GROWTH, ANTIOXIDANT ACTIVITY AND VOLATILE COMPOUNDS OF LEMON BASIL (*Ocimum citriodorum* Vis.) AFFECTED BY LED IRRADIANCE, NUTRIENT CONCENTRATION AND POSTHARVEST STORAGE

By

ZURAFNI BINTI MAT DAUD

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair : Associate Professor Yahya Awang, PhD
Faculty : Agriculture

In this study, the effects of irradiance levels of LEDs of red and blue spectra, EC of nutrient solution, and nitrogen concentration on growth performance, yield productions, phytochemical contents (antioxidant activity), and volatile compounds of lemon basil (*Ocimum citriodorum* Vis.) were investigated. A light-emitting diode (LEDs) has tremendous potential as a sole-source lighting system for crop production in a controlled environment facility. Their small size, long operating lifetime, durability, wavelength specificity, and relatively cool emitting surfaces make these solid-state light sources ideal for use in the plant lighting system. The objective of this study was to examine the effects of varying irradiance levels of LEDs with red and blue spectra (4 to 1 ratio) on the growth performance, yield productions, and phytochemical contents (antioxidant activity) of lemon basil (*Ocimum citriodorum* Vis.) in a controlled environment facility.

The effect of varying irradiance levels of LEDs of red and blue spectra on plant growth can be seen on 12 days after planting and beyond. Similar trends of responses were also seen in the plant canopy, leaf number, and leaf area. Differences in all parameters measured were significant as the plant growth advanced. The fresh weight of leaves, stem, and roots were markedly affected by the treatments. Moreover, lemon basil cultivated at irradiance levels of LEDs with red and blue spectra at 160 µmol m^{-2} s^{-1} also contributed to more significant quality attributes such as chlorophyll *a*, total chlorophyll, carotenoid contents, total flavonoid contents, and total phenolic contents as well as an individual phenolic compound such as rosmarinic acid and gentisic acid, but lower in nitrate content as compared with other irradiance levels. Data generated from this study revealed that LEDs of red and blue spectra at irradiance level of 160 µmol m^{-2} s-

^{1} could be used effectively as an artificial light source for the lemon basil production under controlled environmental conditions.

In the subsequent study, the effects of different irradiance levels of LEDs of red and blue spectra and electrical conductivity of the nutrient solution and nitrogen concentrations on the growth performances, yield productions and phytochemical contents (antioxidant activities) and volatile compounds were determined. The results indicated that the high irradiance levels of LEDs of red and blue spectra at 160 μmol m^{-2} s^{-1} and moderate electrical conductivity of nutrient solution at 2.6 mS cm^{-1} and nitrogen concentrations at mg L^{-1} contributed to better growth performance (plat height, canopy diameter, and the number of leaves), higher yield production and quality attributes as well as carotenoid contents, total flavonoid, and total phenolic contents as well as caftaric acid concentration.

The postharvest quality of lemon basil (*Ocimum citriodorum* Vis.) stored under different storage temperature at different storage period that cultivated under different irradiance levels of LEDs of red and blue spectra was studied. The results demonstrated that irradiance levels of LEDs, storage temperature, and storage period affected the total flavonoid contents, total phenolic contents, and antioxidant activity of lemon basil. Increasing temperature and irradiance levels of LEDs increased total flavonoid and total phenolic contents, and antioxidant activity of lemon basil. Storage temperature at 5˚C was better in retaining total flavonoid contents and antioxidant activity, while storage temperature at 15˚C was better in the retention of phenolic compounds concentration of caftaric and rosmarinic acid.

Overall, the present study's findings have improved our understanding of the effects of irradiance levels of LEDs of the red and blue spectra, the electrical conductivity of the nutrient solution, and nitrogen concentrations and their interaction on lemon basil plants. Besides, this is beneficial for optimizing irradiance levels and electrical conductivity of the nutrient solution and nitrogen concentrations to enhance crop production and quality. In addition, the storage temperature also crucial for better postharvest quality attributes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERTUMBUHAN, AKTIVITI ANTIOKSIDA, DAN SEBATIAN MERUAP DARI SELASIH LEMON (*Ocimum citriodorum* Vis.) DIPENGARUHI OLEH KEAMATAN CAHAYA DARIPADA LED, KEPEKATAN NUTRISI BAJA, DAN PENYIMPANAN LEPAS TUAI

Oleh

ZURAFNI BINTI MAT DAUD

Ogos 2020

Pengerusi : Professor Madya Yahya Awang, PhD
Fakulti : Pertanian

Dalam kajian ini, kesan tahap keamatan cahaya merah dan biru daripada lampu LED, kepekatan nutrisi baja dan kepekatan nitrogen dalam larutan baja terhadap pertumbuhan pokok, pengeluaran hasil, kandungan fitokimia (aktiviti antioksida) dan sebatian meruap dari selasih lemon (*Ocimum citriodorum* Vis.) telah dijalankan. Pengcahayaan buatan daripada diode pemancar cahaya (LED) mempunyai potensi besar untuk digunakan sebagai sumber tunggal bagi menggantikan cahaya matahari untuk pengeluaran tanaman di dalam keadaan persekitaran yang tertutup. Saiznya yang kecil, daya ketahanan yang tinggi, jangka hayat yang panjang, pengkhususan gelombang, warna cahaya dan permukaan pemancar yang sejuk, menjadikan sumber cahaya buatan ini sesuai digunakan untuk sistem penanaman tumbuhan dalam keadaan yang tertutup. Objektif kajian ini adalah untuk mengkaji kesan-kesan tahap keamatan cahaya merah dan biru yang pelbagai dari lampu LED dengan nisbah 4:1 pada prestasi pertumbuhan pokok, pengeluaran hasil, kandungan fitokimia (aktiviti antioksida) dari selasih lemon (*Ocimum citriodorum* Vis.) di dalam ruang pertumbuhan tertutup.

Kesan kepelbagaian keamatan cahaya pada pertumbuhan pokok selasih lemon dapat dilihat pada hari ke-12 dan ke atas selepas penanaman. Pola yang sama dapat dilihat pada lebar kanopi, bilangan daun dan keluasan daun. Perbezaan pada semua parameter yang diukur adalah ketara apabila pertumbuhan pokok semakin meningkat. Berat segar daun, batang dan akar sangat ketara dipengaruhi oleh keamatan cahaya merah dan biru. Di samping itu, selasih lemon yang ditanam di bawah keamatan cahaya merah dan biru LED pada tahap 160 µmol $m^{-2}s^{-1}$ juga menyumbang kepada sifat-sifat kualiti tanaman yang lebih tinggi seperti kandungan klorofil a, jumlah kandungan klorofil, kandungan

karotenoid, jumlah kandungan flavonoid dan jumlah kandungan fenolik serta sebatian fenolik seperti asid rosmarinic dan asid gentisic, tetapi mempunyai kandungan nitrat yang rendah berbanding tahap keamatan cahaya yang lain. Data yang diperolehi daripada kajian ini mendapati bahawa keamatan cahaya merah dan biru daripada lampu LED pada tahap 160 μmol $m^{-2}s^{-1}$ boleh digunakan sebagai sumber cahaya bagi penanaman selasih lemon didalam persekitaran yang tertutup dan terkawal.

Dalam kajian yang seterusnya, kesan-kesan keamatan cahaya merah dan biru daripada lampu LED, kepekatan nutrisi baja dan kepekatan nitrogen dalam larutan baja terhadap pertumbuhan pokok, pengeluaran hasil, kandungan fitokimia (aktiviti antioksida) dan sebatian yang meruap telah dijalankan. Hasil kajian menunjukkan bahawa keamatan cahaya merah dan biru yang tinggi pada tahap 160 μmol m^{-2} s^{-1} dan kepekatan larutan baja dan yang sederhana pada tahap 2.6 mS cm^{-1} dan kepekatan nitrogen pada tahap 2.6 mmol L^{-1} menyumbang kepada pertumbuhan pokok yang lebih baik (ketinggian pokok, lebar kanopi dan bilangan daun), pangeluaran hasil yang tinggi dan juga kandungan kualiti yang bagus seperti kandungan karotenoid, jumlah kandungan flavonoid dan jumlah kandungan fenolik serta kepekatan asid caftaric.

Kualiti lepastuai selasih lemon (Ocimum citriodorum Vis.) yang ditanam d ibawah keamatan cahaya merah dan biru LED yang berbeza dan disimpan pada suhu dan tempoh penyimpanan yang berbeza telah dikaji. Hasil daripada kajian mendapati bahawa keamatan cahaya LED, suhu penyimpanan dan juga tempoh penyimpanan memberi kesan kepada jumlah kandungan flavonoid, jumlah kandungan fenolik dan juga aktiviti antioksida selasih lemon. Apabila suhu penyimpanan dan keamatan cahaya LED meningkat, jumlah kandungan flavonoid, jumlah kandungan fenolik dan juga aktiviti antioksida selasih lemon juga akan meningkat. Suhu penyimpanan pada tahap 5˚C adalah lebih bagus dalam mengekalkan jumlah kandungan flavonoid dan aktiviti antioksida, manakala suhu penyimpanan pada tahap 15˚C adalah lebih bagus dalam mengekalkan kepekatan asid caftaric dan asid rosmarinic.

Secara keseluruhannya, hasil daripada kajian ini dapat meningkatkan pemahaman kita tentang kesan-kesan keamatan cahaya merah dan biru lampu LED, kepekatan nutrisi baja dan kepekatan nitrogen dalam larutan baja dan hubungan antara rawatan terhadap selasih lemon dan bermanfaat untuk pengoptimuman keamatan cahaya, kepekatan nutrisi baja dan kepekatan nitrogen dalam larutan baja untuk meningkatkan pengeluaran hasil dan kualiti. Di samping itu juga, pengendalian lepas tuai seperti suhu penyimpanan juga memainkan peranan penting dalam memastikan kualiti yang lebih baik.

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Sincerely

ZURAFNI BINTI MAT DAUD

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Yahya bin Awang, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Mahmud bin Tengku Muda, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Mohd Firdaus bin Ismail, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 January 2023

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Signature:	______________________
Name of Chairman of Supervisory Committee:	Associate Professor Dr. Yahya bin Awang
Signature:	______________________
Name of Member of Supervisory Committee:	Professor Dr. Mahmud bin Tengku Muda
Signature:	______________________
Name of Member of Supervisory Committee:	Dr. Mohd Firdaus bin Ismail

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LIST OF ABBREVIATIONS

CGR	Crop Growth Rate
DAT	Days after transplanting
DMRT	Duncan Multiple Range Test
EC	Electrical conductivity
FRAP	Ferric Reducing Antioxidant Power
GAE	Gallic acid equivalent
HI	Harvest index
LAR	Leaf area ratio
LEDs	Light-emitting diodes
LWR	Leaf weight ratio
NAR	Net assimilation rate
PAR	Photosynthetically active radiation
PCA	Principal component analysis
PPF	Photosynthetically photon flux
RCDB	Randomized complete block design
RGR	Relative growth rate
SLA	Specific leaf area
SLW	Specific leaf weight
SRR	Shoot-root ratio
TFC	Total flavonoid content
TPC	Total phenolic content
°c	Degree Celsius
g	Gram
g/kg	Gram per kilogram

g/l	Gram per litre
l	Litre
m	Mole
mg	Milligram
ml	Millilitre
mM	Millimole
mm	Millimetre
µmol m^{-2} s^{-1}	Micromole per metre square per second
ppm	Part per million
rpm	Round per minute
v/v	Volume per volume
w/v	Weight per volume
µg	Microgram
µg/l	Microgram per litre
µg/g	Microgram per gram
µm	Micromillimeter
µM	Micromole
mS/cm	milisiemens per centimetre

CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia suffers a lack of food production, and still relies heavily on food imports, despite being blessed with land and natural resources. The cost of importing food has increased every year. Therefore, in order to reduce food import, there is a need to improve food production. Urban agriculture has been proposed as an essential medium to ensure the continuous supply of food, reduction of urban poverty, increase of food security and secure a better quality of the urban environment. To provide high quality and stable crop production, controlled environment agriculture technologies including glasshouse and indoor vertical farming with artificial lighting are alternatives and complementary to traditional field production, especially in urban areas with limited arable land and with other unfavorable environmental conditions.

By emerging crop production in the vertical structure, these systems can produce a higher number of plants per unit area cultivation leading to a greater yield production as compared with traditional cultivation system (Kalantari et al., 2017). In vertical farming with artificial lighting, the adoption of hydroponics for growing plants and the nutrient solution used from the cultivation system can be recirculated avoiding runoff and leaching on soil (Kozai and Niu, 2016). Finally, growing plants in an indoor environment enable to limit the entrance of pathogen or pests, which may allow for a pesticide-free production (Kalantari et al., 2017).

Most controlled environment agriculture systems utilize artificial lighting to ensure optimum plant growth and yield production (Kozai et al., 2016; Kozai, 2013; Despommier, 2010). According to Mirai Co. Ltd. In Japan, annual production capacity is 100 to 200 times higher in controlled environment agriculture systems (Kozai et al. 2016). Plants need light, not necessarily from the sun as light source, for growth and development. Alternative light sources have been used in controlled environment agriculture systems to grow plants efficiently. Current alternative light sources used include fluorescent, metal halide, high-pressure sodium and incandescent. It has been documented that these alternative light sources have been used to increase photosynthetic photon flux density but contain unnecessary wavelengths located outside the photosynthetic active radiation spectrum and are low in quality for promoting plant growth.

The current light sources also generate high radiant heat, consume high electrical energy power, low energy efficient and contain filaments that must be periodically replaced. Compared to those current light sources, light-emitting diodes (LEDs) lighting systems have several unique advantages including high energy conversion efficiency up to 80-90%, ability to control spectral composition at a specific wavelength, a small volume, durability, long operating lifetimes, narrow bandwidth, and relatively cool emitting surfaces (Kim et al., 2007, Kim et al., 2004a). LEDs light source has been proposed to be ideal for use in plant lighting system because its wavelength can be set to match plants' photoreceptors. It has been reported that the method provides optimal production and influence plant morphology and metabolism (Bourget, 2008; Massa et al., 2008; Morrow, 2008).

Light quality and quantity strongly influence plant development (Johkan et al., 2010). Light spectra used by plants are red, blue, orange, yellow, green, indigo, and violet, but plants respond best to red (650-700 nm) and blue (450-500 nm) with increased plant growth because they are highly absorbed by chlorophylls and has a significant impact on photosynthesis and vegetative growth. Several studies have proven that mixture of red and blue LEDs light to be a useful lighting source for the production of lettuce, kale and cabbage in controlled environments (Anuar et al., 2017; Shin et al. 2008; Lee et al., 2007). Besides light quality (spectra), light quantity (intensity) is equally essential as light quality and can positively affect the accumulation of phytochemicals in plants (Fu et al., 2012; Li and Kubota, 2009).

Nutrient management is also an essential element for plant growth and development. High levels of electrical conductivity of nutrient solution can induce osmotic stress, ion toxicity and nutrient imbalance, while low electrical conductivity of nutrient solution usually leads to nutrient deficiencies (Fallovo et al., 2009). The nutrient solution supplied to plants plays a crucial role as it significantly affects plant growth performance such as stem height and dry weight and can also influence plant appearance, nutritional values and shelf life of basil (Bekhradi et al., 2015; De Pascale et al., 2006). Herrera (2005) considered basil as a moderately tolerant species in respect to nutrient solution and concentration.

Besides preharvest handling, postharvest handling is equally crucial as preharvest handling and can positively affect the quality of fresh produces. The quality of lemon basil leaves frequently deteriorate during postharvest handling, primarily through transportation, storage conditions, packaging materials and storage period depending on the environmental conditions. According to Sharma et al. (2018), storage conditions may alter the antioxidant levels and changes in leaves color due to chlorophyll degradation. Besides, the quality of fresh herbs is finest preserved at low temperature (Cantwell and Reid, 2002).

Lemon basil (*Ocimum citriodorum* Vis.) is an ornamental, culinary and medicinal herb cultivated worldwide and has flourished under a variety of growing conditions (Makri and Kintzios, 2007). The species belongs to the family

Lamiaceae and contains a rich source of phenolic compounds. Phenolic acids such as rosmarinic, chicoric, caffeic and caftaric acids have been reported to be found in high concentrations in numerous basil cultivars (Kwee and Niemeyer, 2011; Lee and Scagel, 2009; Javanmardi et al., 2002) and has been documented to be a rich source of antioxidants (Kwee and Niemeyer, 2011). Lemon basil is also an aromatic herb used extensively in adding a distinctive aroma and flavor to food. The leaves have been used, either fresh or dried, as a spice. The meanwhile essential oil extracted from basil can be used as aromatic additives in food, pharmaceuticals, and cosmetics (Javanmardi et al., 2002).

The global basil leaves market is anticipated to increased demand in the forthcoming years due to a wide range of applications. Of them, food and pharmaceuticals are key end-user industries exhibiting high demand in the market. Essential oils are in great demand these days due to their high medicinal properties.

1.2 Problem statement

When plants grow inside the building, laboratory, greenhouse or indoor farming, physical structure shades the plants and induces a light deficit. Thus, the supplemental or sole sources lighting systems is needed to generate light required by the plants.

Presently, there are several types of light sources that can be used as artificial lightings such as incandescent, fluorescent lights, high-pressure sodium lamps and LEDs. In the present study, an LED light source was selected due to its capacity to meet light intensity and spectra requirements of plants and due to its sustainability and economics.It is known that irradiance levels of LEDs affect growth performance, yield production and quality in terms of phytochemical accumulation and antioxidant activity of plants. Besides, the electrical conductivity of the nutrient solution and nitrogen concentration supplied to the plants in the hydroponic system is a crucial and affect plant growth and development.

Selection of plants for cultivation in controlled environment agriculture is critical. *Basil(Ocimum citriodorum* Vis.) is an annual herb that is commercially important and both fresh and dried leaves are used for culinary purposes and known as “king of herbs”and are sources of antioxidants and antioxidant activity. Basil responds with better yield and secondary metabolites constituents under controlled environment conditions than conventional systems.

Lemon basil is highly perishable, which deteriorates rapidly after harvest and has a shelf life of 4-5 days when stored at room temperature. For postharvest handling, storage temperature is important to prolong the shelf life and its quality.

In this study, the different storage temperature for postharvest quality of lemon basil was studied.

However, very little is known regarding interactions between specific irradiance levels of LEDs, EC of nutrient solution, nitrogen concentrations in plants and its effects on the postharvest quality that stored at different storage temperature.

1.3 Objectives

The study was carried out with the following objectives:

i. To examine the effects of different irradiance levels of LEDs with red and blue spectra on plant growth, yield and phytochemical contents of lemon basil;

ii. To examine the interaction between irradiance levels of red and blue spectra of LEDs and nutrient concentrations on plant growth, yield and phytochemicalcontents of lemon basil;

iii. To examine the interaction between irradiance levels of red and blue spectra of LEDs and nitrogen concentrations on plant growth, yield, phytochemical contents and volatile compounds of lemon basil;

iv. To examine the postharvest quality of lemon basil in terms of phytochemical contents and antioxidant activities stored under different storage temperature that grew under different irradiance levels of red and blue spectra of LEDs.

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