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Shading Net and Grafting Reduce Losses by Environmental Stresses during Vegetables Production and Storage †

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Abstract: The aim of this review is to summarize our recently reported findings on the use of preharvest treatments (shade nets), applied either directly or in combination with other techniques (grafting) in order to minimize physiological disorders and maximize and maintain the phytochemical content of vegetables. The use of colored nets for shading vegetables to protect against stress (intense solar radiation, heat stress, drought, drying winds and hailstorms) during the summer months is an effective and inexpensive method and it provides plant protection and altered microclimate and modified intensity and quality of light. Moreover, use of colored nets supports a more intensive vegetative growth, longer vegetation, increased yield and it reduces a number of physiological disorderswhileimproving the morphological and nutritional quality of vegetables. Under color nets, tomato plants provided the fruits with thicker pericarp, firmness, higher content of lycopene, less percent of physiological disorders and better tolerance to transport and storage. Shade-grown plants generally have higher total chlorophyll and carotenoid contents, an increase in the total yield and a decrease in physiological disorders accompanied with an increase in the content of total phenolic compounds and flavonoids. Grafting can increase yield and fruit size and improve or reduce external and/or internal fruit quality and retained better postharvest quality, compared to the fruits from non-grafted plants. Further investigations using shade nets alone or in combination with grafting are needed to ensure the use of adequate strategies for managing plant growth of different plant species with limited physiological disorders, for increased marketable yield and for maintaining quality during storage.

Keywords: prestorage; shading; grafting; vegetables; quality; postharvest

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1. Shading Nets

Environmental stresses represent the most limiting conditions for vegetable production. In order to protect the vegetable from undesirable environmental conditions(weather extremes; temperature and radiation), water shortages, pests and diseases, plant covering can play an important role as an alternative and supplemental production system to conventional open field production [1]. Covering the crop does not only protect it from natural hazards (wind and hail and exclusion of bird and insect-transmitted virus diseases), but also allows for modification of the microenvironment (radiation, temperature and relative humidity) to provide optimal plant performance, induce earliness and extend production period, and improve product quality [2].The nets cover entire tunnels or are placed above the plants inside greenhouses. Color shading nets have evolved over the past decade to transmit a selected portion of the sunlight spectrum, while encouraging diffused-scattered light. Depending on the color and density of the weave (shading index), the nets provide a mixture of natural, unaltered light, along with spectrally modified, scattered light. In addition to providing physical protection from e.g., hail, strong winds and sandstorms, and protection from airborne pests, birds, bats and insects, all of which are potential carriers of viral diseases, the shade nets are aimed at optimizing the desired physiological impact on plants [3]. Photoselective shading nets are based on the introduction of various chromatic additives, as well as elements for dispersion and reflection of light within the materials themselves during their production. Apart from the net structure, the spectrum of the transmittance is also influenced by the diameter of the thread, the color and thickness of the net, and the properties of absorbance, transmittance and reflectance of the plastic material [4]. They are built to selectively transmit different spectral components of solar radiation (UV radiation, visible and long) and/or directly transform light into diffuse-scattered light. Light quality modification (light transmittance and scattering) by different shade nets is illustrated in Table 1.

Table 1. Light quality modification in the UV-B to far-red spectral range by color nets showing distinct effects on horticultural crops.

Net	Enriched Spectral Bands	Reduced Spectral Bands	Light Scattering
Blue	B	UV + R + FR	++
Red	R + FR	UV + B + G	++
Yellow	G+ Y + R + FR	UV + B	++
White	B + G + Y + R + FR	UV	++
Pearl		UV	+++
Grey	-	All to same extent	+
Black (Control)	-	All to same extent	-

Source: Rajapakse and Shahak, 2007:302 [5].

Each of the colored shade nets, specifically modifies the transmitted light spectrum in the ultraviolet, visible and far-red regions, enriching the relative content of scattered light and affects its thermal components (infrared region), in function of the chromatic additives of plastic, scattering elements and weaving design [6]. Thus, black, grey and white nets reduce the light quantity (neutral shade), while red, blue, yellow and pearl nets change the red and blue light composition (photo-selective shade) [7,8]. In addition, pearl, white, red, blue and yellow nets increase the scattered light ratio at luminous environment of cultivated plants [3,6].

Manipulation of the spectral composition aims to directly affect the desired physiological responsibility, while diffused light improves the penetration of light into the plant inner [9]. Nethouses protect the leaf and fruit of vegetable plants from excesses sun radiation, obtaining more vigorous plants, with higher yields and better fruit quality compared to the open field [10].

Light transmission through these cover materials promotes the differential stimulation ofsome physiological responses regulated by light, such as photosynthesis, as a function of photosynthetic photon flux density (PPFD) and leaf content of *a* and *b* chlorophylls [3,11,12] Plant morphology (height, branching, internode length, etc.) is influenced by both light quality and intensity [13]. According to the literature, photo-selective shading nets change plant growth and leaf anatomy [8,13,15,16],reduce physiological disorders [3,14,21] and increment fruit yield and quality [3,17–19] of different cultivated vegetables The quality of vegetables at harvest and after harvest is conditioned by the use of colored nets (Table 2).

Table 2. Influence of colored shade nets on vegetable quality at harvest and during postharvest storage.

Color Nets	Special Finding	Reference
Shade nets	Improve the overall quality, aroma volatiles, and bioactive compounds in vegetables and culinary herbs at harvest	Sivakumar et al., 2018 [20]
	Increased quantity of antioxidant and other bioactive compounds in medical plants	Ilic et al. 2021 [21]
	Higher levels ofessential oil of lemon balm, mint and sweet basil Highest antioxidant activity of thyme, marjoram and oregano	Ilic et al., 2022 [22]
	Reduce fruit susceptibility to fungal infection in the field	Milenkovic et al., 2021 [23] Goren et al., 2011 [24]
Pearl and yellow nets	Reduce pest-borne viral diseases, as well as the occurrence of fungal diseases, in both pre- and post-harvest of sweet pepper fruits	Shahak, 2014 [25]
Red, pearl and yellow	Significantly maintained better pepper fruit quality after prolonged storage mainly by reducing decay incidence	Goren et al., 2011 [24]
Pearl nets	Higher ascorbic acid content at harvest in aromatic herbs, coriander, marjoram, and basil	Mashabela, et al., 2015 [26]; Ntsoane et al., 2016 [27]; Buthelezi et al., 2016 [28] Ilic et al., 2019 [29]
	Increased carotenoid content in leaves of cv. Discoa	
	Increase total phenols and total flavonoids content in lettuce leaves	Ilic Z., et al., 2017 [30]
Pearl and Red nets	Increase total phenols and flavonoids content in lettuce	Ilić et al., 2017 [32]
	Vitamin C content was observed to have increased in chillipepper	Duah et al., 2021 [31]
Red nets	Significantly higher pericarp fruit thickness is in the pepper fruits	Ilić et al., 2017a [30]
	Increased total phenols content in cv. Discoa lettuce	Ilic te al., 2019 [29]
Blue nets	Highest total chlorophyll content in lettuce	Ilic et al., 2017b [32]
	Highest flavonoids content in Discoa and Eglantine lettuce	Ilic et al., 2019 [29]
	Highest eugenol content and highest antioxidant activity in basil	Milenkovic et al., 2019 [33]
Black nets	Highest total chlorophyll content in lettuce leaves	Ilic et al., 2017b [32]
	Increased yield, total soluble solid content, chlorophyll, ascorbic acid, β-carotene, and flavonoid	Ntsoane et al., 2016 [27]
Postharvest storage		
Pearl and red nets	Higher pericarp thickness (exocarp, mesocarp and endocarp) in tomato fruit	Ilić et al., 2015 [10]
Pearl nets	Lowest water loss in external leaves during storage Increase of total organic acids content	Mastilovic et al., 2019 [34]
	Higher SSC/TAratiosof tomato cultivars	Elad, 2007 [35]
	Higher soluble solids concentration (SSC) and SSC/titratable acidity (TA) ratios after postharvest storage of green sweet pepper	Mashabela, et al., 2015 [26]

Pearl and yellow nets	Significantly maintained better pepper fruit quality after after 15 d storage at 7 °C plus 3 d shelf life simulation, mainly by reducing decay incidence Better potential in retaining antioxidant activity of baby spinach	Goren et al., 2012 [36] Mudau et al., 2017 [37]
Pearl nets	Greater antioxidant activity of lettuce after postharvest storage Retained the green grassy aroma (2-isobutyl-3-methoxy pyrazine and hexanal) during green pepper postharvest storage	Ntsoane et al., 2016 [27] Selahle et al., 2014 [39]
Pearl nets	Retention of antioxidants during postharvest storageof culinary herbs	Buthelezi et al., 2016 [28]
Red nets	Retained maximum odor-active aroma volatiles after postharvest storage of green sweet pepper Stimulated the production of aroma volatiles in coriander	Selahle, 2015 [38]
Yellow	Fruit maturation favored higher levels of 2-nonanal trans-3 hexenol compounds after postharvest storage in green peppers.	Selahle, 2014 [39]
Black nets	Maintained high level of flavonoids at 4, 10, and 20 °C of baby spinach during storage period Reduce water loss, decay incidents, and maintain flavonoid content and antioxidant activity of baby spinach Increased the lycopene content after postharvest storage of red and yellow sweet peppers, and tomatoes	Mudau et al., 2017 [37] Selahle2015 [38]

Photo-selective shade nets with light modification in spectral intensity and quality can improve the overall quality, aroma volatiles, and bioactive compounds in vegetables and culinary herbs at harvest [20]. These improvements enable the crop to maintain a substantial content of antioxidants during the postharvest storage [20].

2. Grafting

Grafting is the union (transplantation) of two or more plant tissues, which form a vascular connection and thus joined, the plants continue to grow as one individual. Vegetable grafting is a unique horticultural technology, which has been practiced since 2000 BC [40]. During the last 50 years, it is widely represented in Asia (China, Japan, Korea…) and increasingly in Europe (Spain, Italy, Turkey, Greece, Israel…) in order to overcome the problem of soil quality due to intensive vegetable growing and increasing yields [41]. Grafting protects vegetables from soil pests [42], diseases and nematodes, from abiotic stresses such as high/low temperature [43], salinity [44], drought [45] or excessive water content in the soil, from elevated concentrations of heavy metals [46], and organic pollutants [47–49]. In addition, grafted plants absorb water and nutrients from the soil more efficiently and retain their vitality longer, during the growing season [50].

Grafting makes the production of seedlings more expensive, because it is necessary to occupy twice the area in the greenhouse for the production of young rootstock plants and young seedlings. Also, it is necessary to invest additional work during grafting (which requires experience and skills), and after grafting, shade and additional care measures should be provided. In addition to all the above, an additional difficulty is the procurement of certified seeds, but also seedlings, intended for grafting [51].The combination of rootstocks/seedlings can affect the change in yield and fruit quality of grafted plants directly with the harvest, but also during longer storage [52]. These changes can be attributed to differences in the external environment during production, rootstock/rootstock combination as well as harvest time. Grafted seedlings are more expensive than ordinary, non-grafted ones. Therefore, grafting should be used only if it is economically justified. The goal of grafting fruit vegetables is to increase yield without declining quality and to reduce susceptibility to stress of abiotic and biotic nature.

Yield and fruit quality by combination of rootstock/seedling should be monitored within specific environmental conditions. Grafting is an effective technique in increasing watermelon yield, resistance to biotic and tolerance to abiotic stresses. This technique consists of using a strong or resistant plant (rootstock) to replace the root system, a genotype of economic interest (scion) that is susceptible to one or more stressors. Grafting rootstocks from the pumpkin family in watermelon production are a common practice and effective method in terms of crop safety without any harmful effects on the environment or human health [53,54]. Using appropriate rootstock, grafting can be applied in various agroecological conditions that are unsuitable for watermelon cultivation (presence of pathogens, salinity, heat stress, alkalinity, etc.) [55]. Grafting increases the yield, but delays ripening. The extension of the ripening period depends on the choice of hybrid or rootstocks, but also on the climatic conditions during the growing season. Early yield (harvest until July 5) on grafted varieties is significantly lower. Significantly lower early yields are achieved by plants grafted on the domestic top (*Lagenaria vulgaris* Ser.) Compared to plants grafted on a hybrid medium Emphasis F1 the adequate choice of rootstock and scion is one of the most important factors in achieving high yields andgood-quality fruits [56]. Future development and application of grafting practices should be based on physiological and genetic determinants of interactions and communication between rootstocks and scion, especially those based on favorable ecotypes of rootstock × scion × environment [57]. Grafting can increase yield and improve fruit quality and retained better postharvest quality (Table 3).

Table 3. Influence of grafting on agronomic responses and fruit quality at harvest and during storage.

Scion Cultivar	Rootstock Cultivar	Agronomic Responses and Fruit Quality	References
Watermelon	All rootstocks	Fruit maturity delayed in grafted plants	Davis et al., 2008 [58] Thies et al., 2015 [59]
	Citron as rootstock	High level resistance to nematodes	Fredes et al., 2017 [60]
	Cucurbita hybrids rootstock	Reduced the citric and glutamic acid contents)	Proietti S et al., 2008 [61]
	Mini watermelon grafted commercial hybrid rootstock PS 1313 (*C.maxima x C.moschata*)	Fruit quality parameters were similar in grafted and ungrafted plants, whereas the titrable acidity (TA), TSS/TA ratio, K and Mg concentration were improved by grafted one.	
Tomato	Tomato (S. lycopersicum L.) cv. Zarina (Z) Under deficit irrigation regimes	Higher total phenols, flavonoids, anthocyanins, lycopene, β-carotene, antioxidant activity, sugars and organic acids, sweetness index and sugars: acids ratio, Ca, K and Mg in J/Z than in the nongrafted and other grafting combinations under water stress	Sanches-Rodrigez, 2012a, 2012b [62,63]
Pepper	Pepper (C. annum L.) cv. Atlante (A), Creonte (C), and Terrano (T). Under deficit irrigation regimes	Higher fruit yield in H/C, H/A, and H/T than ungrafted control across all irrigation regimes. Lower the antioxidant capacity in H/C and H/A, vitamin C in H/C, and total phenolic content in H/A, H/C, and H/T than ungrafted control across all irrigation regimes.	Lopez-Marin et al., 2017 [64]

	'Herminio' F1 grafted onto Terrano rootstock	Grafting increased the total and marketable fruit yields by 30 and 50% under unshaded and shaded conditions, respectively compared with non-grafted plants. However, grafting did not influence TA or TSS contents.	López-Marín et al. (2013) [65]
	Postharvest		
Watermelon	Hybrid rootstocks (C. maxima × C. moschata)	Slight delay in preharvest accumulation of sucrose. Grafting on hybrid rootstocks increased flesh firmness and red color and limited its postharvest decline. Higher fruit lycopene content postharvest; they improved flesh color and limited discoloration during storage.	Kyriacou and Soteriou, 2015 [66]
	Commercial hybrid pumpkin rootstocks (*C. maxima* × *C. moschata*)	Greater phenolic content than ungrafted plants during two growing periods	Evrenosoğlu et al., 2010 [67]
		Increased rind thickness improved the postharvest integrity of the fruit by reducing damage during transport.	Rouphael et al., 2010 [68]
	Citron or Cucurbita rootstocks.	Larger fruits with thicker rinds were observed growing on plants grafted onto either	Fredes et al., 2017 [60]
	'Crisby' and 'Crimson Tide' grafted onto Ferro and RS841 rootstocks	Retained better postharvest quality, compared to the non-grafted fruit for both cultivars.	Ozdemir et al., 2018 [69]

In our most recent publication from 2021 [71], descriptive analysis showed that the dominant features in the sensory profile of watermelon were grafted onto Emphasis F_1 and *L. siceraria* rootstocks: moderately watery, refreshing, crunchy, ripe and sweet. The fruits of plants grafted on the basis of Strong tosa F_1 are characterized by spongy, drier and firmer consistency, with a moderately pronounced feeling of sweetness or salinity that remains in the mouth (after taste). Fruits from the nongrafted plants have a soft and watery consistency, with a sweet taste. A pleasant typical smell characterizes watermelon fruits grafted on Emphasis F_1 rootstock, while the remaining grafting combinations to some extent encourage the appearance of the smell of cucumber (Strong tosa F_1) or pumpkin (*L. siceraria*) with increased acidity. Cooling the samples contributes to a more intense feeling of refreshment compared to samples at room temperature. Interspecies hybrid rootstocks increase the firmness of watermelon flesh and prolong the storage period after harvest [71].

The arrangement of the seeds is correct, the presence is moderate and the color and shape are uniform. The thickness of the bark is significantly higher only in the fruits of watermelon grafted on the substrate of Strong tosa F_1 compared to non-grafted plants. Increasing the thickness of the bark in grafted plants improves the transportability of fruits [71]. Although changes in fruit quality have been observed by grafting, the mechanisms of action involved in the regulation of fruit quality factors with different rootstocks are still unknown [72]. Therefore, the authors' recommendation is that future research focus on the specificity of rootstocks in certain growing regions, soil type and weather conditions, in order to improve fruit quality and extend the storage period.

Postharvest decline in flesh firmness may compromise watermelon fruit quality in less than 14 days following harvest. Hybrid rootstocks (*C. maxima* × *C. moschata*) do not affect the SSC of diploid cultivars but may cause slight delay in preharvest accumulation of sucrose. Hybrid rootstocks sustain higher fruit lycopene content postharvest, improve flesh color and limit discoloration during storage. Overall, grafting diploid watermelon hybrid cultivars on *C. maxima* × *C. moschata* rootstocks enhances plant vigor and improves overall fruit quality and storability [66].

The molecular mechanism related to fruit quality affected by grafting (compatibility/incompatibility) is still not well understood. The high consumer demand for very good internal and sensorial fruit quality after harvest has become essential in the determination of the mechanism influencing the fruit quality of a grafted plant [73].

3. Shading and Grafting

Grafting and shading provide an alternative strategy for achieving higher fruit yield and avoiding or reducing tomato quality decrease, caused by environmental stresses, e.g., excess radiation and temperature [3]. However, rootstock/scion combinations affect the final size, yield and quality of fruits from grafted plants, at harvest and during prolonged storage [73].

The interaction between grafting and shading influences the main constituents and flavour compounds in tomato fruits [74]. Grafting does not restore the decreased concentrations of sugars and β-carotene in either scion, or volatiles in shaded tomato plants. At the same time, shading and grafting enhances the concentration of titratable acids and certain volatiles in the tomato fruit [74]. In this review, we have evaluated the effects of grafting and shading on vegetable postharvest quality, including physical properties, flavour, and health-related contents of the product (Table 4).

Table 4. Grafting and shading in vegetable production as cultivation practices to increase the marketable yield and quality.

	Scion/Rootstock	Quality Parameters	Reference
	Rootscockinterspecific hybrid 'Maxifort' (*Solanum lycopersicum L.* × *Solanum habrochaites* S. De Ruiter)/Optima and Big beef scion	A decrease in sugar content increased the uptake of some micro elements (Fe and Zn) and macro elements (Ca). In some cases, firmer and less elastic skin may be expected due to grafting. Shading with pearl net might result in fruit with lower firmness and higher total, and particularly malic, acid content.	Ilic et al., 2020 [55]
Tomato		The ascorbic acid content of the tomato increases during storage regardless of growing conditions and cultivar Grafted tomatoes are characterized by lower sugar content, both after harvest and after storage. The increase in succinic acid during storage, resulting in possible bitterness, may similarly be more expressed in fruits from grafted plants.	
	Optima and Big beef grafted onto 'Maxifort' rootscock	Total phenol content decreased in grafting plants under shading in both cultivars. Grafting decrease citric acid in fruit from both cultivars. In same time, shading increased citric acid only in fruits from grafted plants. Total sugar content is higher in fruits from non grafted and shade plants.	Milenkovic et al., 2018 [70]
	'Paronset F1' grafted onto He-Man rootstock	Sugar and total organic acids content in tomato fruits from grafted plants increased under shading nets in comparison to	

	under moderate salt stress	non-shaded control but it decreased in comparison to shaded control when moderate salinity water was used for irrigation.	Šunić et al., 2022 *in press* [76]
	'Piccolino', 'Classy' grafted onto two rootstocks 'Brigeor', 'Maxifort'	Grafting 'Classy' onto 'Brigeor' decreased carotenoids by 8%, resulting in a decrease of three carotenoid-derived volatiles (geranylacetone, -cyclocitral and -ionone). Titratable acids were increased by both shading (by 9%) and grafting (by 6%). Lignin-derived volatiles such as methyl salicylate and guaiacol were enhanced by grafting both scions Flavor compounds (sugars, acids, and aroma volatiles) in tomato fruits grown under shaded condition depends on rootstock-scion combination. Grafting onto 'Brigeor' and 'Maxifort' enhanced the concentrations of titratable acid and three volatiles, grafting was unable to raise the decreased concentrations of sugars, -carotene and five volatiles in shaded tomato plants.	Krumbein and Schwarz, 2013 [74]
Pepper	'Herminio' F1 grafted onto Terrano rootstock	Combination of shading and grafting onto Terrano rootstock provided an additional benefit, reducing the unmarketable yield by 50% compared with the ungrafted plants. The use of grafting seems to be an efficient alternative to using shading screens to improve yield and reduce the impact of thermal stress on sunscald disorder in non-shaded condition.	Lopez-Marin et al., 2013 [65]

Grafting is an efficient alternative to shading screens in alleviating thermal stress in greenhouse-grown sweet pepper [65]. Ilic et al. [55] reported that grafting tomato cover by shade nets represent a growing technology during the summer months, which would increase yields and reduce losses due to sunburn that would be acceptable to growers and distributors of tomatoes.

Grafting tomatoes under shading may have an influence on the external and internal quality of the fruit. Thus, pearl nets may positively influence the fruit firmness after prolonged storage. On the other hand, there have been reports of a negative effect of grafting on lycopene content in fruits from plants grown under shading nets. Grafted tomatoes are characterized by lower sugar content, immediately at harvest and after storage. The increase in succinic acid during storage, resulting in possible bitterness, may similarly be more expressed in fruits from grafted plants. Changes in tomato fruits during storage related to sugars and acid content and composition expose probable differences in sensory properties of tomato fruits after storage and are correlated with shading and grafting, which must be further analyzed and confirmed in future investigations [55]

The agronomical and physiological processes that affect the fruit quality of grafted plants have received much research attention, because rootstock/scion combinations need to be carefully selected for specific climatic and geographic conditions. The rootstocks have been selected especially for disease resistance and vigour. Breeding programmes are needed, to select rootstock/scion combinations with high fruit quality parameters under various growing conditions [75]. Identification of rootstocks and rootstock/scion combinations with positive impacts on fruit quality and health-promoting compounds forms a basic requirement for the continued success of grafting [51]. In most vegetable species, the molecular mechanism related to the quality of fruit affected by grafting (compatibility/incompatibility) is still unknown and unclear [73].

Therefore, it is necessary to determinethe mechanism that affects the quality of products in grafted species with additional nets for shading plants due to the growing demands of consumers for internal sensory qualities of fruits after harvest.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

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