OVERVIEW: THE ABIOTIC FACTORS 'STRESS AND LIGHTING' HAVE AN INFLUENCE ON THE BIOACTIVE COMPOUND FLAVONOID IN STRAWBERRY PLANT

Enceng Sobari [1,2])

[1]) Graduate Doctoral Student, Faculty of Agriculture, Universitas Padjadjaran; [2]) Department of Agriculture, State Polytechnic of Subang

[1]) Bandung Sumedang Highway KM.21, Hegarmanah, Jatinangor District, Sumedang Regency, West Java 45363, Indonesia.
[2]) Brigadier General Katamso Street No. 37 (Behind Subang General Hospital), Dangdeur, Subang District, Subang Regency, West Java 41211, Indonesia

[1,2]) ncesobari@gmail.com

ABSTRACT

The increasing demand for strawberries is driving advancements in technology that support strawberry production, which is expected to become far more effective and efficient. Strawberries are one of the plants whose fruits contain substances that are highly beneficial for human health. Abiotic factors such as stress and light often play a decisive role in the production of secondary metabolites like flavonoids, which are important compounds in strawberry plants. This article aims to provide information related to the impact of abiotic factors 'stress and lighting" that can affect these compounds. The studies used to support the information in this article include reputable scientific journals published and indexed in ScienceDirect, Springer, articles indexed in Scopus, and relevant literature on GoogleScholar. All literature providing insights on the importance of biological activity and plant physiology, secondary metabolites, flavonoid biosynthesis, and the phytochemistry of plants. The influence of abiotic stress and lighting on plants can affect various aspects of plant growth, which will eventually impact the response in terms of quality produced and also the compounds contained within the plant itself. Based on the study of abiotic factors such as stress and lighting, these have a crucial role in the biosynthesis of flavonoid compounds that affect production in strawberry plants.

Keywords: Abiotic stress, Bioactive, Flavonoid, Secondary metabolites, Lighting, Strawberry.

1. INRODUCTION

Strawberries are among the most popular fruits worldwide, not only consumed fresh but also used in various types of processed food products such as snacks and beverages due to their excellent nutritional content. Strawberries contain vitamin C (39-86 mg per 100 g of fruit) and vitamin A (60 IU per 100g), as well as minerals, pectin, potassium, calcium, and phosphorus. (Singh et al., 2018). Additionally, strawberries are one of the plants whose fruits contain substances that are highly

beneficial for human health. These include antioxidant agents such as anthocyanins, which are flavonoid compounds, vitamins, sugars, and other phenolic compounds (Martinsson et al., 2006). Flavonoids are a class of secondary metabolites produced by plants, including phenolic compounds that belong to the flavonoid group. These can produce natural antioxidants (Saija et al., 1995). Flavonoids, as part of the metabolites, play a significant role in plant growth and stress response (Li et al., 2021). These metabolites function as compounds used in plant growth and development, divided into two types: primary metabolites, which are produced in limited quantities and used by plants for growth, and secondary metabolites, which serve as a defense mechanism for plants against both biotic and abiotic stress (Angin et al., 2019). The compounds found in strawberries, such as antioxidants, offer significant health benefits.

Secondary metabolites are compounds possessed by plants that function in the processes of growth and development. They are small molecular organic compounds that serve as bioactive substances, whose formation depends on the plant's stimulation by abiotic factors such as environmental stress (T. Wang et al., 2019). Secondary metabolites are produced by plants to enhance their competitiveness in their environment, offering various benefits to the plant itself as well as other living organisms, and acting as antimicrobials. More than 50,000 types of plants have been identified as producers of secondary metabolites, with many modern medicines beginning to rely on these plant-derived compounds (Teoh, 2016). There are over 4,000 flavonoids widely distributed across plants and prokaryotes, which belong to a large group of secondary metabolites that can be categorized as phenolic compounds (Woo et al., 2002; Middleton, 1998). Research findings suggest that flavonoids can perform various functions as antioxidants and regulators of development in photoprotection (Agati & Tattini, 2010).

Flavonoids are known to increase tolerance to various abiotic stresses, serving as a defense mechanism for plants, and as a basis for allelopathic interactions with other plant species. Species across all orders in the plant kingdom, from liverworts to angiosperms, invest a significant amount of metabolic energy in producing these compounds (Kevin S. Gould & Lister, 2005). The environmental conditions for growing strawberries are not always ideal, abiotic factors present challenges that must be navigated during the growth and development of strawberry plants. Secondary metabolite compounds such as flavonoids can serve as defense mechanisms and signals for strawberry plants in conditions of both biotic and abiotic stress. (Goyal et al., 2012). Therefore, this study is expected to provide deeper insights into abiotic factors such as stress and lighting that can affect these compounds in the physiological aspects of strawberry plants. It aims to serve as an important piece of information in the development of strawberry plant research.

2. RESEARCH METODOLOGY

The materials used in compiling the database for the creation of this article were obtained from primary scientific article sources such as ScienceDirect, Springer, articles indexed in Scopus, and relevant literature on GoogleScholar. The method used in creating this review article involves utilizing a literature study to search for information related to the necessary aspects as follows:

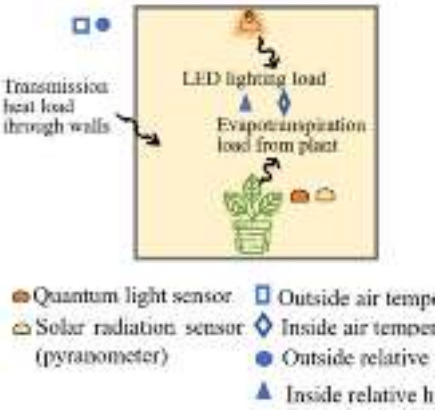
i. Related to the topic of metabolites: All literature providing insights on the importance of biological activity and plant physiology, secondary metabolites, flavonoid biosynthesis, and the phytochemistry of plants.
ii. Abiotic factors in plants: Literature searches focusing on topics related to abiotic stress such as drought stress, lighting, and other aspects related to enhancing flavonoid compounds, considered beneficial regardless of the journal impact factor, popularity, or its source.

3. RESULTS AND DISCUSSION

A. The Impact of Light on the Quality and Biosynthesis of Flavonoids in Strawberries

Strawberry plants often face many issues during the cultivation process, especially in the field, such as low productivity and the quality of the fruit produced, necessitating a good system to anticipate these problems. Adverse and extreme weather conditions, which can result in strawberry production losses, the concept of controlled environment agriculture accompanied by technology application is a good alternative for the agricultural sector (Hernández-Martínez et al., 2023;Wai et al., 2023). Strawberries face numerous challenges during the cultivation process, resulting in yield losses of about 30-70%. Proper management is necessary to mitigate these issues (Mahmud et al., 2019). Cultivating strawberries in controlled indoor environments has become the most modern alternative for producing high-quality strawberry fruits. The majority of indoor strawberry cultivation uses greenhouse technology, widely adopted in response to unpredictable weather conditions that can affect the yield and quality of cultivated strawberries, such as a decrease in the sweetness and texture of the strawberry fruit (Gavilán et al., 2015;Chaichana et al., 2020). A decline in the quality of strawberry fruits can also lead to consumers deciding against purchasing them (Zhou et al., 2022).

Lighting is a crucial factor in the physiological aspect of plants that can influence the growth and development of strawberry plants due to its connection with the photosynthesis process, which impacts the formation of strawberry fruits. Lighting issues are particularly significant for the leaves and can greatly affect the quality and characteristics of the produce (Pydipati et al., 2006). Supplemental lighting has been widely successful in enhancing vegetable production in greenhouses, providing significant differences in growth and yield. The rate of photosynthesis in leaves of plants exposed to additional LED lighting is much higher, as indicated by increases in leaf dry weight, leaf area, and specific leaf dry weight. These improvements significantly impact the average fruit weight, fruit count, and overall yield (Hidaka et al., 2013).



(Chaichana et al., 2020) (Wai et al., 2023)

Figure 1. Addition of LED lighting for the growth of strawberry plants

In addition to nutrients and water, another factor such as light becomes an important factor that affects the quality of fruit from strawberry plants cultivated in greenhouses. Figure 1 shows the use of LED lighting on strawberry plants. Supplemental lighting is recommended for producing high quality strawberry fruits (Xu et al., 2023). Exposure to light can trigger a series of physiological processes in strawberries and affect their commercial value. Light is one of the most important environmental factors influencing the biosynthesis of anthocyanins in plants and can enhance the red coloring of strawberry fruits after harvest. This is combined with a doubling of the anthocyanin content, which is a compound derived from flavonoids (Miao et al., 2016; L. Wang et al., 2022).

B. The Impact of Drought Stress on Plant Physiological Mechanisms

One-third of the Earth's surface is classified as arid or semi-arid, while areas that are humid, where the world's food is produced, experience periods of severe drought. Consequently, the impact of drought has become a primary focus on the influence of plant productivity worldwide (Díaz et al., 2005). Drought stress is a factor that significantly affects agricultural productivity in developing countries, reaching 50-70%. Among abiotic stresses, it is considered the most detrimental, thereby hindering maximum agricultural productivity worldwide (Verma & Deepti, 2016). The harmful impact of drought conditions can have detrimental effects on growth, chlorophyll content, cell integrity, photosynthesis, leaf water potential, and water deficiency (Hussain et al., 2020). Drought stress causes a significant inhibition of growth and the rate of photosynthesis, as well as inducing a number of major changes in the morphological, physiological, and biochemical responses when plants are exposed to drought stress. These changes can enhance the plant's ability to survive and grow during periods of drought (Yin et al., 2005). Abiotic stress can result from atmospheric pollutants, the presence of heavy metals, low temperatures, or soil acidity, which can also affect the productivity and quality of plants (Figure 2).

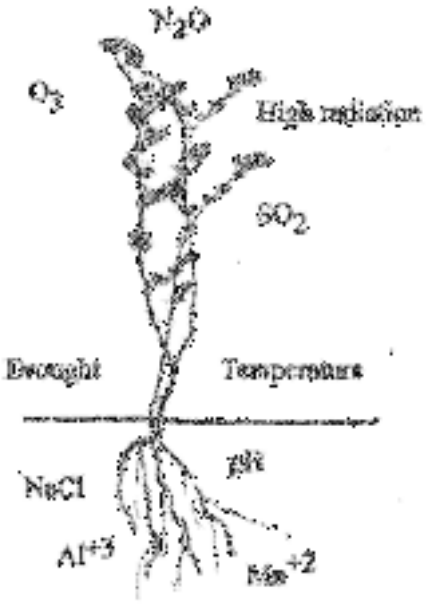


Figure 2. The impact of abiotic stress on plants that can affect growth and plant productivity (Díaz et al., 2005)

Under stress conditions, plants are capable of initiating defense responses such as physiological, biochemical, and molecular mechanisms under drought to enhance their survival ability in conditions of water scarcity during growth and development periods (Amoah et al., 2019). Drought in plants elicits a complex response, ranging from wilting processes, reduced photosynthesis rates, causing stomatal closure, and increased leaf temperature at physiological, metabolic, and developmental response levels, dependent on the degree of drought stress (Guimarães-Dias et al., 2012). Once stress occurs, complex biochemical and physiological mechanisms are activated to protect crucial processes such as cell respiration, photosynthetic activity, and nutrient transport. Additionally, stress tolerance responses are induced to preserve organelles and tissue structures, such as the meristem (Kramer, 1983; Kramer & Boyer, 1995).

C. The Role of Secondary Metabolites in Plants

Bioactive compounds are substances found in nature and are part of the food chain. Possessing the ability to interact with one or more living tissue compounds, demonstrating effects on human health (Biesalski et al., 2009). Possessing an unlimited combination of functional groups, including hydroxyl, alcohol, aldehyde, alkyl, benzyl rings, and steroids, each can produce a diversity of plant compounds, with unique characteristics (Beckles & Roessner, 2012). More than 8,000 different phenolics have been identified within the plant kingdom, representing one of the most abundant and widespread classes of plant secondary metabolites (Cheynier et al., 2013). Through complex metabolic pathways, these are referred to as secondary metabolites, whose compounds have the capability for synthesis used by plants for various functions, especially in responding to biotic and abiotic stress encountered (Michel, 2011). Various research findings indicate that these metabolites fall into three classes: polyphenols, alkaloids, and terpenoids, demonstrating the bioactivity of these molecules in antitumor, antiviral, antimicrobial, antioxidant, and anti-inflammatory activities. Therefore, plants containing these metabolites can be

utilized in the fields of therapy, pharmacology, cosmetology, and food (Rispail et al., 2005; Sompila et al., 2021).

D. The Role of Flavonoids in Plants

Flavonoid content is abundantly stored within plant bodies, aiding in the response to growth and development throughout their lifespan. Flavonoids are the most plentiful secondary metabolite compounds in plants (Han et al., 2023). These compounds protect against UV rays, pests, and diseases, and also play a crucial role in the color, taste quality, and nutritional value of the fruits produced (Gouot et al., 2019). Flavonoids primarily consist of five subclasses: anthocyanins, flavanones, flavanonols, flavonols, and flavanols (Durazzo et al., 2019). The accumulation of flavonoids can be a key defense for plants against various environmental stresses, as flavonoids belong to the polyphenol compounds with antioxidant activity, comprising flavones, flavanones, flavonols, isoflavones, and anthocyanins (P. Wang et al., 2018;Sun et al., 2020). Flavonoids, as bioactive polyphenolic compounds in plants with structures like Kaempferol-3-O-rutinoside, quercetin-3-O-glucoside, and kaempferol-3-O-glucoside, can play a significant role in the prevention and mitigation of the impact of several diseases in humans. These flavonoid glycosides are responsible for antioxidant activities and form the scientific basis for their use in traditional medicine. (Badmus et al., 2016). The flavonoid fraction from each plant possesses an effective hepatoprotective effect as flavones, which clinically reduces symptoms in liver damage (Gupta et al., 2015). The flavonoid content has a close relationship between plant parts and the phenological development of the plant, which can affect the content of compounds such as rutin, amentoflavone, hyperoside, isoquercitrin, quercitrin, quercetin, avicularin, (+)-catechin, and (–)-epicatechin (Çirak et al., 2014).

E. Flavonoid Biosynthesis Induced by Stress

The role of flavonoids can offer new insights into enhancing plant production potential by utilizing plant varieties rich in flavonoids as crops tolerant to biotic and abiotic stress (Nakabayashi et al., 2014). High flavonoid content is found in the early development stages of young fruit tissue, evidenced by high gene expression related to the biosynthesis and accumulation of flavonoids (Moriguchi et al., 2001). The enhancement of anthocyanin biosynthesis enzymes from the pathway involved in phenylpropanoid metabolism, which converts phenylalanine and related substrates through phenylalanine ammonia-lyase (PAL) into flavonoids including anthocyanins. The proteins whose synthesis is concurrently increased include phenylalanine ammonia-lyase (PAL), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol 4-reductase (DFR), and UDP-glucose:flavonoid-3-O-glucosyltransferase. PAL has been identified as an enzyme positively associated with the ripening of strawberry fruits (Song et al., 2015).

4. CONCLUSIONS

Abiotic factors such as stress and light play a crucial role in the biosynthesis of flavonoid compounds in strawberry plants. These factors influence the production of flavonoids and can optimize growth. The production of strawberry plants containing bioactive compounds is beneficial for human health.

REFERENCES

Agati, G., & Tattini, M. (2010). Multiple functional roles of flavonoids in photoprotection. *New Phytologist*, *186*(4), 786–793. https://doi.org/10.1111/j.1469-8137.2010.03269.x

Amoah, J. N., Ko, C. S., Yoon, J. S., & Weon, S. Y. (2019). Effect of drought acclimation on oxidative stress and transcript expression in wheat (Triticum aestivum L.). *Journal of Plant Interactions*, *14*(1), 492–505. https://doi.org/10.1080/17429145.2019.1662098

Angin, M., Volant, S., Passaes, C., Lecuroux, C., Monceaux, V., Dillies, M. A., Valle-Casuso, J. C., Pancino, G., Vaslin, B., Le Grand, R., Weiss, L., Goujard, C., Meyer, L., Boufassa, F., Müller-Trutwin, M., Lambotte, O., & Sáez-Cirión, A. (2019). Metabolic plasticity of HIV-specific CD8+ T cells is associated with enhanced antiviral potential and natural control of HIV-1 infection. *Nature Metabolism*, *1*(7), 704–716. https://doi.org/10.1038/s42255-019-0081-4

Badmus, J. A., Ekpo, O. E., Rautenbach, F., Marnewick, J. L., Hussein, A. A., & Hiss, D. C. (2016). Isolation and antioxidant activity of flavonoids from Holarrhena floribunda (G.don) leaves. *Acta Biochimica Polonica*, *63*(2), 353–358. https://doi.org/10.18388/abp.2015_1178

Beckles, D. M., & Roessner, U. (2012). Plant metabolomics: Applications and opportunities for agricultural biotechnology. In *Plant Biotechnology and Agriculture: Prospects for the 21st Century* (pp. 67–81). https://doi.org/10.1016/B978-0-12-381466-1.00005-5

Biesalski, H. K., Dragsted, L. O., Elmadfa, I., Grossklaus, R., Müller, M., Schrenk, D., Walter, P., & Weber, P. (2009). Bioactive compounds: Definition and assessment of activity. *Nutrition*, *25*(11–12), 1202–1205. https://doi.org/10.1016/j.nut.2009.04.023

Chaichana, C., Chantrasri, P., Wongsila, S., Wicharuck, S., & Fongsamootr, T. (2020). Heat load due to LED lighting of in-door strawberry plantation. *Energy Reports*, *6*, 368–373. https://doi.org/10.1016/j.egyr.2019.11.089

Cheynier, V., Comte, G., Davies, K. M., Lattanzio, V., & Martens, S. (2013). Plant phenolics: Recent advances on their biosynthesis, genetics, andecophysiology. *Plant Physiology and Biochemistry*, *72*, 1–20. https://doi.org/10.1016/j.plaphy.2013.05.009

Çirak, C., Radusiene, J., Ivanauskas, L., Jakstas, V., & Çamaş, N. (2014). Phenological changes in the chemical content of wild and greenhouse-grown Hypericum pruinatum: Flavonoids. *Turkish Journal of Agriculture and Forestry*, *38*(3), 362–370. https://doi.org/10.3906/tar-1308-17

Díaz, P., Monza, J., & Márquez, A. (2005). Drought and Saline Stress. In A.J. Márquez (Ed.), *Lotus japonicus Handbook* (Issue 1.3, pp. 39–40). Springer Netherlands. https://doi.org/https://doi.org/10.1007/1-4020-3735-X_3

Durazzo, A., Lucarini, M., Souto, E. B., Cicala, C., Caiazzo, E., Izzo, A. A., Novellino, E., & Santini, A. (2019). Polyphenols: A concise overview on the chemistry, occurrence, and human health. *Phytotherapy Research*, *33*(9), 2221–2243. https://doi.org/10.1002/ptr.6419

Gavilán, P., Ruiz, N., & Lozano, D. (2015). Daily forecasting of reference and

strawberry crop evapotranspiration in greenhouses in a Mediterranean climate based on solar radiation estimates. *Agricultural Water Management*, *159*, 307–317. https://doi.org/10.1016/j.agwat.2015.06.012

Gouot, J. C., Smith, J. P., Holzapfel, B. P., & Barril, C. (2019). Grape berry flavonoid responses to high bunch temperatures post véraison: Effect of intensity and duration of exposure. *Molecules*, *24*(23), 2–24. https://doi.org/10.3390/molecules24234341

Goyal, S., Lambert, C., S. Cluzet, J. M. M., & Ramawat, K. G. (2012). Plant defence: Biological control. In *Plant Defence: Biological Control* (Issue June 2014). https://doi.org/10.1007/978-94-007-1933-0

Guimarães-Dias, F., Neves-Borges, A. C., Viana, A. A. B., Mesquita, R. O., Romano, E., de Fátima Grossi-de-Sá, M., Nepomuceno, A. L., Loureiro, M. E., & Alves-Ferreira, M. (2012). Expression analysis in response to drought stress in soybean: Shedding light on the regulation of metabolic pathway genes. *Genetics and Molecular Biology*, *35*(SUPPL.1), 222–232. https://doi.org/10.1590/S1415-47572012000200004

Gupta, A., Sheth, N. R., Pandey, S., Yadav, J. S., & Joshi, S. V. (2015). Screening of flavonoids rich fractions of three Indian medicinal plants used for the management of liver diseases. *Revista Brasileira de Farmacognosia*, *25*(5), 485–490. https://doi.org/10.1016/j.bjp.2015.06.010

Han, S. A., Xie, H., Wang, M., Zhang, J. G., Xu, Y. H., Zhu, X. H., Caikasimu, A., Zhou, X. W., Mai, S. Le, Pan, M. Q., & Zhang, W. (2023). Transcriptome and metabolome reveal the effects of three canopy types on the flavonoids and phenolic acids in 'Merlot' (Vitis vinifera L.) berry pericarp. *Food Research International*, *163*(August 2022), 112196. https://doi.org/10.1016/j.foodres.2022.112196

Hernández-Martínez, N. R., Blanchard, C., Wells, D., & Salazar-Gutiérrez, M. R. (2023). Current state and future perspectives of commercial strawberry production: A review. *Scientia Horticulturae*, *312*(October 2022). https://doi.org/10.1016/j.scienta.2023.111893

Hidaka, K., Dan, K., Imamura, H., Miyoshi, Y., Takayama, T., Sameshima, K., Okimura, M., & Kitano, M. (2013). Investigation of supplemental lighting with different light source for high yield of strawberry. In *IFAC Proceedings Volumes (IFAC-PapersOnline)* (Vol. 1, Issue PART 1). IFAC. https://doi.org/10.3182/20130327-3-jp-3017.00028

Hussain, T., Koyro, H. W., Zhang, W., Liu, X., Gul, B., & Liu, X. (2020). Low Salinity Improves Photosynthetic Performance in Panicum antidotale Under Drought Stress. *Frontiers in Plant Science*, *11*(May), 1–13. https://doi.org/10.3389/fpls.2020.00481

Kevin S. Gould, & Lister, C. (2005). Chemistry, Biochemistry and Applications. In Ø. M. Andersen & K. R. Markham (Eds.), *Flavonoids : chemistry, biochemistry, and applications* (pp. 397–425). CRC Press. http://www.crcpress.com

Kramer, P. (1983). *Water Relations of Plants*. Academic Press, Inc. http://www.sciencedirect.com/science/book/9780124250406

Kramer, P., & Boyer, J. (1995). *Water Relations of Plants and Soils* (1st ed.). Academic Press.

Li, B., Fan, R., Sun, G., Sun, T., Fan, Y., Bai, S., Guo, S., Huang, S., Liu, J., Zhang, H., Wang, P., Zhu, X., & Song, C. peng. (2021). Flavonoids improve drought tolerance of maize seedlings by regulating the homeostasis of reactive oxygen species. *Plant and Soil*, *461*(1–2), 389–405. https://doi.org/10.1007/s11104-020-04814-8

Mahmud, S., Zaman, Q. U., Esau, T. J., Price, G. W., & Prithiviraj, B. (2019). Development of an artificial cloud lighting condition system using machine vision for strawberry powdery mildew disease detection. *Computers and Electronics in Agriculture*, *158*(December 2018), 219–225. https://doi.org/10.1016/j.compag.2019.02.007

Martinsson, M., Kwast, A., Cieslinski, G., & Treder, W. (2006). Impact of Production Systems and Fertilizer Application on Yield and Quality of Strawberries. *Acta Horticulturae*, *708*, 59–64. https://doi.org/10.17660/ActaHortic.2006.708.4

Miao, L., Zhang, Y., Yang, X., Xiao, J., Zhang, H., Zhang, Z., Wang, Y., & Jiang, G. (2016). Colored light-quality selective plastic films affect anthocyanin content, enzyme activities, and the expression of flavonoid genes in strawberry (Fragaria × ananassa) fruit. *Food Chemistry*, *207*, 93–100. https://doi.org/10.1016/j.foodchem.2016.02.077

Michel, T. (2011). *Nouvelles méthodologies d'extraction, de fractionnement et d'identification : application aux molécules bioactives de l'argousier (Hippophae rhamnoides). Thése* [Universit´e d'Orl´eans]. https://theses.hal.science/tel-00677211

Middleton, E. (1998). Effect of plant flavonoids on immune and inflammatory cell function. *Advances in Experimental Medicine and Biology*, *439*, 175–182. https://doi.org/10.1007/978-1-4615-5335-9_13

Moriguchi, T., Kita, M., Tomono, Y., Endo-Inagaki, T., & Omura, M. (2001). Gene expression in flavonoid biosynthesis: Correlation with flavonoid accumulation in developing citrus fruit. *Physiologia Plantarum*, *111*(1), 66–74. https://doi.org/10.1034/j.1399-3054.2001.1110109.x

Nakabayashi, R., Yonekura-Sakakibara, K., Urano, K., Suzuki, M., Yamada, Y., Nishizawa, T., Matsuda, F., Kojima, M., Sakakibara, H., Shinozaki, K., Michael, A. J., Tohge, T., Yamazaki, M., & Saito, K. (2014). Enhancement of oxidative and drought tolerance in Arabidopsis by overaccumulation of antioxidant flavonoids. *Plant Journal*, *77*(3), 367–379. https://doi.org/10.1111/tpj.12388

Pydipati, R., Burks, T. F., & Lee, W. S. (2006). Identification of citrus disease using color texture features and discriminant analysis. *Computers and Electronics in Agriculture*, *52*(1–2), 49–59. https://doi.org/10.1016/j.compag.2006.01.004

Rispail, N., Nash, R., & Webb, K. J. (2005). Lotus japonicus Handbook. In A. J. Márquez (Ed.), *Lotus japonicus Handbook*. Springer Netherlands. https://doi.org/10.1007/1-4020-3735-X

Saija, A., Scalese, M., Lanza, M., Marzullo, D., Bonina, F., & Castelli, F. (1995). Flavonoids as antioxidant agents: Importance of their interaction with biomembranes. *Free Radical Biology and Medicine*, *19*(4), 481–486. https://doi.org/10.1016/0891-5849(94)00240-K

Singh, G., Kachwaya, D. S., Kumar, R., Vikas, G., & Singh, L. (2018). Genetic variability and association analysis in strawberry (Fragaria x ananassa Duch).

Electronic Journal of Plant Breeding, *9*(1), 169–182. https://doi.org/10.5958/0975-928X.2018.00021.2

Sompila, A. W. G. T., Mabika, A. B. M., Pambou-Tobi, N. P. G., Gouollaly, T., Moussounga, J. E., N'simba, G. L. L. B., Nguie, R., & Matos, L. (2021). Evaluation of Some Secondary Metabolites and Determination of the Antioxidant Potential of Different Extracts from the Plant of <i>Pteridium aquilinum</i> *American Journal of Analytical Chemistry*, *12*(12), 506–519. https://doi.org/10.4236/ajac.2021.1212032

Song, J., Du, L., Li, L., Kalt, W., Palmer, L. C., Fillmore, S., Zhang, Y., Zhang, Z. Q., & Li, X. H. (2015). Quantitative changes in proteins responsible for flavonoid and anthocyanin biosynthesis in strawberry fruit at different ripening stages: A targeted quantitative proteomic investigation employing multiple reaction monitoring. *Journal of Proteomics*, *122*, 1–10. https://doi.org/10.1016/j.jprot.2015.03.017

Sun, J., Qiu, C., Ding, Y., Wang, Y., Sun, L., Sun, L., Fan, K., Gai, Z., Dong, G., Wang, J., Li, X., Song, L., & Ding, Z. (2020). Fulvic acid ameliorates drought stress-induced damage in tea plants by regulating the ascorbate metabolism and flavonoids biosynthesis. *BMC Genomics*, *21*(1), 1–13. https://doi.org/10.1186/s12864-020-06815-4

Teoh, E. S. (2016). Secondary Metabolites of Plants. In *Medicinal Orchids of Asia: Vol. Chapter 5* (pp. 1–752). https://doi.org/10.1007/978-3-319-24274-3

Verma, A., & Deepti, S. (2016). Abiotic Stress and Crop Improvement: Current Scenario. *Advances in Plants & Agriculture Research*, *4*(4), 345–346. https://doi.org/10.15406/apar.2016.04.00149

Wai, T. S., Chaichana, C., & Maruyama, N. (2023). Energy cost analysis of growing strawberries in a controlled environment chamber. *Energy Reports*, *9*, 677–687. https://doi.org/10.1016/j.egyr.2022.11.045

Wang, L., Luo, Z., Yang, M., Liang, Z., Qi, M., Dong, Y., Xu, Y., Lin, X., & Li, L. (2022). The action of RED light: Specific elevation of pelargonidin-based anthocyanin through ABA-related pathway in strawberry. *Postharvest Biology and Technology*, *186*(January), 1–8. https://doi.org/10.1016/j.postharvbio.2022.111835

Wang, P., Zhang, L., Jiang, X., Dai, X., Xu, L., Li, T., Xing, D., Li, Y., Li, M., Gao, L., & Xia, T. (2018). Evolutionary and functional characterization of leucoanthocyanidin reductases from Camellia sinensis. *Planta*, *247*(1), 139–154. https://doi.org/10.1007/s00425-017-2771-z

Wang, T., Zou, Q., Guo, Q., Yang, F., Wu, L., & Zhang, W. (2019). Widely Targeted Metabolomics Analysis Reveals the Effect of Flooding Stress on the Synthesis of Flavonoids in Chrysanthemum morifolium. *Molecules*, *24*(20), 2–11. https://doi.org/10.3390/molecules24203695

Woo, H. H., Kuleck, G., Hirsch, A. M., & Hawes, M. C. (2002). Flavonoids: Signal molecules in plant development. *Advances in Experimental Medicine and Biology*, *505*, 51–60. https://doi.org/10.1007/978-1-4757-5235-9_5

Xu, X., Zhang, Y., Li, Y., Liao, S., Sun, Y., & Liu, F. (2023). Supplemental light and silicon improved strawberry fruit size and sugars concentration under both full and deficit irrigation. *Scientia Horticulturae*, *313*(December 2022), 111912.

https://doi.org/10.1016/j.scienta.2023.111912

Yin, C., Peng, Y., Zang, R., Zhu, Y., & Li, C. (2005). Adaptive responses of Populus kangdingensis to drought stress. *Physiologia Plantarum*, *123*(4), 445–451. https://doi.org/10.1111/j.1399-3054.2005.00477.x

Zhou, X., Ampatzidis, Y., Lee, W. S., Zhou, C., Agehara, S., & Schueller, J. K. (2022). Deep learning-based postharvest strawberry bruise detection under UV and incandescent light. *Computers and Electronics in Agriculture*, *202*(July), 107389. https://doi.org/10.1016/j.compag.2022.107389