UNIVERSITI PUTRA MALAYSIA

EFFECTS OF SUPPLEMENTARY LIGHTING ON VARIOUS PHYSIOLOGICAL PROCESSES AND PERFORMANCE OF CHINESE KALE (*Brassica oleracea* L.) GROWN ON DIFFERENT TIERS OF L-FRAME STRUCTURE

NUR ALYANI BINTI SHAKRI

FP 2018 107

EFFECTS OF SUPPLEMENTARY LIGHTING ON VARIOUS PHYSIOLOGICAL PROCESSES AND PERFORMANCE OF CHINESE KALE (*Brassica oleracea* L.) GROWN ON DIFFERENT TIERS OF L-FRAME STRUCTURE

By

NUR ALYANI BINTI SHAKRI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

October 2018

COPYRIGHT

DEDICATION

THIS THESIS IS DEDICATED TO

MY BELOVED PARENTS SHAKRI B MOHAMAD AND HALIMAH BT ISMAIL

MY SENIOR RESEARCH OFFICER, MOHAMMAD HARIZ B ABDUL RAHMAN

MY LOVELY HUSBAND SHAREL B SALIMAN

ALL MY KIND HEARTED SIBLINGS, LECTURERS AND FRIENDS

Abstracts of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

EFFECTS OF SUPPLEMENTARY LIGHTING ON VARIOUS PHYSIOLOGICAL PROCESSES AND PERFORMANCE OF CHINESE KALE (*Brassica oleracea* L.) GROWN ON DIFFERENT TIERS OF L-FRAME STRUCTURE

By

NUR ALYANI BINTI SHAKRI

October 2018

Chairman : Associate Professor Yahya Bin Awang, PhD
Faculty : Agriculture

Vertical farming is an advanced level of agricultural technology practiced when agricultural land is less available, where plants are grown in vertically stacked or inclined layers and/or integrated in other structures. Vertical farming would have different growth performances at every tier position, associated with differences in light availability. Incorporating artificial light within vertical farming would give greater impact on the growth of plants. The present study was conducted to evaluate the effect of artificial light regimes using light-emitting diode (LED) on growth and physiological processes, yield and quality parameters of two Chinese kale (*Brassica oleracea*) varieties (Type B Curly Leaf and Hong Kong Chinese Kale) grown on five descending tiers (Tier 1, 2, 3, 4 and 5) of vertical L-frame structures. In the first experiment, plants grown on Tier 1 or upper most tier produced the highest fresh weight, leaf area, canopy diameter, plant height, number of leaves, root length and stem diameter compared to those grown on lower tiers (Tier 2, 3, 4 and 5). Type B Curly Leaf Chinese kale had higher fresh weight and total leaf area compared to Hong Kong Chinese kale. The interaction effect of combination between upper tier positions and Chinese kale variety Type B Curly Leaf showed significantly higher stem diameter and total leaf area. Fresh weight of Type B Curly Leaf Chinese kale on Tier 2 was significantly the highest. In the second experiment, growth of Type B Curly Leaf Chinese kale grown under different light regimes and different tier positions of L-frame structure was observed. The four different light regimes were L1: 12 hours daylight condition (1180 μmol $m^{-2}s^{-1}$), L2: 12 hours daylight (1180 μmol $m^{-2}s^{-1}$) with 3 hours LED light at night time (228 μmol $m^{-2}s^{-1}$), L3:12 hours daylight (1180 μmol $m^{-2}s^{-1}$) with 6 hours LED light at night time (228 μmol $m^{-2}s^{-1}$) and L4: 12 hours LED light (1170 μmol $m^{-2}s^{-1}$) on daytime. Plants grown in L4 light regime on day time resulted in higher number of leaves, canopy diameter, root length, fresh weight, total leaf area, chlorophyll content and vegetable firmness at different tier positions. Plants grown under L4 light regime and Tier 1 showed significant positive effects on most parameters. For the contrast analysis resulted shows that the Chinese kale grown under light regimes L1 was different from light regime L4 at the

most parameters. The result also indicate that contrast analysis for the light regimes L2 and L3 which is supplementary light at night was different from light regimes L4 which is the better light regimes than others and more efficient in this study. In conclusion, growth and physiological processes of kale were significantly affected when grown under different light regimes and tier positions. The 12-hour LED light on day time had significant impact on plants grown on the vertical L-frame structure. The study proposes the use of LED lights to overcome low growth performance of Chinese kale on lower tiers to reduce the effect of shading in vertical structure. Plants exposed to natural light on upper tier position and receiving supplemental LED light on day time would yield positively on plant productivity and quality.

Keywords: kale, light emitting diode (LED), vertical structure.

Abstrak thesis tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk Ijazah Master Sains

KESAN PENGGUNAAN CAHAYA TAMBAHAN TERHADAP PPROSES FISIOLOGI DAN PERTUMBUHAN SAYUR KAILAN CINA (*Brassica oleracea* L.) YANG DI TANAM PADA STRUKTUR VERTIKAL YANG BERBEZA (L-FRAME)

Oleh

NUR ALYANI BINTI SHAKRI

Oktober 2018

Pengurusi : Associate Professor Yahya Bin Awang, PhD
Fakulti : Pertanian

Kaedah penanaman menegak merupakan perkembangan terkini dalam teknologi pertanian yang sesuai digunakan sebagai alternatif tatkala berlakunya pengurangan kawasan pertanian, di mana tumbuhan yang ditanam pada tingkat tanaman menegak atau cenderung menegak dan / atau terintegrasi pada struktur lain. Penanaman secara vertikal akan menunjukkan prestasi pertumbuhan pokok berbeza mengikut ketinggian deretan bertingkat pada struktur vertikal yang berkait rapat dengan kadar penerimaan cahaya yang berbeza. Menggabungkan penggunaan cahaya buatan pada kaedah penanaman menegak ini merupakan alternatif yang memberi kesan yang besar pada pertumbuhan pokok. Kajian ini dijalankan untuk menilai kesan rejimen cahaya buatan menggunakan diod pemancar cahaya (LED) terhadap proses pertumbuhan dan fisiologi, penghasilan dan kualiti pada dua jenis sayur kailan China (*Brassica oleracea* L.) iaitu Kailan Cina Jenis Daun B Kerinting dan Kailan Hong Kong yang ditanam pada lima tingkat para tanaman (tingkat 1, 2, 3, 4 dan 5) pada struktur vertikal (L-frame). Pada eksperimen pertama, tanaman yang ditanam di tingkat 1 atau tingkat paling atas memberi kesan yang lebih dari segi hasil, luas permukaan daun, diameter kanopi, ketinggian pokok, jumlah daun, panjang akar dan diameter batang kailan berbanding dengan yang ditanam di tingkat bawah (tingkat 2, 3, 4 dan 5). Manakala kailan Cina Jenis Daun B Kerinting menunjukan hasil dan jumlah keluasan daun yang lebih tinggi berbanding dengan sayur kailan Cina jenis Hong Kong. Kombinasi di antara tingkat tanaman yang paling tinggi dan jenis sayur kailan Daun B Kerinting menunjukan hasil yang lebih ketara pada diameter batang dan keluasan daun. Berat bersih sayur kailan jenis Daun B Kerinting yang ditanam pada tingkat 2 menunjukan hasil yg lebih ketara. Pada eksperimen kedua adalah mengenai pemerhatian kesan pertumbuhan sayur kailan Cina jenis Daun B Kerinting terhadap rejim pencahayaan berbeza dan kedudukan tingkat tanaman berbeza pada struktur 'L-frame'. Empat jenis rejim pencahayaan yang diguna dalam kajian ini adalah seperti L1: 12 jam cahaya pada waktu siang (1180 μmol $m^{-2}s^{-1}$), L2: 12 jam cahaya waktu siang (1180 μmol $m^{-2}s^{-1}$) tambah 3 jam lampu LED pada waktu malam (228 μmol m^{-}

$^{2}s^{-1}$), L3: 12 jam cahaya pada waktu siang (1180 μmol $m^{-2}s^{-1}$) ditambah 6 jam lampu LED pada waktu malam (228 μmol $m^{-2}s^{-1}$) dan L4: 12 jam lampu LED pada waktu siang (1170 μmol $m^{-2}s^{-1}$). Pokok yang ditanam di bawah cahaya L4 menghasilkan peningkatan terhadap bilangan daun, diameter kanopi, berat bersih, luas daun, panjang akar, kandungan klorofil daun, dan tekstur sayur pada tingkat tanaman yang berbeza. Rejim cahaya L4 dan tingkat tanaman teratas menghasilkan kesan yang lebih tinggi pada kebanyakan parameter yang di uji. Analisis perbandingan menunjukankan sayur kalian yang ditanam dibawah regim pencahayaan L1 berbeza dengan pencahayaan regim L4 pada kebanyakan parameter yang diuji. Dalam kajian ini juga menunjukkan bahawa analisis kontras untuk rejim cahaya L2 dan L3 yang merupakan cahaya tambahan pada waktu malam adalah berbeza dengan cahaya regim L4 yang merupakan rejim pencahayaan yang lebih baik dan efisien berbanding yang lain. Kesimpulannya, pertumbuhan dan proses fisiologi sayur kailan sangat dipengaruhi oleh faktor rejim cahaya dan tingkat tanaman yang berbeza. Cahaya LED 12 jam pada siang hari memberi impak yang besar kepada pertumbuhan yang lebih sekata pada struktur vertikal (L-frame). Selain itu cahaya LED digunakan untuk meningkatkan prestasi pertumbuhan sayur kailan yang ditanam di tingkat bawah dan ianya juga dapat mengatasi kesan naungan yang berlaku pada struktur vertikal. Pokok yang terdedah kepada cahaya semulajadi pada kedudukan teratas tingkat tanaman dan menerima cahaya LED 12 jam pada siang hari akan menyumbang kepada kesan positif keatas produktiviti dan kualiti sayuran.

Kata kunci: Kailan, diod pemancar cahaya (LED), struktur vertikal.

ACKNOWLEDGEMENTS

Alhamdullilah, thanks to Allah S.W.T for giving me an opportunity to complete this final year project. I would like to express my sincere thanks and profound appreciation to the chairman of my supervisory committee, Associate Prof. Dr. Yahya B. Awang. Under his supervision, I have received heaps of assistance without which this work could not have been reality. I am also indebted to Dr. Khairulmazmi B. Ahmad my co-supervisor who for his help, advice, tolerant, guidance and encouragement. Special thanks to En Mazlan Bin Bangi for his time and advice when used the photosynthesis equipment.

I am certainly grateful to Haji Mohd. Khoiri B. Kandar and En Azahar B. Othman for his guidance on chemical analysis and permitting me to run a part of this research work and providing me with all facilities needed.

I also would like to give appreciation and thanks to En Mohammad Hariz B. Abdul Rahman Senior Research Officer for his most valuable support and encouragement for me to complete this final year project. Thanks also to all staff members from Department Horticulture and MARDI for their assistance and help during my studies.

Last but not least, I would like take this point to dedicate this Master thesis to my parent Shakri B. Mohamad and Halimah Bt. Ismail for their encouraging and moral support, which made life easy throughout my studies. Finally, my special appreciation and gratitude go on particularly to my husband Sharel B. Saliman, family and all friends for being source of advice and always ready to offer a helping hand.

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

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

Khairulmazmi Bin Ahmad, PhD.
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

_____

ROBIAH BINTI YUNUS, PhD.
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work
- quotation, illustrations and citations have been duly referenced;
- This thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the university Putra Malaysia (Research) Rules 2012. The Thesis has undergone plagiarism detection software.

Signature:_____ Date:_____

Name and Matric No.: Nur Alyani Shakri; GS40402

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of
Supervisory Committee: Yahya Bin Awang.

Signature: _____
Name of Member of
Supervisory Committee: Khairulmazmi Bin Ahmad,

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
DOA	Department of Agriculture
GAE	Gallic acid equivalent
g/mol	Gram Per Mol
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
LAI	Leaf Area Index
LED	Light-emitting diode
MeOH	Methanol
mmol m^{-2} s^{-1}	Millimol per meter square per second
mS/cm^2	Milli-Siemens per centimeter
NaOH	Sodium hydroxide
PPFD	photosynthetic photon flux density
RCBD	Randomized Complete Block Design
TFC	Total flavonoid content
TPC	Total phenolic content
µg	Microgram
µmol $m^{-2}s^{-1}$	Micromole per meter square per second

CHAPTER 1

INTRODUCTION

1.1 General introduction

Leafy vegetables, also called leafy greens, potherbs, vegetable greens or salad greens refer to any leafy plants including their leaves and stems that are eaten as a vegetable. They are a valuable part of human diet because of their nutritive values. They are also known as nutritional powerhouses filled with minerals and vitamins. Leafy vegetables have always been important in the Malaysian food diet with the majority consuming green vegetables such as Chinese kale, lettuce, spinach, mustard, okra and cabbage (Ismail and Sook Fun, 2003). Furthermore, leafy vegetables are rich in human nutrition with the dark green leafy ones that are a great source of antioxidants (Gupta and Prakash, 2008). They are also rich in fibre, folate, carotenoids and chlorophyll which are good alkalinizers of the human blood. The substances in dark green leafy vegetables has been documented to inhibit the growth of certain types of cancer which become harmful to the human body beside acting as antioxidants (Adams, 2013).

Chinese kale, *Brassica oleracea*, var. Alboglabra, is a vegetable belonging to Brassicaceae family and is eaten fresh or cooked. This vegetable is usually preferred for its bolting stems as the common edible and crunchy parts. According to Sun et al. (2011) the tender bolting stem has a favourable flavour and a high source of nutritional values for the human body. The time frame for harvesting kale is usually a personal choice loosely based on flavour preferences. According to Mateljan (2007), cruciferous vegetables, like kale, are among the vegetables that have the highest concentrations of phytonutrients. It has well been documented that phytonutrients increase the ability of the liver to produce enzymes that assist in the detoxification of the body. Kale is high in fibre and a functional cancer prevention making the demand for the vegetable all-time high.

The Chinese kale was use in this study because this plant need consistent of light and water supplied. Beside that Chinese kale has short time of growth and lower cost in handling, According to Qian et al (2016), state that the effects of different light qualities including white, red and blue lights were effect the growth performance and quality of Chinese kale like antioxidant capacity was investigated using light emitting diodes as a light source for plant. The LED also needed for enhancing the chlorophyll a, b and ß-carotene contents of Chinese kale (Lefsrud et al. 2008). The great temperatures for the growing of Chinese kale were 18-28 °C (Department of Agriculture and Fisheries, Queensland Government, 2010).

Vertical farming is an advance level of agricultural technology, practiced when agricultural land has become less available and traditional farming methods have

become outdated, time consuming and wasteful. Not limited to these reasons, vertical farming has become a very useful indoor farming (Frediani, 2017). It has been proposed to be very suitable for leafy vegetables and other short term crops. The concept is said to be able to fulfil ever increasing demand for leafy vegetables when urbanisation is also increasing. Vertical farming could increase vegetable production with less cost on land preparation when cities expand. In vertical farming, plants, grown on different tier positions on vertical system, intercept different quantity of light affecting growth, yield and quality of crops. Plants on lower tiers receive low light intensity which affects plants growth rate as a result of low net photosynthesis.

Hydroponic, which involves growing plants in nutrient solutions that are free of soil as a growing medium, is the predominant growing system used in vertical farming and hydroponics. Hence, the vertical farming would take up considerably much less space than traditional farming method. It has been equated that 1 indoor acre of vertical farm can grow the equivalent of 4-6 outdoor acres on a traditional farm depending on the plants (Banerjee and Adenaeuer, 2014). The L-frame hydroponic system is a popular structure in a vertical garden that has been documented to maximize the number of plants that can be grown in a small space giving benefits to the environment, economic and social being (Safikhani et al., 2014).

As an important environmental factor, light not only source of energy for plant photosynthesis, but also for regulating plant growth and development (Jiao et al., 2007). In recent years, attention has been paid to the blue and red LED lights as essential energy sources for photosynthetic carbon assimilation (Lin et al., 2013). LED also functional increase the nutrient contents, reduce contamination from microbial and changing the ripening of postharvest fruits and vegetables. LED treated agronomic products can be beneficial for human health due to their good nutrient value and high antioxidant properties (Hasan et al., 2017).

Light-emitting diode (LED) has long been implemented in horticultural industry. It has brought the interest of numerous researchers in investigating the influence of LED light regimes on horticultural crops. Light, being very important in influencing physiological factors in plant growth, supplies energy for growth and plays an important role in directing energy along the various possible metabolic pathways. LED light also has its impact on plant growth in vertical structures suitable for plant growing in shaded areas (Hakkim et al., 2016; Touliatos et al., 2016). Therefore, in optimizing the quality and productivity of Chinese kale in vertical farming system, studies on the effects of supplementary light regimes and L-Frame planting system were justified.

Information gained from the studies on the effect of different levels of vertical structures and different light regimes on Chinese kale would lead to the determination of light regimes in a vertical structure on Chinese kale. Better growth performance and quality of Chinese kale would be beneficial in giving new perspectives in vertical farming and light regimes research in the future.

1.2 Research hypothesis

The hypothesis of the present study is:

1. Crop grown on upper tier received full light exposure giving better growth performance and quality of Chinese kale when compared to other tier levels.
2. Better and uniform Chinese kale growth performance and quality is under artificial light (LED) on day time.

1.3 Objective of study

The general objective of the study was to examine the effect of growing position on growth, yield and quality of Chinese kale grown on an L-Frame structure using hydroponic system. The specific objectives were:

1. To determine the effect of tier positions on growth, physiological processes, and productivity of Chinese kale grown on L-frame structures.
2. To evaluate the changes in physiological processes, productivity and quality of Chinese kale grown under different regimes of light emitting diode (LED) at different tiers on L-Frame growing structures.

REFERENCES

Adams, I. (2013). *The Health Benefits of Dark Green Leafy Vegetables*. University of Kentucky College of Agriculture.

Ali, M. B., Khandaker, L. and Oba, S. (2009). Comparative study on functional components, antioxidant activity and color parameters of selected colored leafy vegetables as affected by photoperiods. *Journal of Food, Agriculture and Environment*, 7(3-4): 392-398.

Anderson, R. G. and Specialist, E. F. (2004). *Light for Plant Growth in The Classroom*. University of Kentucky, USA. Retrieved from www.ca.uky.edu.

Annamarie, K., Lewallen, S., Lewallen, S. and Marini, R. P. (2000). *Effect of Light Availability and Canonpy Position on Peach Fruit Quality*. (Master Thesis).Virginia Polytechnic Institute and State University, USA.

Antognozzi, E., Boco, M., Famiani, F., Palliotti, A. and Tombesi, A. (1995). Effect of different light intensity on quality and storage life of kiwi fruit. *Acta Horticulturae*, 379: 483-490.

Awang, Y., Shaharom, A.S., Mohamad, R.B. and Selamat, A. (2009). Chemical and physical characteristics of cocopeat-based media mixtures and their effects on the growth and development of *Celosia cristata*. *American Journal of Agricultural and Biological Science*, 4(1): 63-71.

Baker N.R. (2008). Chlorophyll fluorescence: a probe of photosynthesis in vivo. *Annual Reviews Plant Biology*, 59: 89-113.

Banerjee, C. and Adenaeuer, L. (2014). Up, up and away! the economics of vertical farming. *Journal of Agricultural Studies*, 2(1): 40.

Bantis, F., Ouzounis, T. and Radoglou, K. (2016). LED lighting enhances growth characteristics and total phenolic content of *Ocimum basilicum*, but variably affects transplant success. *Scientia Horticulturae*, 198: 277-283.

Barku, V. Y. A. and Mensah, E. F. (2013). Antioxidant activity and the estimation of total phenolic and flavonoid contents of the root extract of *Amaranthus spinosus*. *Asian Journal of Plant Science and Research*, 3(1): 69-74.

Barrett, D. M., Beaulieu, J. C. and Shewfelt, R. O. B. (2010). Nutritional quality of fresh-cut fruits and vegetables: desirable levels, Instrumental and Sensory Measurement and the Effects of Processing. *Critical Reviews in Food Science and Nutrition*, 50: 369-389.

Böhme, M., Grbic, N., Paschko, K. and Pinker, I. (2015). Growth and internal quality of Vietnamese coriander (*Polygonum odoratum* Lour.) affected by additional lighting with blue, red and green LEDs. *Acta Horticulturae*, 1107: 113-120.

Boonen, C., Samson, R., Janssens, K., Pien, H. and Lemeur, R. (2002). Scaling the spatial distribution of photosynthesis from leaf to canopy in a plant growth chamber. *Ecological Modelling*, 156: 201-212.

Bourget, C. M. (2008). An introduction to light-emitting diodes. *Horticultural Science*, 43(7): 1944-1946.

Choi, H.G., Moon, B.Y., Kang, N.J. (2015). Effects of LED light on the production of strawberry during cultivation in a plastic greenhouse and in a growth chamber. *Science Horticultural*, 189: 22-31.

Cooper, A.J.J. (1976). *Nutrient Film Technique of Growing Crops. Grower Books*, London, p. 181.

Darko, E., Heydarizadeh, P., Schoefs, B. and Sabzalian, M. R. (2014). Photosynthesis under artificial light: the shift in primary and secondary metabolism. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 369(1640):1-5 .

de Anda, J. and Shear, H. (2017). Potential of vertical hydroponic agriculture in Mexico. *Sustainability*, 9(140): 1-17.

Department of Agriculture. (2015). Vegetables and cash crops statistic Malaysia. Retrieved from http:www.Doa.govmy/index/resources/Perangkaan_ sayur_tnmn_ lading.

Department of Agriculture and Fisheries, Queensland Government. (2010). Chinese broccoli. Retrieved from https://www.daf.qld.gov.au/plants/fruitandvegetables/ vegetables/asian-vegetables/ chinese-broccoli.

Despommier, D. (2009). The rise of vertical farms. *Scientific American*, 301(5): 80-87.

Despommier, D. (2010). *The Vertical Farm: Feeding The World in The 21st Century*. New York: St. Martin's Press.

Despommier, D. (2011). The vertical farm : controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. *Journal of Consumer Protection and Food Safety*, 6(2): 233–236.

Eigenbrod, C. and Gruda, N. (2014). Urban vegetable for food security in cities. A review. *Agronomy Sustainable Development*, 35: 483-498.

Ellingsen Eric, D. D. (2008). The vertical farm - the origin of a 21st century archetectural typology. *Council on Tall Buildings and Urban Habitat Journal*, III: 25-34.

Frąszczak, B., Golcz, A. and Renata Zawirska-Wojtasiak, B. J. (2014). Growth rate of sweet basil and lemon balm plants grown under fluorescent lamps and LED

modules. *Acta Scientiarum Polonorum Hortorum Cultus*, 13(2): 3-13.

Frediani, K. L. (2010). Vertical plant productions a public exhibitat at paignton zoo. *Journal of Botanic Garden Horticulture*, 8: 139-147.

Frediani, K., Zoo, P., Park, E. and Frediani, K. (2017). Sustainable food production using high density vertical growing (Verticrop). *Acta Horticulturae*, 921: 95-104.

Fu, W., Li, P., Wu, Y., and Tang, J. (2012). Effects of different light intensities on anti-oxidative enzyme activity, quality and biomass in lettuce. *Horticultural Science*, 39(3): 129-134.

Gautam, P., Terfa, M. T., Olsen, J. E. and Torre, S. (2015). Red and blue light effects on morphology and flowering of Petunia × hybrida. *Scientia Horticulturae*, 184: 171-178.

Gupta, S. and Prakash, J. (2008). Studies on Indian green leafy vegetables for their antioxidant activity studies on Indian green leafy vegetables for their antioxidant activity. *Plant Foods for Human Nutrition*, 64(1): 39-45.

Gupta, S.D. and Jatothu, B., (2013). Fundamentals and applications of light-emitting diodes (LEDs) in in vitro plant growth and morphogenesis. *Plant Biotechnology Report*, 7: 211-220.

Ghasemzadeh, A. and Jaafar, H. Z. E. (2014). Optimization of reflux conditions for total flavonoid and total phenolic extraction and enhanced antioxidant capacity in pandan *(Pandanus amaryllifolius Roxb*) using response surface methodology. *The Scientific World Journal*, 14: 1-10.

Gruda, N. (2005). Impact of environmental factors on product quality of greenhouse vegetables for fresh consumption. *Critical Reviews in Plant Sciences*, 24(3): 227-247.

Hakkim, A., Prabhakar, M. and Sibin, C. (2016). Impact of grow lights on plant growth in vertical farming under simulated growing enviroment. *International Journal of Latest Engineering and Management Reasearch*, 1(3): 5-11.

Hao, X., Jing Ming Zheng, Little C. and Khosla, S. (2012) LED inter-lighting in year round greenhouse mini-cucumber production. *Acta Horticulturae*, 956:335-340.

Hasan, M., Bashir, T. and Ghosh, R. (2017). An Overview of LEDs ' Effects on the Production of Bioactive Compounds and Crop Quality. *Molecules*, 22(1420): 1-12.

Hayden, A. L. (2006). Aeroponic and hydroponic systems for medicinal herb, rhizome and root crops. *Horticultural Science*, 41(3): 536-538.

Hemming, S. (2011). Use of natural and artificial light in horticulture - interaction of plant and technology. *Acta Horticulturae*, 907: 25-36.

Hogewoning, S. W., Trouwborst, G., Maljaars, H., Poorter, H., van Ieperen, W. and Harbinson, J. (2010). Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light. *Journal of Experimental Botany*, 61(11): 3107-3117.

Ismail, A., and Sook Fun, C. (2003). Determination of vitamin C, β-carotene and riboflavin contents in five green vegetables organically and conventionally grown. *Malaysian Journal of Nutrition*, 9(1): 31-39.

Issarakraisila, M., Ma, Q. and Turner, D. W. (2007). Photosynthetic and growth responses of juvenile Chinese kale (*Brassica oleracea* var . *alboglabra*) and Caisin (*Brassica rapa* subsp . *parachinensis*) to waterlogging and water deficit. *Scientia Horticulturae*, 3(2): 107-113.

Jiao, Y., Lau, O. S. and Deng, X. W. (2007). Light-regulated transcriptional networks in higher plants. *Nature Reviews Genetics*, 8(3): 217-230

Jintong Xin, Houvheng Liu, Shiwei Song and Riyuan Chen, G. S. (2015). Growth and quality of Chinese kale grown under different LEDs. *Agricultural Science and Technology*, 16(1): 68-115.

Johkan, M., Shoji, K., Goto, F., Hashida, S. and Yoshihara, T. (2010). Blue light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. *Horticulturae Science,* 45: 1809-1814.

Jou, J. H., Lin, C. C., Li, T. H., Li, C. J., Peng, S. H., Yang, F. C. and Hsu, B. D. (2015). Plant growth absorption spectrum mimicking light sources. *Materials*, 8(8): 5265-5275.

Kalantari,F., Mohd Tahir, O., Joni, R. A. and Fatemi, E. (2017). Opportunities and challenges in sustainability of vertical farming : A review, 2050(1): 35-60.

Kang, S. (2015). Response of evapotranspiration and yield to planting density of solar greenhouse grown tomato in northwest China. *Agicultural Water Management*, 130: 44-51.

Kurlicik A., Dapkunienie S., Kurlicik G., Zilinskaite S., Zukauskas A., Duchovskis P., (2008). Effect of photoperiod duration on the growth of Chrysanthemum plantlets in vitro. *Horticulture Vegetable Growing*, 27(2): 39-43.

Kim, H. H., Goins, G. D., Wheeler, R. M. and Sager, J. C.(2004). Green light supplementation for enhanced lettuce growth under red-and blue-light-emitting diodes. *Horticultural Science*, 39(7): 1617-1622.

Kopta, T. and Pokluda, R. (2010). Evaluation of Chinese radish under organic growing conditions. *Acta Agriculturae Serbica*, XV(30): 173-178.

Pardo, G. P., Aguilar, C. H., Martínez, C. L. and Ortiz, E. M. (2013). High intensity

led light in lettuce seed physiology (*Lactuca sativa L.*). *Acta Agrophysica*, 20(4): 665-677.

Lee, D.W., Oberbauer, S.F., Johnson. P., Krishnapilay, B., Mansor, M., Mohamad, H. and Yap, S.K. (2000) Effects of irradiance and spectral quality on leaf structure and function in seedlings of two Southeast Asian Hopea (Dipterocarpaceae) species. *American Journal of Botany,* 87: 447-455.

Lefsrud, M.G., Kopsell, D.A., and Sams C.E. (2008). Irradiance from distinct wavelength light-emitting diodes affect secondary metabo- lites in kale. *Horticultural Science,* 43: 2243-2244

Li, H., Tang, C., Xu, Z., Liu, X. and Han, X. (2012). Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris L.*). *Journal of Agricultural Science*, 4(4): 262-273.

Liu, W., Chen, D. K. and Liu, Z. X. (2005). High efficiency column culture system in China. *Acta Horticulturae*, 691: 495-500.

Lin, K.H., Huang, M.Y., Huang, W.D., Hsu, M.H., Yang, Z.W. and Yang, C.M. (2013). The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (*Lactuca sativa* L. var. capitata). *Scientia Horticulturae*, 150: 86-91.

Marowa-wilkerson, T., Weaver, L., Hovius, C. and Zandstra, J. W. (2007). *Nutritional and Health Benefits of Fresh Vegetables – Past , Present and Future :A Literature Review*. Fresh Vegetable Growers of Ontario, Ridgetown, Ontario, Canada.

Massa, G. D., Kim, H. H., Wheeler, R. M. and Mitchell, C. A. (2008). Plant productivity in response to LED lighting. *Horticulturae Science*, 43(7): 1951-1956.

Mateljan, G. (2007). *The World's Healthiest Foods.* Seattle, Washington, USA, 1-28. Retrieved from http://whfoods.org/

Matsuda, R., K. Ohashi-Kaneko, K. Fujiwara, E. Goto, and K. Kurata. (2004). Photosynthetic characteristics of rice leaves grown under red light with or without supplemental blue light. *Plant and Cell Physiology*, 45:1870-1874.

Maxwell, K. and Johnson, G. N. (2000). Chlorophyll fluorescence - a practical guide. *Journal of Experimental Botany*, 51(345): 659-668.

Mitchell, C. A., Both, A. J., Bourget, C. M., Burr, J. F., Kubota, C., Lopez, R. G. and Runkle, E. S. (2012). LEDs: The Future of greenhouse lighting. *Chronica Horticulturae*, 52(1): 6-12.

Mills, T., and Dunn, B. (2016). *LED Grow Lights for Plant Production*. Oklahma State University.

Moreno, D. A., Carvajal, M., López-Berenguer, C. and García-Viguera, C. (2006). Chemical and biological characterisation of nutraceutical compounds of broccoli. *Journal of pharmaceutical and biomedical analysis*, 41(5): 1508-1522.

Morrow, R. C. (2008). LED lighting in horticulture. *Horticultural Science*, 43(7): 1947-1950.

Ohashi-Kaneko, K., Takase, M., Kon, N., Fujiwara, K. and Kurata, K. (2007). Effect of light quality on growth and vegetable quality in leaf lettuce, spinach and komatsuna. *Environment Control in Biology*, 45(3): 189-198.

Olle, M. and Viršile, A. (2013). The effects of light-emitting diode lighting on greenhouse plant growth and quality. *Agricultural and Food Science*, 22(2): 223-234.

Pardossi, A., Malorgio, F., Incrocci, L., Alberto, C. and Tognoni, F. (2002). A comparison between two methods to control nutrient delivery to greenhouse melons grown in recirculating nutrient solution culture. *Scientia Horticulturae*, 92(2): 89-95.

Piovene, C., Orsini, F., Bosi, S., Sanoubar, R., Bregola, V., Dinelli, G. and Gianquinto, G. (2015). Scientia Horticulturae Optimal red : blue ratio in led lighting for nutraceutical indoor horticulture. *Scientia Horticulturae*, 193: 202-208.

Pollastrini, M., Di, V., Ferretti, M., Agati, G., Grifoni, D., Zipoli, G. and Bussotti, F. (2011). Influence of different light intensity regimes on leaf features of *Vitis vinifera* L . in ultraviolet radiation filtered condition. *Environmental and Experimental Botany*, 73: 108-115.

Qian, H., Liu, T., Deng, M., Miao, H., Cai, C., Shen, W. and Wang, Q. (2016). Effects of light quality on main health-promoting compounds and antioxidant capacity of Chinese kale sprouts. *Food Chemistry*, 196: 1232-1238.

Qiu, R., Song, J., Du, T., Kang, S., Tong, L., Chen, R. and Wu, L. (2013). Response of evapotranspiration and yield to planting density of solar greenhouse grown tomato in northwest China. *Agricultural Water Management*, 130: 44-51.

Rakow G. (2004). *I.1 Species Origin and Economic Importance of Brassica*, Saskatoon, Saskatchewan, Canada.

Ryu, J.H., Seo, K.S., Choi, G.L., Rha, E.S., Lee, S.C., Choi, S.K., Kang, S.Y. and Bae, C.H. (2012). Effects of led light illumination on germination, growth and anthocyanin content of dandelion (*Taraxacum officinale*). *Korean Journal Plant Resource*, 25: 731-738.

Safikhani, T., Abdullah, A. M., Ossen, D. R. and Baharvand, M. (2014). A review of energy characteristic of vertical greenery systems. *Renewable and Sustainable Energy Reviews*, 40: 450-462.

Sandhya, S., Tsui, w. C., An, Y., Jie, H. and Zhong, C. (2016). An efficient method for adventitious root induction from stem segments of *Brassica* species. *Frontiers in Plant Science*, 7(943): 1-10.

Semchenko, M., Lepik, M. and Go, L. (2012). Positive effect of shade on plant growth : amelioration of stress or active regulation of growth rate. 459-466. Retrieved from https://doi.org/10.1111/j.1365-2745.2011.01936.x.

Şenol, R., and Taşdelen, K. (2014). A new approach for LED plant growth units. *Acta Polytechnica Hungarica*, 11(6): 57-71.

Simpraga, M., Verbeeck, H., Bloemen, J., Vanhaecke, L., Demarcke, M., Joó, E. and Steppe, K. (2013). Vertical canopy gradient in photosynthesis and monoterpenoid emissions: An insight into the chemistry and physiology behind. *Atmospheric Environment*, 80: 85-95.

Singh, D., Basu, C., Meinhardt-Wollweber, M. and Roth, B. (2015). LEDs for energy efficient greenhouse lighting. *Renewable and Sustainable Energy Reviews*, 49: 139-147.

Son, K. and Oh, M. (2013). Leaf shape, growth and antioxidant phenolic compounds of two lettuce cultivars grown under various combinations of blue and red light-emitting diodes. *Horticulturae Science*, 48(8): 988-995.

Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A. and Dierich, A. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, 31(1): 33-51.

Sultana, B., Anwar, F. and Ashraf, M. (2009). Effect of extraction solvent/technique on the antioxidant activity of selected medicinal plant extracts. *Molecules*, 14: 2167-2180.

Sun, B., Liu, N., Zhao, Y., Yan, H. and Wang, Q. (2011). Variation of glucosinolates in three edible parts of Chinese kale (Brassica alboglabra Bailey) varieties. *Food Chemistry*, 124(3): 941-947.

Touliatos, D., Dodd, I. C. and Mcainsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and Energy Security*, 5(3): 184-191.

Trouwborst, G., Hogewoning, S. W., Harbinson, J. and Van Leperen, W. (2011). The influence of light intensity and leaf age on the photosynthetic capacity of leaves within a tomato canopy. *Journal of Horticultural Science and Biotechnology*, 86 (4): 403-407.

Tuquero, J., and Extension, C. (2016). Chinese Kale (*Brassica oleracea*), Cultivar Group alboglabra a potential commercial crop for Guam. *Food Plant Production*, 8:1-4.

Urbonavičiūtė, A., Samuolienė, G., Brazaitytė, A. and Žukauskas, A. (2009). The effect of light quality on nutritional aspects of leafy radish. *Scientific Works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture*, 28(1): 147-156.

Vaillant, N., Monnet, F., Sallanon, H., Coudret, A. and Hitmi, A. (2003). Treatment of domestic wastewater by an hydroponic NFT system. *Chemosphere*, 50(1):121-129.

Vogelmann, T. C. and Han, T. (2000). Measurement of gradients of absorbed light in spinach leaves from chlorophyll fluorescence profiles. *Plant, Cell and Environment*, 23(12): 1303-1311.

Wang, Z., Tian, J., Yu, B., Yang, L. and Sun, Y. (2015). LED Light Spectrum Affects the Photosynthetic Performance of *Houttuynia Cordata* Seedlings. *American Journal of Optics and Photonics*, 3(3): 38-42.

William, C. and Motes. (2010). *Modern Agricultue and its Benefits: Trends, Implications, and Outlooks. Pre- Publication Draft.* Global Harvest intiative, USA.

Wojciechowska, R., Kołton, A., Długosz-Grochowska, O., ˙Zupnik, M. and Grzesiak, W. (2013). The effect of LED lighting on photosynthetic parameters and weight of lamb's lettuce (*Valerianella locusta*). *Folia Horticulture,* 25: 41-47.

Wojciechowska, R. and Olga, D. (2015). Effects of LED supplemental lighting on yield and some quality parameters of lamb's lettuce grown in two winter cycles. *Scientia Horticulturae,*187: 80-86.

Yahya, A. and Atherton, J. G. (1995). Growth and fruiting responses of strawberry plants grown on rockwool to shading and salinity. *Scientia Horticulturae*, 62(1-2): 25-31.

Zervoudakis, G., Salahas, G., Kaspiris, G. and Konstantopoulou, E. (2012). Influence of Light intensity on growth and physiological characteristics of common Sage (*Salvia officinalis* L.). *Brazilian Archives of Biology and Technology*, 55: 89-95.

Zhai R., Feng Y., Wang H., Zhan X., Shen X., Wu W., Zhang Y., Chen D., Dai G., Yang Z., Cao L. and Cheng S. (2013). Transcriptome analysis of rice root heterosis by RNA-Seq. *BMC Genomics*, 14(19): 1-14.

BIODATA OF STUDENT

Nur Alyani Shakri was born in Wilayah Persekutuan Kuala Lumpur in October 11, 1986. She received her Bachelor of Science (Hons) Plantation Technology and Management in 2009 and Diploma in Planting Industry Management in 2007 from Universiti Teknologi Mara.

In 2009 until the present, she is working at Malaysian Agricultural Research and Development Institute (MARDI) in the Department of Agrobiodiversity and Environmental.

Alyani is registered for the degree of Master of Science (M.S) in the field of Horticulture at the Faculty of Agriculture, Universiti Putra Malaysia (UPM) in 2014 under the supervision of Associate Professor Dr. Yahya bin Awang.

PUBLICATION

Publication in journal

Nur Alyani, S and Yahya, A. (2018) Growth performance of different varieties of Chinese kale grown on different tier of L-frames. Bragantia (Submitted).

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _____

TITLE OF THESIS / PROJECT REPORT :

EFFECTS OF SUPPLEMENTARY LIGHTING ON VARIOUS PHYSIOLOGICAL PROCESSES AND PERFORMANCE OF CHINESE KALE (*Brassica oleracea* L.) GROWN ON DIFFERENT TIERS OF L-FRAME STRUCTURE

NAME OF STUDENT: NUR ALYANI BINTI SHAKRI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from_____ until _____ (date) (date)

Approved by:

_____	_____
(Signature of Student)	(Signature of Chairman of Supervisory Committee)
New IC No/ Passport No.:	Name:
Date :	Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]