR is reduced beneath optimal levels. However, the possibility of certain nets diffusing radiation must be taken into account, since diffuse light has a better penetration capability into dense canopies, and radiation utilization efficiency increases when the diffuse component of direct radiation is increased in the shadow [6,16,35]. This means that photoselective nets with high light-scattering ability have a higher capacity to alleviate the negative effects of shading than those with low or no ability. In addition, the influence of nets on the manipulation of light quantity by their effect on vegetative growth should not be neglected (Section 5). Dense canopies overshadow the lower parts of trees, which hurts productivity [100]. Regarding the light quality effect on generative bud differentiation, in two studies [77,101] the importance of the R:FR ratio was noted but not that of blue light. It was also reported that the emission of dark red light exclusively at 735 nm caused the initiation of generative buds in *Fragaria chiloensis* (L.) Mill., which was probably the result of a phytochrome-mediated response [102]. Additionally, in the same study, with continuous exposure to daylight, the highest number of initiated generative buds was recorded during additional emission with an incandescent lamp as well as a far-red fluorescent lamp. The ability of nets to modify such light spectra was recorded (Section 3). In addition to light, temperature is also an important environmental factor that can affect the generative bud differentiation process. High temperatures can indirectly inhibit bud formation in some apple cultivars through a change in the length of the plastochrone under the influence of the gibberellins produced in the apices of the growing long shoots ([98] according to [103]). Cool temperatures are important factors determining mango flowering under subtropical conditions and in the upper altitude tropics [104]. The ability of nets to decrease the temperature of plant organs was recorded [39,40,42]. Variations in temperature with great day and night amplitudes also have a depressing influence on flower bud formation ([98] according to [105]). Since nets have no or only a small effect on night temperatures (Section 4), this is probably not an important factor. The next important parameter is the availability of carbohydrates, which can also be influenced by the above-described ability of nets to modify the microclimate. According to a few studies [7,106,107], the application of nets to apples limits the differentiation of generative buds for the next growing season, due to shading—which causes a reduced availability of carbohydrates, thus increasing competition between organs (shoots, fruits, buds)—and also due to the allocation of carbohydrates to vegetative growth. Carbohydrate availability is also directly related to photosynthetic efficiency (Section 6). In the same way, through the availability and competition of carbohydrates, the differentiation of generative buds can be influenced by yield and vegetative growth. According to Wünsche and Ferguson [108], high yield can delay, reduce, or inhibit flower initiation. Vegetative growth and fruiting are antagonists, and flowering can be reduced in very vigorous trees [109].

The application of nets on fruit trees can harm entomophilic pollination of fruit trees, and, thus, certain measures must be taken, such as the application of nets after the end of flowering, removal of parts of nets during flowering, or introduction of beehives during flowering in orchards protected by nets [7,58,110]. In addition, shading and high temperatures can also cause a reduction in fruit sets. Byers et al. [111] reported that shading apple trees with polypropylene material (92% shading) reduced the fruit set by about 50% over 4 days. High temperatures can lead to reduced fruit sets [112,113], while Lakso [114] states that its effect is pronounced in low-light conditions. There is the example of mangos, which usually flower during months with warm periods [115] and to which temperatures above 40 °C cause heat stress [104]. In such cases, temperature reduction realized by net usage can potentially have a positive effect on the fruit set. Furthermore, excessive vegetative growth can also hurt the fruit set [100]. The ability of nets to achieve the effect on each of these parameters is described in Sections 3 and 4.

Yield is the most important production parameter for producers, since it has a crucial impact on production profitability. The effect of nets on yield through changes in fruit size will be described in the next chapter. The effect of net application on yield can be due to changes in fruit number, photosynthesis efficiency, and reduction in stressful conditions [5,17,27,31,90]. Many of these factors are interconnected. For example, Shahak et al. [22] hypothesized that the yield increase of the 'Golden Delicious' apple was due to the fact that fruit size was probably limited by environmental stress, limiting canopy assimilation metabolism, which certain types of nets alleviated, thus resulting in yield differences. Lobos et al. [5] reported a positive and curvilinear relationship between fruit yield per blueberry plant and the % PAR modified by net application; the maximum yield was achieved with about 50% shading.

8. Fruit Quality

8.1. Fruit Size

The effect of net application on the fruit size of different fruit species has been extensively studied; however, results are diverse, probably due to the variability of agroecological conditions, net properties, fruit species, varieties, etc. Generally, in most cases, the application of nets caused, fully or partly (depending on fruit variety and net type), an increase in fruit size or mass [5,16,22,25,32,39,58–61,116]. Only Bosco et al. [4] reported a fully negative impact, while, in other studies, this impact was not recorded [26,43,117], was mixed (positive and negative), or could not be assessed due to lack of a control group (open-field conditions) [19,21,54,57,118].

Net influence on the fruit size or mass of various fruit species presents a very complex process where the interaction of various factors is involved. Jackson et al. [119] reported that the reduced fruit size of the 'Cox's Orange Pippin' apple shaded by nets was due to a reduction in the size and number of cells per fruit. On the other hand, Shahak et al. [22] attributed the positive effect of net application on apple fruit size to cell elongation, because the application of nets before flowering did not achieve the effect, while application 2 to 4 weeks after flowering did. Generally, the effect of nets on fruit size can be described through their capacity to affect photosynthesis efficiency, vegetative and generative growth, and stressful conditions, i.e., all conditions that affect carbohydrate availability and the source–sink relationship. Since fruit development essentially depends on current photosynthesis [120], it presents a crucial factor. Based on their own unpublished data, Gindaba and Wand [92] stated that the reason for the smaller fruit size of the 'Royal Gala' apples grown under a black anti-hail net was due to the influence of shading on photosynthesis. Shahak et al. [22] attributed, among others, the lack of positive effect of the application of photoselective nets on fruit size of the 'Topred' apple, in comparison to the 'Golden Delicious', to lower productivity and stronger vegetative growth. According to Middleton and McWaters [7], reduced fruit size occurs more frequently on vigorous trees grown under nets compared to trees grown without them. However, in trees under nets where vigor was controlled, fruit size increased. Smit [109] stated that the mass of apple fruits grown under nets decreased more notably with increasing yields than for apples grown in natural conditions. Basile et al. [62] suggested that the increase in the mass of kiwifruits grown under photoselective nets was due to reduced competition for nutrients, owing to a smaller yield. In another study, anti-hail nets, regardless of color (red, gray, blue, green, or black), intensified the natural thinning of fruitlets, which, according to the authors, can have an impact on fruit size [121]. To confirm the aforementioned results, it can be mentioned that Wünsche et al. [122] found that, in leaves of non-cropping trees, mean seasonal total non-structural carbohydrate concentrations were 20 and 45% higher than in leaves on low- and high-cropping trees, respectively. Accordingly, it is evident that, with increasing competition for carbohydrates (due to increased vegetative growth or yield), fruit mass declines faster under nets than in natural conditions. This is probably due to the shading properties of nets, which limit photosynthesis. In such conditions, photoselective nets have an advantage due to their ability to scatter radiation (Section 3). On the other hand, in stressful conditions, shading can have a positive impact on photosynthesis and carbohydrate availability and, hence, positively affect fruit growth. Bastias [19] believes that the impact of nets on carbohydrate production, measured through CO_2 assimilation in apples, is closely related to the reduction in leaf temperature and the difference in leaf and air vapor pressure. Lobos et al. [5] stated that nets have the potential to positively affect the size of blueberry fruits by reducing solar radiation and, thus, decreasing temperature stress. Shahak et al. [16] observed that the positive effect on apple fruit size may be partly related to reduced water stress in apples grown under nets, as evidenced by the lower value of the afternoon steam water potential. The importance of water stress in apple fruit growth was also mentioned by Bastias [19]. An orchard covered with nets generally has higher relative air humidity and better conserves soil moisture (Section 4).

8.2. Fruit Color and Pigments

Food color (along with appearance) plays an undeniably important role in the process of product quality and acceptability evaluation [123]. Fruit color is one of the main traits (among other visual attributes) that influence the customer's decision to consume fruit and is, therefore, of crucial importance. It is usually measured by a visual method through the proportion of additional fruit coloration or using a colorimeter. The effect of netting on fruit coloration was mostly studied in apple fruits. In the majority of studies, netting had a negative or no impact on apple (depending on the net type, variety, or studied year) [32,42,43,57,58,60,90,96,109,124] or peach [125] additional coloration. A lack of impact was also reported in apricots [55]. In addition, Jemrić et al. [59] reported that red nets proved to be effective against fruit red blush development (an undesirable trait in "Granny Smith" apples). Based on the aforementioned studies, it can be said that the application of black nets in most cases harmed apple coloration, which was not always common for other applied nets. During the ripening of fruit of the majority of fruit species and varieties, they lose their green color and obtain red, blue, purple, or yellow colors [97]. Since pigments determine the fruit color, the effect of nets on their development will also be discussed in this chapter. Anthocyanins are the main pigments in fruits and are responsible for the formation of the characteristic reddish, bluish, and purple tones, which is why they contribute to fruit quality [126]. Anthocyanins are a sign of ripening, because most fruits of various fruit species typically accumulate them during the ripening phase [25,127]; thus, a possible mechanism of net influence on anthocyanin content should be sought in this period. Most studies reported that anthocyanin content in fruits was generally lower when grown under nets than in natural conditions [23,25,32,37,124,125], except in certain cases where the use of nets alleviated stressful conditions (temperature) or in shade-tolerant species [23,25].

Westwood [97] stated that exposure of the fruit to direct light was necessary for the development of red color in pear, peach, nectarine, apricot, and apple. Thus, the intensity of the light that reaches the fruit skin has a crucial role in color development [128–131]. Similarly, Solomakhin and Blanke [32] reported that the reduced level of the additional color of apple fruit grown under different net types depended on the level of light transmission. Greater light exposure may increase the concentration of anthocyanins (especially in the skin), while shading reduces it ([132] according to [133–137]). In two studies [32,42], this was stated as the main cause of higher anthocyanin content in apples grown without the use of nets and, hence, better color development. However, not all fruits are required to have skin exposed to direct light for anthocyanin synthesis, such as grapes, cherries, plums, blackberries, and blueberries [97,138]. In such cases, the capability of certain net types to diffuse radiation can alleviate the negative effects of shading, particularly in the inner parts of the canopy (Section 3).

However, in certain cases, a reduction in solar radiation will not have a negative impact on anthocyanin accumulation. Some fruit species do not require strong exposure to light to accumulate high amounts of flavonoids [132], such as blueberries, which are one of the best sources of anthocyanins, although they prefer shade, and anthocyanin accumulation is greatly influenced by fruit development [139]. Zoratti et al. [25] reported that, in northern Italy, light stress inhibited anthocyanin accumulation in wild blueberries but not in cultivated ones. In addition, in certain fruit species, such as pears, intense light can reduce anthocyanin synthesis [140]. Light quality can also have an important impact on color development. Arakawa et al. [141] noted that, in red-colored apple cultivars, the synthesis of anthocyanins was under the control of UV-B radiation. Radiation with blue-purple and ultraviolet (UV) light is most effective, while far-red is the least effective or even inhibitory on anthocyanin synthesis in apple skin [142]. Zoratti et al. [132] noted that the positive effect of UV light on anthocyanin content was species-dependent. In the study where, during the night, treatment grapes were exposed to LED lamps, anthocyanin concentrations were shown to be highest in the treatment with blue and then red light [143]. The possibility of nets modifying light quality is discussed in Section 2.

In addition to light, temperature also has a strong influence on the accumulation of anthocyanins [25,144,145], but it needs to be viewed in interaction with light. There is an optimal temperature range for anthocyanin synthesis, and for apples it is between 15 and 20 °C, depending on their maturity [57,144,146]. High temperatures (30–35 °C) have been shown to reduce anthocyanin content in apple peel and grape berries ([126] according to [134,147,148]). By temperature modifications, nets can, therefore, achieve the effect of anthocyanin accumulation, especially in warm areas, by alleviating temperature stress (Section 4). García-Sánchez et al. [43] attributed the acceleration of the degreening process (better yellow coloration) of lemons grown under an aluminet net to the decrease in the air temperature in winter due to shading. They explain that, when nights become colder between the end of November and mid-December, the chlorophylls present in the lemon peel are degraded, and the previously masked carotenoids begin to appear, imparting the characteristic 'lemon yellow' color to the fruit. In the same study in December (but not in August), they reported a slightly lower night temperatures under the net than in natural conditions. There are also other possible modes of action. Arena et al. [149] stated that anthocyanin synthesis may also be affected by water availability. Zoratti et al. [25] observed a decrease in anthocyanin content in cultivated blueberries below nets due to an increase in berry size and weight, which led to an increase in water content and, hence, lower anthocyanin content. The effect of net application on the microclimate is discussed in Section 4. Iglesias and Alegre [42] assumed that the reduced fruit apple coloration under the black net was due to the lower availability of carbohydrates necessary for anthocyanin synthesis, due to reduced light availability. García-Sánchez et al. [43] suggested that the effect of minimum air temperature in fruit degreening in lemon trees could also depend on the rootstock on which the scion is grafted.

8.3. Fruit Firmness

Fruit firmness is an important internal fruit quality parameter which, among other parameters, is used for the determination of the optimal harvest window [150,151]. The possibility of nets affecting fruit firmness can be attributed to their light manipulation ability. According to Campbell and Marini [152], the lower firmness of apple fruits in shading conditions may be due to poor cell wall formation and a higher inflow of water into fruit cortex cells. Loreti et al. [153] stated that limited solar radiation affects the formation and composition of the cell wall in such a way that it becomes more elastic, swells, and contains more water. Similarly, Amarante et al. [58] hypothesized that the observed decrease in firmness of apple fruit grown under a white net was due to the possibility of shading influencing the reduction in fruit structural components (cell wall components and middle lamellae). In another study, the authors attributed the reduction in fruit flesh firmness of the fruit under the anti-hail nets to a greater tendency to natural thinning under the nets or weather conditions in the orchard [121]. Lobos et al. [5] reported, in comparison to medium and low shade levels, a significant positive effect of high shade levels on blueberry fruit firmness. Accordingly, there are conflicting reports regarding shading's influence on fruit firmness. Similarly, there is no general consistency between studies regarding net influence on fruit firmness of apples [4,19,26,32,42,57,59,109,116,124,154], peaches [8,16,61,125], or other fruit species [5,21]. Therefore, other possible mechanisms should also be taken into account. Fruit firmness can, among other things, also be influenced by yield, fruit size, and maturity at harvest time [151]. Similarly, Shahak et al. [16] stated that the positive effect of photoselective nets on peach fruit size was, among other things, at the expense of fruit firmness (based on the inverse relationship between these two parameters). In addition, Amarante et al. [58] noted that the effect of the white net on apple fruit firmness was also variety-dependent (with an emphasis on ripening time).

8.4. Sugar Content in Fruits

Sweetness, a fruit quality trait that is crucial for customer satisfaction with the product, is most often obtained by a refractometer, which measures the content of total soluble solids (TSS) in the fruit juice [151,155]. Generally, the application of nets achieved negative or no effect on TSS in apples [4,26,32,42,57–60,90,116,124,154], peaches and nectarines [16,61,125], blueberries [25,31], or lemons [54]. In only one study, TSS levels in kiwifruit were lower in natural conditions than under nets [21], while, in a few studies, the net effect could not be assessed, due to lack of a control group (natural conditions) [8,19,118]. Light is the primary factor through which nets can achieve an effect on fruit sugar content. Cronje [156] stated that the TSS content was greatly influenced by light availability. This was confirmed by Lobos et al. [5], who noted a linear increase in TSS in blueberry fruit along with an increase in PAR. Light energy is absorbed by chlorophyll so it can be used for photosynthesis, which in turn affects the fruit TSS content [157]. Amarante et al. [58] hypothesized that the decrease in TSS of apple fruit cultivated under white nets was due to shading, which reduced carbohydrate reserves in the fruit, leading to lower starch content and, consequently, soluble sugar at commercial maturity. In two studies [8,158], it was stated that the fruit quality (i.e., TSS content) also depended on the distribution of light within the canopy. Given that the influence of nets on the light was recorded and the fact that some nets can enhance the diffuse light component (Section 3), it is clear that this is one of the primary mechanisms through which nets achieve an impact on this trait. However, this impact is not unambiguous, because, through the impact on light, nets can also achieve effects on other factors that may consequently influence fruit sugar content. Corelli Grappadelli and Marini [159] stated that an increase in vegetative growth was associated with an increase in canopy density, which caused suboptimal light distribution in the canopy and could lead to losses in peach fruit quality. The influence of photoselective nets on TSS may be the result of different source–sink relationships induced by the nettings, which may be causedby direct (air temperature, light availability, photo-morphogenic effects, etc.) and/or indirect effects (crop load, canopy density, competition between vegetative and reproductive growth, light distribution within the canopy, etc.) [21]. On the other hand, in some studies, a different approach to this issue was suggested. Lakso [160] stated that the higher TSS content in apple fruit was associated with water stress, and, based on that, Bastias [19] concluded that the cause of the higher TSS concentration in apple fruit grown under a white net was due to higher soil evaporation compared to the gray and blue nets (although there was no difference in the water potential of apple leaves between different nets). The higher amount of water in blueberry fruit grown under nets may be the cause of lower TSS content, due to solution dilution [5]. Shahak et al. [16] reported that the positive effect of photoselective nets on the size of peach fruits was, among other things, at the expense of the TSS content in the fruit (based on the inverse relationship between the two parameters).

8.5. Acid Content in Fruits

Acidity is a fundamental property of internal fruit quality that represents the sensory intensity of the total acid content (malic, citric, and tartaric acid) [161]. Fruit acidity is, among other quality parameters, a property that is associated with consumer satisfaction [162]. Acidity is usually represented by titratable acidity (TA) and the pH of fruit juice [163]. Although the effect of net application on fruit acidity has been extensively studied, results are not consistent. In the majority of studies, positive or negative effects of net application on fruit acidity were mixed, with a lack of significant difference (depending on the net type, variety, or year) [4,21,42,58,60,109,154], while, in some, no effect at all was reported [16,32,54,59,90,116]. In one study [124], the application of nets caused a reduction, while, in another [125], an increase in TA in fruit. Moreover, Lobos et al. [5] reported that, if both years were combined and the influences of color (black, red, and white) and shading properties of nets (weak, medium, and strong—shading of 25, 50, and 75%, respectively) were considered separately, then no significant effect of net color on TA content in "Elliott" blueberry fruit was observed. Based on results from certain publications, it is evident that acid content in fruit is negatively correlated with the amount of light [130,164,165]. Similarly, Lobos et al. [5] noted a positive effect of the degree of shading on the acid content in blueberry fruit. In addition, Lewallen [158] stated that the distribution of light within the canopy also affected the fruit acid content. Based on the aforementioned, it can be assumed that nets can influence the acid content in fruits by modifying light quantity and, if possible, diffuse light components (Section 3). However, since studies regarding the net effect on acidity in fruits are not consistent, no clear conclusion can be made.

8.6. Bioactive Components in Fruits

The effects of nets on fruit bioactive components were up-to-date scarcely studied. Mainly, the application of nets caused a reduction in bioactive components or did not achieve a significant effect [21,23,32,37,59,125]. Only Šavikin et al. [23] reported both an increase and decrease (variety-dependent) in the antioxidant activity of blueberry fruit grown under a green net. Although pigments are also bioactive components, they were explained in Section 8.2, due to their unavoidable influence on fruit color. Thus, in this chapter, emphasis will be given to basic components. According to Bakhshi and Arakawa [166], light intensity and quality can affect the biosynthesis of antioxidants and phenols. Gullo et al. [167] noted that, with higher PAR exposure, the antioxidant activity of peach fruit increased. Light conditions play a major role in flavonoid biosynthesis and accumulation, and removing the sunlight available to fruits has, in many cases, led to a reduction in flavonoid content in climacteric and non-climacteric fruits [132]. Growing strawberries in conditions of higher light intensity resulted in increased amounts of ascorbic acid [168]. However, the influence of light intensity on the content of these components is not so simple, i.e., lower intensity does not automatically mean lower content of bioactive components in fruits. Anttonen et al. [133] noted that shading did not significantly affect the reduction in total polyphenols in strawberries. Moreover, in some cases, the high light intensity can reduce the synthesis of some bioactive components, such as, according to Zhang et al. [140], anthocyanins in pears. This area is still being extensively studied and is largely genetically determined, as noted by Šavikin et al. [23]. In addition to light quantity, the content of these components can also be affected by light quality. The concentration of some polyphenols increases when fruits are exposed to UV light, because flavonoids can absorb UV radiation and, thus, prevent tissue damage [141]. Phenols and their derivatives are highly sensitive to UV light, and, as a result of their exposure, they accumulate in epidermal cells to reduce penetration into deeper tissue [169,170]. Similarly, Basile et al. [21] hypothesized that, since applied nets had a higher shading percentage in the UV than in the PAR spectrum, the reduction in UV radiation below the nets was responsible for the reduction in antioxidant activity and the concentration of total polyphenols in kiwifruit. The influence of the quality of the visible light spectrum on the content of bioactive components has been intensively investigated recently [143,171,172]. However, further studies are needed. Based on stated studies, it can be mentioned that a certain influence of blue, red, and yellow light on the content of bioactive components was recorded. However, not all phenolic compounds are light-dependent. It was reported that chlorogenic acid in apple skin was largely independent of light conditions, and, in that study, photoselective nets did not achieve a significant effect on this compound [37]. In addition to light, temperature also plays a notable role; i.e., it has been reported that high temperatures during fruit development have increased the content of several bioactive components in strawberries and raspberries ([173] according to [174,175]). Josuttis et al. [173] even concluded that temperature had a greater effect on the content of bioactive components in strawberry fruit than light. Since nets can affect light and, to a certain extent, temperature (Sections 3 and 4), this presents the main mode of action.

9. Physiological Disorders—Sunburns

The application of various nets reduces sunburn occurrence on apples [16,24,27,28,40,42,44,57–60,90], table grapes [22], and mandarins [56]. Sunburn is a physiological disorder that, in apple fruit, is caused by a strong intensity of solar radiation and can manifest as browning, necrosis, and photooxidative burns [176]. They present an important physiological disorder in apples that causes great losses. In Australia, about 10% of the total yield of certain apple varieties can be lost due to the onset of fruit sunburn symptoms [24]. In the Republic of South Africa, producers estimate the losses caused by sunburns at 10 to 20% and, in some years, as much as 30 to 50% of the total yield [177]. Felicetti and Schrader [178] stated that a temperature higher than 46 to 49 °C on the skin of an apple fruit causes sunburn with a symptom of browning and a temperature higher than 52 °C with symptoms of necrosis. In high-light conditions, the fruit surface temperature can be 12 to 15 °C higher than the average air temperature [179]. Therefore, when the air temperature reaches 35 °C the fruit surface temperature approaches or exceeds the temperature threshold for the appearance of sunburns characterized by browning symptoms [40]. Thus, even a slight reduction in temperature caused by the application of nets can be crucial in their prevention or intensity reduction. A detailed representation of net influence (in particular gray quad anti-hail net with 10% shading) on the reduction in fruit temperature can be seen in a study conducted by McCaskill et al. [24]. The authors noted that, during a clear day, the share of fruits with a temperature higher than 46 °C amounted to 45% for apples grown in natural conditions and 9% for apples grown under a net. However, on a partly cloudy day, 79% of apple fruits grown without the use of a net and 32% with the use of a net reached a temperature higher than 46 °C. Kalcsits et al. [40] reported that the application of pearl, blue, and red nets on average reduced the apple fruit surface temperature by 2.6–4.3 °C, and Lee et al. [56] reported that the application of white nylon nets reduced mandarin fruit surface temperature by 5.6–5.7 °C. This demonstrates that nets cause a reduction in the occurrence and intensity of sunburns due to a decrease in fruit temperature. The influence of direct solar radiation on sunburn development is still the subject of research. While sunburns with symptoms of necrosis can develop only due to high fruit temperature and without direct sunlight ([176] according to [180]), other forms of sunburn require direct light (browning and photooxidative burns) [176]. Schrader et al. [179] suggested that UV-B radiation was more important than visible light for the induction of sunburns in the form of browning symptoms. However, visible radiation is the main cause of photooxidative burns on non-acclimatized apples, while UV-A and UV-B radiation and temperature are not the primary factors [178]. Moreover, Brglez Sever et al. [29] predicted that, with increased climate change, the distinct reduction in PAR could reduce the risk of sunburn. The influence of nets on PAR and UV radiation has been recorded (Section 3), and this can also present one of the mechanisms. Racsko and Schrader [176] reported that, among other factors, relative humidity and airflow could indirectly affect the occurrence of sunburns. They added that, although the transpiration of the fruit is considered to be very small, low relative humidity causes stress to the tree and, consequently, to the fruit itself. Makeredza et al. [181] recorded a linear increase in the occurrence of sunburns with a decrease in orchard irrigation, i.e., stress due to lack of water. According to the aforementioned studies, nets can have a positive effect on reducing sunburn occurrence also by increasing relative humidity and, as well, through higher soil moisture content (Section 4), since this mitigates plant water stress.

10. Shift in Fruit Ripening Time

Determination of the optimal harvest window in fruit growing is of crucial importance for ensuring long storage possibility and achieving the optimal physicochemical and organoleptic fruit properties on which consumer satisfaction will depend. In addition, it is important from the economic point of view, because earlier ripening usually means achieving a higher price on the market due to lower fruit availability. However, in certain situations, later maturation is also desirable. Shahak et al. [22] stated that later harvests of table grapes in Israel could allow berries to achieve a greater size and result in a wider range of color intensities, which can satisfy various consumer preferences and shorten the expensive storage of grapes until sale. The shift in ripening time may also be one of the mechanisms by which nets modify fruit quality parameters. Similarly, Giaccone et al. [8] hypothesized that the observed effect of the red net (in comparison to the white net) on the quality of the "Laura" nectarine fruit could be due to delayed ripening. Moreover, Ordóñez et al. [26] reported that, although at the point of commercial maturity (162 days after full flowering) apples grown under a white net had significantly higher firmness and TA as well as lower TSS than those under a black net, at the beginning of climacteric rise (162 and 154 days after full flowering for fruits grown under black and white net, respectively) these differences had disappeared. On the other hand, Basile et al. [21] concluded that the influence of various net types on the growth and composition of the kiwifruit was not correlated with an indirect effect on maturation acceleration. In another study, anti-hail nets did not have a direct impact on ripening dynamics or differences in apple fruit color; however, the authors emphasized that they could affect the onset of ripening and that the use of blue, red, and green nets induced a faster development dynamic of fruit skin color [121]. Thus, this possibility must be taken into account but is not always responsible for fruit quality changes. In some studies, the accelerated ripening of fruits was observed in shading conditions (i.e., by net usage) [16,22,58,60], while, in most studies, it was recorded in conditions of reduced shading (i.e., without the use of nets or under nets with lower shading properties compared to those with higher) [5,8,22,25,26,32,42,124]. There are also studies where the application of nets did not cause a shift in ripening time [19,42,58–60,116]. Since this effect is strongly dependent on the applied net, fruit species or variety, and studied year, some studies are mentioned in more than one case. Ordóñez et al. [26] suggested suggested that nets influence maturation through light availability and Lobos et al. [5] noted a significant influence of the degree of shading of the nets on the ripening time of blueberry fruits. The influence of light availability on fruit maturation has also been studied in other studies, but the results were partly contradictory. Hicklenton et al. [182] managed to delay the harvest time of blueberry cultivars 'Brigitta' and 'Bluegold' for 2.5 weeks by applying 50% shade, and Smart et al. [183] noted that, by increasing the degree of shading (realized using shading fabrics), ripening in "Cabernet Sauvignon" grapes was significantly reduced. Jackson et al. [119] did not record the effect of high shading levels (63–89%) on the time of apple fruit ripening. The possibility of certain net types producing diffuse radiation must also be taken into account (Section 3), since it can act positively on light conditions in inner canopy parts and, hence, influence the fruit ripening process. It is also important to mention agroecological conditions, because a reduction in solar radiation will not have the same impact in all agroecological conditions. In conditions with high levels of solar radiation, a certain reduction is generally desirable, and so this will differently affect fruit ripening. The adaptability of the plant species to shade is also a crucial factor. Altogether, it presents a strong explanation of why the impact of nets on harvest period can vary. In addition to the direct effect, light can also indirectly affect ripening. Nets, potentially through enhanced vegetative growth, can also affect the availability of light and, thus, have an impact on the source–consumer relationship and, therefore, potentially, on the harvest time. A similar assumption was made by Shahak et al. [22], where the blue net reduced vegetative growth and significantly accelerated the ripening of the more vigorous table grape variety 'Superior' while delaying the less vigorous and more productive 'Perlette' variety. The authors explained that the opposite effect could be due to genetic differences in the stated generative–vegetative balance between the two varieties and that, therefore, nets could change the balance of each variety for better or worse.

11. Conclusions

New netting technologies correspond with the overall trend in agriculture for higher crop protection as a result of an increased hazard occurrence due to ongoing climatic changes and, at the same time, achieving more sustainable production as consumers' environmental and health awareness rises. Although the application of standard nets protects against numerous hazards (hail, wind, excessive sun radiation), new netting systems also enable pest protection with reduced pesticide usage and specific plant morphogenic and physiologic manipulation achieved by light modifications. Such outputs contribute to the overall sustainability of fruit production and reduced risk production. However, since nets are usually made of high-density polyethylene, their proper disposal after usage is a necessity. Although, to date, there is an increasing number of studies that deal with the effect of photoselective nets on different fruit tree traits, there are many differences and conflicts in results between them. Such can be due to different net properties, agroecological conditions, or genetics (species or variety). All of the above emphasizes the importance of understanding the mechanisms involved in nets' effects on fruit tree traits, which will enable better utilization of this technology for scientists as well as for fruit growers. These mechanisms for the following traits include:

- Vegetative growth—R:FR ratio, blue light, PAR intensity, phytochrome equilibrium, carbohydrate availability, stressful conditions;
- Photosynthesis efficiency—shading (regarding optimal light levels—genetically determined), red and blue light, light and temperature stress reduction;
- Differentiation of generative buds, fruit set, and yield—shading (especially within PAR), far-red light and R:FR ratio, temperature reduction, carbohydrate availability, and source–sink relationship, pollination, reduction in stressful environmental conditions;
- Fruit size—shading, carbohydrate availability, source–sink relationship (balance between vegetative and generative growth), reduction in stressful environmental conditions (especially water and temperature stress), thinning;
- Fruit color—light exposure (direct and non-direct (scattered) light—species-dependent), UV light, blue and red light, temperature reduction, carbohydrate availability;
- Fruit sugar content—shading, carbohydrate availability, source–sink relationship, water content (solution dilution);
- Fruit bioactive components—shading, UV radiation, and certain visible light spectra, temperature reduction;
- Fruit sunburn occurrence—temperature reduction on fruit surface, shading, humidity;
- Fruit ripening time—shading, source–sink relationship, reduction in stressful environmental conditions.

This study is a part of an ongoing doctoral thesis entitled "Vegetative growth, yield and fruit quality of peach (*Prunus persica* (L.) Batsch.) cv. 'Suncrest' cultivated under photoselective nets" by the first author, M.V.

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