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An Analysis of Strawberry Photobiology and Fruit Flavonoids in Controlled Environments

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ABSTRACT:

A wide range of plants have benefited from rapid technological advancements in controlled environment (CE) plant production. Because of their excellent economic and nutritional benefits, strawberries have been a popular crop for CE production in recent years. Growers may control strawberry growth and development by supplying particular light spectra thanks to the extensive usage of light-emitting diode (LED) technology in the produce sector. Strawberry secondary metabolism may be influenced by varying light intensity and spectral composition, which has a significant effect on fruit quality and antioxidant qualities. While the effect of visible light on secondary metabolite profiles in other greenhouse crops has been well established, further research into the impact of various light spectra on strawberry plants, ranging from UV radiation to visible light, is needed. Growers will be able to optimize production and quickly react to changing customer tastes as a result of this. This article presents a comparison of how light spectrum affects strawberry photobiology and secondary metabolism, as well as a collection of research examining the effect of light characteristics on strawberry fruit flavonoids. The impacts of UV and visible light pre-harvest and post-harvest light treatments are examined. Future study and consequences for researchers and farmers of LED lighting setups in strawberry fruit production are addressed.

KEYWORDS: Fragaria Ananassa, Fruit, Light-Emitting Diode (LED), Rosaceae, Strawberry.

1. INTRODUCTION

Strawberry (Fragaria ananassa) is a lucrative crop that is grown all over the globe. All strawberry species are part of the Rosaceae family, which includes several commercially important crops, mainly fruits like the apple (Malus domestica), pear (Pyrus communis), and peach (Pyrus persica). F. ananassa is the most widely grown strawberry species in North America, resulting from crossbreeding between two species: F. virginiana and F. chiloensis. Strawberry fruits are rich in fiber, micronutrients, and ascorbic acid, and offer a broad variety of sensory elicitation and health advantages to the customer. Strawberry fruits are also part of a rising movement that emphasizes the health advantages of plant-derived antioxidants. Strawberry's significant economic significance in the fruit business is due to its consumer appeal and health-promoting qualities[1].

Because the environment has a significant effect on strawberry fruit production and nutritional content, strawberries are often grown in controlled environments (CEs) with regulated lighting and temperature. Artificial illumination is a widely used method for flower initiation and increased fruit production. Depending on cultivars and temperature interactions, the required photoperiod for strawberry flower initiation varies. Strawberry plants with blooming tendencies under various photoperiods have been shown to be inhibited in flower initiation when exposed to high temperatures. As a result, it is recommended that classifying strawberry cultivars purely on the basis of their blooming patterns without considering temperature impacts is insufficient. Strawberry fruit production and quality are also influenced by artificial light characteristics such as wavelength and intensity. For example, compared to other light sources, single blue light treatment increases strawberry (F. ananassa cv. Elsanta) fruit yield by around 25%. The use of 735-nm radiation at the end of the day resulted in a greater amount of strawberry sucrose. These research have shown that using artificial lighting systems enables farmers to maximize fruit output while also satisfying the sensory needs of customers[2].

Plant-derived antioxidants are generated through secondary metabolic pathways and serve as a protective barrier against biotic and abiotic stressors, including light stress. Plants are protected against oxidation induced by free radical scavenging by secondary metabolites such as flavonoids and quinones. The amount of secondary metabolite accumulation has an impact on plant and fruit characteristics such as color and antioxidant capabilities, which are highly valued by consumers. Strawberry fruit has a high overall antioxidant capacity, which allows it to neutralize free radicals and decrease oxidative stress in the human body. Flavonoids, such as anthocyanins, are the most common secondary metabolites in strawberry fruits, and they have antioxidative and anti-inflammatory effects. Anthocyanins protect plants from blue and green light, whereas flavonoids protect them from UV rays. Strawberry fruit consumption has increased globally in recent years due to its antioxidant qualities[3].

1.1 Flavonoid Profile and Function in Strawberry Fruits:

Plant secondary metabolites have a variety of roles in light signaling and abiotic stress defense. Phenolic compounds, which contain at least one phenol unit (aromatic organic ring) in their chemical structures, are the most common type of secondary metabolites found in strawberry fruits. Coumarins, flavonoids, phenolic acids, and tannins are among the various sub-groups of phenolic chemicals. Flavonoids are abundant in plant-based meals and drinks. Flavonoids, often known as floral pigments, are responsible for the color and fragrance of flowers. Flavonoids are further divided into three categories: anthocyanins, flavonols, and flavanols. After terpenoids and alkaloids, flavonoids are the third biggest category of naturally occurring secondary metabolites, with over 10,000 documented. Because most flavonoids absorb wavelengths between 315 and 400 nm, they are useful in UV radiation protection and as plant antioxidants. The amount of flavonoid accumulation in plants is directly influenced by sunlight and UV radiation exposure[4].

1.1.1 Anthocyanins:

Anthocyanins are the most common phenolic component found in the outer cell layers of different fruits, accounting for up to 40% of total phenols in certain strawberry varieties. The main anthocyanin in strawberries is pelargonidin 3-glucoside, which has anti-inflammatory properties. Although anthocyanin accumulation is linked to UV–B protection (280–315 nm), it also occurs in the presence of visible light and far-red radiation under stressful situations. Anthocyanins are the pigments that give flowers and fruits their color, and they're frequently used as a visual cue for insect-mediated pollination and seed dispersers. Light, temperature, pH, and co-pigmentation with other flavonoids all have a role in anthocyanin stability. Because of its ionic nature, the color of anthocyanin pigments is pH-dependent; anthocyanin pigments look red in acidic circumstances and blue in alkaline ones. Anthocyanin builds rapidly in strawberry plants during the late stages of ripening, starting when the fruits change from white to red and increasing more than 10-fold in red, ripe berries. These phytochemicals have a significant role in antioxidant capacity, influencing the fruit's nutritional value. Anthocyanins account for about 70% of overall antioxidant capacity, emphasizing their significance among plant secondary metabolites[5].

1.1.2 Flavonols:

Flavonols are prevalent in a range of fruits and vegetables, such as apples, grapes, and berries, and have been linked to antioxidant activity and a lower risk of cardiovascular disease in humans. The flavonols quercetin and kaempferol are the most abundant in cultivated strawberries. At the start of fruit growth, flavonols are the primary flavonoids, but as the fruit ripens, the flavonoid pathway changes to anthocyanin synthesis. Flavonols provide greater antioxidant protection against UV-B radiation than anthocyanins, although they are more susceptible to light characteristics. According to studies, flavonol accumulation in grape (Vitis vinifera) skins is greatly decreased under shadow treatment and is affected by light levels in grape berries. Flavonols are floral pigments that attract and repel insects, in addition to acting as a tissue protector against UV radiation. Plants' reactions to gravity are influenced by flavonols, although these effects were only seen in mutants[6].

1.1.3 Flavanols:

The most prevalent dietary flavonoids are flavanols, commonly known as flavan-3-ols. They are utilized in food processing as functional additives to regulate microbial levels and offer oxidative stability. Monomeric units, as well as oligomeric and polymeric molecules, make up flavanols. Flavanol accumulation is stage-dependent, much as anthocyanins and flavonols. Supplemental UV light, for example, increases flavanol concentration in developing grape berries but not in mature grape berries. Plants use flavanols to defend themselves against diseases including bacteria and fungus, as well as insects and herbivorous animals. Flavanols may enhance vascular function and nitric oxide availability, as well as regulate metabolism and respiration, according to their dietary effects. Proanthocyanidins, which are flavanol polymers, have been shown to have antioxidative and cardio-protective effects[7].

1.2 Plant Photo morphogenetic Responses and Flavonoid Biosynthesis under UV Radiation:

The range of biologically active radiation is 300 to 800 nm. UV radiation has wavelengths below 380 nm, while visible light has wavelengths between 380 and 720 nm. UV radiation comprises 95 percent UV-A radiation (315–380 nm) and 5 percent UV-B radiation (280–315 nm) when exposed to the sun outdoors or in an area illuminated without supplementary light. The ozone layer prevents UV-C radiation (280 nm) from reaching the Earth's surface. The majority of UV radiation-plant research is now focused on the UV-B wavelength range, with just a few studies focusing on UV-A radiation.

Plants respond to UV-A and UV-B radiation by producing secondary metabolites such as phenolic compounds and antioxidants, and most flavonoids absorb UV-A radiation. UV radiation may harm plants on a variety of levels, including DNA and lipids, resulting in gene transcription and photosynthesis problems. .UV-A radiation is detected by various photoreceptors, including cryptochromes and phytochromes, and affects plant shape and biomass accumulation throughout both vegetative and reproductive phases. Cryptochromes (cry1 and cry2) are flavin-type blue light photoreceptors (320–500 nm) involved in a variety of developmental and circadian signaling pathways. Light-sensitive proteins with photo-reversible conformers: Pr and Pfr are known as phytochromes (phyA through phyE). The inactive version of phytochrome, phytochrome Pr, has a main absorption peak of 660 nm and a secondary absorption peak of 380 nm. The active form's absorption peaks shift around 20–70 nm toward longer wavelengths.

Plant responses to UV-A radiation in terms of leaf growth, shape, and biomass accumulation have been documented, however the processes behind this process are poorly understood in plants. One of the most significant factors of light uptake and productivity is leaf size. Different Arabidopsis thaliana accessions cultivated indoors under 1.59 W m2 UV-A radiation and 30 mol m2 s1 white light showed increased rosette growth. UV-blocking sheets were also used to show that when soybean (Glycine max) was grown in a greenhouse, UV-A radiation increased total leaf area. When compared to UV-A and UV-B radiation, the solar spectrum lacking UV-A and UV-B radiation caused greater leaf size in various sorghum cultivars. Inconsistent responses to UV-A-mediated biomass responses have been documented in published data, indicating that there is no obvious connection between the effect of UV-A radiation and biomass accumulation. Some research found that UV-A radiation had stimulatory effects on biomass accumulation, whereas others found that it had inhibitory effects. One research found that UV-A-mediated responses in plants are determined by genotype; however, the study was limited to A. thaliana ecotypes.

Changes in morphology and photosynthetic activity, as well as the buildup of secondary metabolites, may explain such conflicting results. Different UV-A radiation circumstances, in addition to the effect of plant physiological characteristics on UV-A radiation, may contribute to these contradictory results. UV-blocking films and the sun spectrum were used as radiation sources in the majority of UV-A-mediated response investigations. UV-blocking films allow only a small proportion of UV light from solar energy to be reflected, and their cut-off wavelengths vary depending on the manufacturer. Although all studies reported the same radiation treatments (UV-A radiation), the radiation spectra may vary in this situation. Plant responses may be affected by differences in UV spectrum and radiation characteristics. Furthermore, unlike with bandpass optical filters, users cannot choose particular wavelengths that pass through UV-blocking coatings (i.e., blocking UV-A radiation only). As a result, UV-A + UV-B treatments are often used as a comparison and discussion point on the effect of UV-A radiation. Although no reports of possible interactions between UV-A and UV-B radiation have been published, they should be addressed and investigated in the future.

1.3 The Impact of UV Radiation on Strawberry Fruit Flavonoids:

UV-blocking films (i.e. pure polyethylene) and light-emitting diodes are often used to control wavelength in CE manufacturing. Although both systems can alter wavelengths, their limitations and effective spectrum ranges are distinct. Earlier research, mostly employing UV-blocking films, looked at the effect of UV dose (combined UV-A and UV-B radiation) on strawberry fruit flavonoid levels. Strawberry fruits cultivated under UV-transparent screens have more anthocyanin and phenolic compounds than strawberry fruits produced under UV-blocking films. Furthermore, UV radiation has an effect on strawberry fruit firmness and color, with UV-ripened fruit being smaller, firmer, and darker than fruit produced beneath UV-blocking film. The effect of UV radiation on strawberry fruit quality and flavonoid content is explored in these previous research. However, both UV-A and UV-B radiation have been found to have an influence on the impact of UV radiation. Solar UV radiation and UV-blocking films cannot accomplish specific wavelength or radiation treatments within the UV wavelength range. Strawberry flavonoid buildup may have interaction effects within the UV range, although this is unclear.

LEDs, unlike UV-blocking materials, allow for more precise control of light characteristics such as wavelength(s), photoperiod modification, and a broad variety of intensities. Many recent research on a variety of greenhouse crops have shown the possibility of using visible spectrum LED illumination to manipulate plant development and regulate secondary metabolite profiles. In recent years, there has been continuous improvement in terms of wall-plug efficiency and UV-LED life-span. When researching UV radiation, UV-LEDs may be preferable than UV-blocking films. The bulk of strawberry UV-LED research, on the other hand, are for increased strawberry fruit production rather than pest and disease control. To our knowledge, just one research utilizing UV-LED on strawberry flavonoid levels has been published to far, showing that when the Seolhyang cultivar was irradiated with a combination of 254, 306, and 352-nm LED radiation, anthocyanin content rose. Insufficient data indicate that there has been a distinct lack of research in this area, and further research is needed to fully understand the effect of narrow UV-A and UV-B spectra on the accumulation of strawberry flavonoids and other secondary metabolites.

1.4 UV Radiation and Photobiological Safety:

UV light causes flavonoids and other secondary metabolites to accumulate. However, broad use is a long way off, owing to a restricted number of UV radiation sources and the photobiological risk it poses to people. In plant photobiology research, a variety of UV light sources are seldom utilized. UV gas-discharge lamps emit a crisp 255-nm spectrum, but they have a number of drawbacks, including poor radiation output and a small effective radiation area. These drawbacks restrict future research into the effects of UV radiation on plants. UV-LEDs on the market, unlike traditional UV radiation sources, provide a broad variety of wavelength options. The emitting UV wavelengths vary from 220 to 380 nm when aluminum nitride (AlN) is added to GaN diodes. Unlike previous UV devices with a lifetime of fewer than 100 hours, today's UV-LEDs emitting at 280–310 nm have a lifespan of at least 3,000 hours, with some reaching 10,000 hours. Despite the fact that UV-LEDs have poorer reliability and lifespan than visible-spectrum LEDs, they have emerged as a new radiation source for UV germicidal irradiation studies, such as water treatment and microbial inactivation.

2. LITERATURE REVIEW

Betts N et al. discussed Strawberry as a Functional Food in which they discussed how new study shows that strawberries may be classified as a functional food with a variety of health advantages, both preventative and curative. Strawberries, which are abundant in phytochemicals (ellagic acid, anthocyanins, quercetin, and catechin) as well as vitamins (ascorbic acid and folic acid), have been rated as one of the best sources of polyphenols and antioxidant capacity in the diet. It should be emphasized, however, that variations in strawberry cultivars, farming techniques, storage, and processing procedures may have a major impact on these bioactive factors: freezing vs dry heat has been linked to the best preservation of strawberry bioactives in many studies. Strawberry consumption has an inverse relationship with the incidence of hypertension or serum C-reactive protein, according to nutritional epidemiology; controlled feeding studies have identified strawberries' ability to reduce high-fat diet-induced postprandial oxidative stress and inflammation, as well as postprandial hyperglycemia and hyperlipidemia in subjects with cardiovascular risk factors[8].

Colquhoun T et al. discussed diverse chemical compositions, a seasonal influence, and effects on sensory perception of strawberry in which they discussed how Strawberry (Fragaria x ananassa) is prized for its bright red color, juicy texture, unique fragrance, and sweet fruity taste. Genetic and environmental variation are used to capture biochemically varied strawberry fruit for metabolite profiling and consumer rating in this research. Using a psychophysics method, researchers discover strawberry fruit characteristics that influence hedonics and sensory perception. Sugar concentrations, particular volatile chemicals, and fruit firmness all influence sweetness intensity, taste intensity, and texture like. Sweetness and strawberry flavor intensity are the most important factors in overall enjoyment, which are harmed by environmental forces that decrease sucrose and total volatile content. Although the volatile profiles of commercial strawberry cultivars are diverse and varied, a list of perceptually important chemicals from the broader mix is more well established. The most important factors to strawberry taste intensity are certain esters, terpenes, and furans. Only one volatile component, out of thirty-one, is shown to have a negative correlation with strawberry taste intensity. Individual volatile chemicals that have an increasing impact on perceived sweetness intensity of fruit, irrespective of sugar level, are identified via further investigation. These results open the door for consumers to have a say in the development of more appealing fruits and vegetables. This method also yields information on fruit metabolomics, taste chemistry, and a paradigm for improving the liking of natural and processed foods[9].

Guerreiro A et al. discussed Chemical and biological properties of strawberry in which they discussed how the strawberry tree, Arbutus unedo L., is widespread across the Mediterranean, including western, central, and southern Europe, north-eastern Africa (excluding Egypt and Libya), the Canary Islands, and western Asia. Despite their attractive look, strawberries are mostly used to make alcoholic beverages (wines, liqueurs, and brandies), jams, jellies, and marmalades, and are seldom consumed as fresh fruit. The chemical makeup of various components of the plant, as well as strawberry tree honey and strawberry tree brandy, will be discussed. The biological characteristics of A. unedo's various components, as well as strawberry tree honey, will be discussed[10].

3. DISCUSSION

An increasing amount of evidence indicates that eating a phytochemical-rich diet lowers the risk of chronic human illnesses including cancer, heart disease, and neurological disorders. Strawberry (Fragaria x ananassa Duch.) fruits are high in phytochemicals (plant chemicals), the majority of which are phenolic compounds. In vitro and in vivo research performed by our group and others have demonstrated that phenolic compounds have strong antioxidant, anticancer, anti-atherosclerotic, and anti-neurodegenerative effects. Large polymeric components (ellagitannins and gallotannins) as well as monomeric molecules make up strawberry phenolics (ellagic acid and ellagic acid glycosides, anthocyanins, flavonols, catechins and coumaroyl glycosides). Ellagitannins are hydrolyzable tannins found in pomegranates, red and black raspberries, blackberries, and certain almonds, among other commonly eaten foods. Anthocyanins are pigments that give berry fruits, red grapes (and therefore red wine), and many vegetables their appealing hues. The strawberry fruit contains flavonols (antioxidants found in onions, apples, and other berries) as well as catechins (antioxidants found in green tea). In this study, we provide a comparison of how light spectrum affects strawberry photobiology and secondary metabolism, as well as a collection of research examining the effect of light characteristics on strawberry fruit flavonoids.

4. CONCLUSION

Aspects of photobiology and flavonoid accumulation important to strawberry plant development are discussed here. Nearly a century of research has been dedicated to improving strawberry plant growth, development, metabolites, and crop condition. Artificial light spectra may be tailored to target the growth of flavonoid content in strawberry fruits using information from photobiology studies. More precisely, various wavelengths will evoke different reactions in terms of fruit development and quality. Optimized light recipes, when used in practice, decrease the amount of electricity used while improving crop yields and quality. Pre-harvest UV therapy that combines UV-A and UV-C wavelengths is an effective technique for promoting flavonoid production in strawberries; however, UV-C radiation alone has an influence on taste profile. UV-C radiation has shown promise in increasing secondary metabolites in post-harvest treatments. UV LEDs are expected to be employed more often to promote beneficial fruit metabolites, with just brief exposures (minutes per day) required to trigger a response. Blue LED light has been shown to increase flavonoid accumulation in greenhouse crops, however this has not been seen in strawberry plants. In strawberry fruit flavonoid accumulation, blue-light-mediated reactions are bandwidth-dependent rather than wavelength-dependent.

According to the research, for increasing flavonoid accumulation, a spectrum with board blue light spectrum or several peaks in the blue wavelength region addressing both phototropin and cryptochrome is ideal and suggested. Understanding the action spectrum (or spectral dose-response curve) of flavonoid biosynthesis in various tissues is critical for improving flavonoid production accuracy and antioxidant capacity in strawberry CE production, thus making these "super foods" even more exceptional. Continued research into this diversity in flavonoid response to light spectrum may offer vital information on light signaling apparatus in strawberry and potentially other fruit-producing species, such as COP1-mediated pathways.

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