特定波段光輻射夜間光照對菊花開花期及花朵品質之影響

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摘要

如一般花卉植物，光照啟動及帶領著菊花植株的生長、發育與生產，而光照起伏對於其生命循環的各種衝擊可歸納為光質、光強度與光照時間長短等三大因素。為瞭解特定波段光輻射夜間光照調節菊花開花期的效應，並釐清其影響植株生長及開花性狀的機制，乃進行本項研究。本項盆栽試驗設於臺中市霧峰區之行政院農業委員會農業試驗所簡易設施內，在 2011 年 2 月 11 日栽植歸類夏菊產季的大花栽培種‘黃精競’及小花栽培種‘芬蘭小粉’作為試材，自苗株種植於盆缽當日起即行夜間(22:00-02:00，計 4 小時)特定波段光輻射照明處理，直至不照光對照組(CK)植株花蕾形成時為止。特定波段光輻射人工光源包括發光二極體(light-emitting diode; LED)和省電燈泡(energy-saving light bulb; ELB)，以不照光為對照組，合計 10 種光源。依照最小顯著性差異測驗(Least Significant Difference test; LSD)結果比較開(切)花時之生長性狀及花朵特性，發現紅光 10 W LED (R)及白光 10 W LED (W_{10W})之夜間照明會提高大花種‘黃精競’的花莖高度，R、紅藍光組合 10 W LED (RB)及 23 W 省電燈泡兩顆(ELB_2)等夜間光照處理則會促進葉位數(即葉片數)增加，而黃光 10 W LED (Y_{10W})及 ELB_2 之處理株具有較佳花朵特性。在小花種‘芬蘭小粉’的試驗結果，顯示 W_{10W} 會促使花莖高度、葉位數及地上部鮮重增加，R 則會提高花莖周長，而黃光 5 W LED 及 Y_{10W} 之花朵特性皆優於不照光對照組。在生育進展的試驗結果，發現 W_{10W}、RB、ELB_2 及 R 等處理均可延長‘黃精競’與‘芬蘭小粉’之達到見蕾及開花期所需天數。由於顯示出光強度的差別效應，綜合試驗結果以 W_{10W}、RB、ELB_2、R 及 Y_{10W} 等 5 種人工光源處理對大花種‘黃精競’具有較佳處理效果，小花種‘芬蘭小粉’亦有類似結果。

關鍵詞：菊花、夜間光照、達見蕾所需天數、達切花所需天數、開花期、花朵品質。

Effects of Nighttime Illumination with Specific Wavebands on Flowering Stage and Flower Quality of Chrysanthemum

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ABSTRACT

The flower characteristics of Chrysanthemum [*Dendranthema* × *grandiflorum* (Ramat.) Kitamura] have been greatly improved through conventional cultivation practices and breeding programs in past decades. Similar to many floral plants, growth, development and production of Chrysanthemum spp. are manipulated by light, in terms of factors such as light quality, light intensity and lighting duration. To clarify effects of nighttime illumination with varied wavebands on flowering of Chrysanthemum spp. and

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responses of treated plants in growth traits and flowering characters, artificial light sources of light-emitting diodes (LEDs) and energy-saving light bulb (ELB; 23 W) were adopted for this potted experiment in structure. As a summer season production scheme, seedlings of a big flower variety 'Hunag-Jing-Ching' and a small flower variety 'Finnish-Hsiao-Fen' were planted under structures located at the experimental farm of Taiwan Agricultural Research Institute on February 11, 2011. Treatments of nighttime illumination, during dark period of 22:00-02:00, started from planting day till the date of floral bud formation appearing on control plants with no light treatment (CK). There were 10 treatments in total including CK. From results of Least Significant Difference test, treatments of red light LED (R; 10 W) and white light LED (W_{10W}; 10 W) increased height of floral stem of variety 'Huang-Jing-Ching', while treatments of red-blue combined LED (RB; 10 W) and two bulbs of ELB (ELB_2) stimulated number of leaf node (leaf number) and treatments of yellow light LED (Y_{10W}; 10 W) and ELB_2 improved flower characteristics. In variety 'Finnish-Hsiao-Fen', height of floral stem, number of leaf node and aboveground fresh weight were enhanced by lighting with W_{10W}, circumference of floral stem was promoted by treating with R, and flower characteristics were ameliorated by irradiating yellow light LED (Y_{5W}; 5 W). As to effects on plant development, plants treated with W_{10W}, RB, ELB_2 and R were found extending its days required to floral bud formation and flowering in both varieties. Additionally there existed differential performance in the tested varieties owing to differences in light intensity. Light sources having higher light intensity, such as W_{10W}, RB, ELB_2, R and Y_{10W}, obtained better treatment effects than those with relatively lower intensity treatments.

Key words: Chrysanthemum, Nighttime illumination, Days required to floral bud formation, Days required to flowering, Flowering stage, Flower quality.

前言

菊花 [*Dendranthema* × *grandiflorum* (Ramat.) Kitamura]為臺灣大宗切花作物之一，依照「農業統計年報」(2011)資料顯示 2010 年栽培面積為 827 公頃(ha)，以彰化地區為主要的栽培區域。由於合適的天候臺灣周年均有菊花生產，主要產季可依季節及開花特性區分，大致為 4-5 月之夏菊、7-9 月之夏秋菊、10-11 月之秋菊及 12-翌年 3 月之冬菊等四大類。目前臺灣生產的菊花主要以外銷日本為主，國內銷售市場漸趨縮小，使得提高品質與降低生產成本的研究更為重要。

隨著吾人對於植物生理的日益瞭解及科技的進步，如今已可運用不同的栽培技術來調節植物的光週期(photoperiodism)，以達到作物的周年生產目的。短日照植物(short-day plants)使用低透光黑布遮蔽，即可減少日長而促進開花(Post 1934)，長日照植物(long-day plants)以人工光源進行暗期中斷(night interruption)處理，可因縮短夜間暗期而提前開花(Lane *et al.* 1965, Runkle *et al.* 1998)。菊花為短日照植物，其開花特性亦受到光週期調控，通常置於超過 12 小時的黑暗環境下將可誘導花蕾(芽)形成，若於黑暗下給予持續性或間歇性的光照處理則會使頂芽維持營養生長，進而抑制花芽分化及開花現象(Cathey and Borthwick 1964, Cathey and Borthwick 1970)。

由文獻報告已知，光照是調控植物生長發育的重要環境訊息因子之一，經由對光合作用的影響改變提供生長所需的生質量來源，又透過感光色素(photoreceptors; 如光敏色素、花青素、胡蘿蔔素)控制諸如種子萌芽、植體生長向性及開花等許多光刺激生理反應 (Franklin *et al.* 2005, Sullivan and Dengej 2003)。研究顯示光合作用光子流(photosynthetic photon flux; PPF) 及日累積光量(daily quantum integrals; PPF × light duration) 會影響花朵的生長發育(Karlsson *et al.* 1989, Warrington and Norton 1991)，光質與光週期的差異會造成植物形態上的變化，如藍光抑制天竺葵(*Pelargonium*)莖桿的延長、紅光則促進莖的

延長(Appelgren 1991)，又大豆的細胞分裂受到藍光抑制而縮短節間長度、減少細胞擴展而縮小葉片面積(Dougher and Bugbee 2004)。菊花的生長、發育、開花及切花品質受到光照的影響，另溫度效應亦會改變菊花葉片展開速率、開花時間及後續發育進展，光照與溫度的交感作用更是複雜而深遠(Adams *et al.* 1998, Larsen 1982, Van der Ploeg and Heuvelink 2006, Van der Ploeg *et al.* 2007)。有關溫度的文獻指出，高溫會誘導花芽形成而使得花朵數增加(Lepage *et al.* 1984, Carvalho *et al.* 2005)，低溫環境將會提高花朵直徑(Vince 1960)，當溫度低於 13℃時則將會延遲開花天數 5~56 天(De Jong 1984)。此外，高溫加速呼吸作用且消耗切花植株的水分與碳水化合物，導致菊花瓶插壽命的急劇縮短(Coorts 1973, Whealy *et al.* 1987, Cockshull and Kofranek 1994)，主要係高溫改變了菊花植株體內的葡萄糖(glucose)及果糖(fructose)濃度，也將使得切花品質劣化(Adachi *et al.* 2000)。

由半導體材料所製成的元件發光二極體(light-emitting diode; LED)，是目前國內光電產業中最具競爭力的產品之一，具有體積小、壽命長及低耗電量等特性，其光源特性為單一波段或混合波段。LED 光源依照光輻射波段區分，概可分為可見光 LED (如 450~680 nm 波段)及非可見光 LED (如 850~1550 nm 波段)兩大類，使用者可直接選購規格化產品，或自行依需求客製化特定波段光源燈具。例如，選擇介於 400~700 nm 範圍的光波段以提供植物光合作用所需的人工光源，挑選大於 700 nm 波長範圍的近紅外光波段以供保溫功能，或選用干擾植物形態的特殊波段以探討光質與形態發生關係等，由此顯示出 LED 光源在作物栽培與形態上的多元用途(Brown *et al.* 1995, Bula *et al.* 1991, Kim *et al.* 2004, Yang and Lee 2009)。

現行國內菊花栽培多以 100 W 或 60 W 白熾鎢絲燈或省電燈泡進行夜間光 (電)照，以調節菊花開花期與生產期，電照費用係主要支出成本。本研究改以 LED 光源取代現行光源來提供菊花的夜間照明，比較不同特定波段光輻射在調節開花期、促進植株生長及改進開花品質上之差別效應，期以建立最佳光照條件來從事菊花的栽培管理，並以提高產業的能源使用效率及達到節能減碳政策目標。

材料與方法

本項試驗設於臺中市霧峰區之行政院農業委員會農業試驗所簡易設施內，在 2011 年 2 月栽植歸類夏菊產季的栽培種[大花種'黃精競(Huang-Jing-Ching)'及小花種'芬蘭小粉(Finnish-Hsiao-Fen)']作為試驗材料，扦插發根苗購自彰化縣田尾鄉。苗株種植於直徑、深度皆為 0.3 m 之塑膠盆缽，每個盆缽栽植'黃精競'或'芬蘭小粉' 2 株、每個處理各 10 盆，盆內填以 3:1 比例均勻混合之泥炭土和南海珍珠石的栽培介質。自苗株種植於盆缽當日起即行夜間(22:00-02:00，計 4 小時)特定光輻射照明處理(暗期光中斷)，每週隨著植株生長而調整光源高度 2 次，以全程維持植株頂部至光源距離 1.5 m，直至對照組(不照光處理組)花蕾形成('見蕾')才停止光照處理。

特定光輻射人工光源包括發光二極體 LED 和省電燈泡，分別有紅光 LED (R; 光強度 1.61 μmol m^{-2} s^{-1}、電壓 110 V、功率 10 W)、藍光 LED (B; 光強度 0.78 μmol m^{-2} s^{-1}、電壓 110 V、功率 10 W)、紅藍光組合 LED (RB, 1 : 1; 光強度 2.4 μmol m^{-2} s^{-1}、電壓 110 V、功率 10 W)、黃光 LED 5 W (Y_{5W}; 光強度 0.55 μmol m^{-2} s^{-1}、電壓 110 V、功率 5 W)、黃光 LED 10 W (Y_{10W}; 光強度 1 μmol m^{-2} s^{-1}、電壓 110 V、功率 10 W)、白光 LED 5 W (W_{5W}; 光強度 0.54 μmol m^{-2} s^{-1}、電壓 110V、功率 5 W、白光 LED 10 W (W_{10W}; 光強度 0.8 μmol m^{-2} s^{-1}、電壓 110V、功率 10 W)、省電燈泡 1 顆(ELB_1; 光強度 0.73 μmol m^{-2} s^{-1}、電壓

110-120 V、功率 23 W、色溫 6500 K，Philips Helix 晝光色)及省電燈泡 2 顆(ELB$_2$; 光強度 1.48 μmol m^{-2} s^{-1})等 9 種人工光源，並以不照光(no light treatment; CK)為對照組，合計 10 種光源處理。

試驗期間的肥培管理，分別於定植後 3 wk 及 7 wk 施以新樂園 1 號混合有機質肥料(粒劑，興農股份有限公司；成分為 4% N、3% P_2O_5、3% KO、1% MgO_2 及有機質 70%，重量比 4-3-3-1-70)。病蟲害管理，則視設施內病蟲害的發生情形而定，若發生疫病及萎凋病，施以 27.12%三元硫酸銅水懸劑(稀釋 800 倍，1.5 L ha^{-1}，Nufarm GmbH & Co KG, Austria，臺灣日產化工股份有限公司代理)及 25%撲克拉乳劑(稀釋 500 倍，1.5 L ha^{-1}，興農股份有限公司)；若發生灰黴病，施以 50%撲滅寧可濕性粉劑(稀釋 1,000 倍，100 g L ha^{-1}，立農化學股份有限公司)；若發生蚜蟲、薊馬、粉蝨、二點葉蟎及鱗翅目幼蟲等蟲害，則酌施以 24%納乃得溶液(稀釋 1,000 倍，1 L ha^{-1}，興農股份有限公司)、2%阿巴汀乳劑(稀釋 1,000 倍，2 L ha^{-1}，興農股份有限公司)、2.8%畢芬寧乳劑(稀釋 1,000 倍，2 L ha^{-1}，興農股份有限公司)及 40.8%陶斯松乳劑(稀釋 1,000 倍，2 L ha^{-1}，興農股份有限公司)。

至開花前的生育期間，每隔 10 天進行植株生長調查，分別量測株高及葉位數(即葉片數)。當不照光對照組植株達'見蕾'後，停止夜間光照處理，並持續調查各特定波段光輻射處理植株達到'見蕾'及開花所需天數。對大花種'黃精競'而言，生育期間隨時去除新生側芽使維持單一莖稈之"一條龍"狀態，當植株生長至可切花階段，即橫切土壤表面花莖，量測切花植株下列性狀: 花莖高度(LS; cm)、地上部鮮重(AFW; g)、葉位數(NLN; No. leaf^{-1})、花莖周長(CFS; mm)、花最大直徑(LDF; cm)、花周長(CF; cm)等。切花植株置於內徑 0.06 m 和高度 0.25 m 且含有 200 mL 逆滲透 RO 過濾水之圓柱形玻璃容器中，每隔 7 天進行換水 1 次，直到花朵凋謝為止，並計算花開天數。對於小花種'芬蘭小粉'，僅保留頂部 5 個側芽，其餘新生側芽皆予去除，其'見蕾'係指第一個花蕾形成期，花莖高度為含最上位第 1 朵花之莖長，葉位數為含最上位第 1 朵花之莖上葉位數目，花莖周長為含最上位第 1 朵花之莖最大周長，花最大直徑為最上位 5 朵花各最大直徑之平均值，花周長則為最上位 5 朵花周長之平均值。取樣時大花種'黃精競'逢機取 4 盆及小花種'芬蘭小粉'逢機取 5 盆，以平均值為代表值。

試驗資料分析以 SAS 統計軟體(version 9.1) 進行變方分析(ANOVA; analysis of variance)檢定，並使用最小顯著性差異測驗(least significance difference; LSD)以判定處理間的差異是否達到顯著性。統計繪圖，則使用 SPSS 公司之 SigmaPlot 軟體(version 10.0)。

結果與討論

本試驗在 2011 年 2 月栽植歸類夏菊產季的大花種'黃精競'及小花種'芬蘭小粉'，其等以不同特定波段光輻射進行夜間光照處理後，達到見蕾、開花與切花的日期及瓶插後花朵萎凋的日期整理如 Table 1。供作切花使用的大花種'黃精競(Huang-Jing-Ching)'，在未以人工光源 4 小時夜間光照處理之對照組植株，其達到見蕾日期為 04/04/2011、距離種植日期約 53.8 天，達到開花日期為 05/03/2011、距離種植日期約 82.3 天，而切花的萎凋日期為 05/13/2011、瓶插後花朵的壽命約 11.6 天，除了 B 處理之外，其餘夜間光照處理植株的相對日期皆往後延遲，顯示出夜間照明延緩花蕾形成及開花的效果，同時也延長了花開的天數(Table 1 及 Table 3A)。供盆花使用的小花種'芬蘭小粉(Finnish-Hsiao-Fen)'，亦有類似結果，B 處理以外的其他夜間光照處理植株，其達到見蕾日期(第一個花蕾)及開花日期(第一朵花開)皆往後延遲，而最上位 5 朵花的平均萎凋

Table 1. The recorded dates of different growth stages, from planting to flower-wilted, for two varieties of *Chrysanthemum*, big flower variety 'Huang-Jing-Ching' and small flower variety 'Finnish-Hsiao-Fen' grown in 2011 under nighttime illumination treatments using LEDs (light-emitting diodes) and ELB (energy-saving light bulb) as light sources.

Stage	ELB_1[x]	W_{10W}	RB	ELB_2	R	Y_{10W}	Y_{5W}	W_{5W}	B	CK
Variety 'Huang-Jing-Ching'										
Planting	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11
FBF[y]	04/07	04/23	04/22	04/22	04/20	04/16	04/11	04/11	04/02	04/04
Flowering	05/13	05/26	05/22	05/26	05/21	05/17	05/15	05/14	05/02	05/03
Flower-cut	05/13	05/26	05/22	05/26	05/21	05/17	05/15	05/14	05/02	05/03
Flower-wilted	05/19	06/15	06/13	06/13	06/09	06/05	05/24	05/22	05/10	05/13
Variety 'Finnish-Hsiao-Fen'										
Planting	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11	02/11
FFBF[z]	04/28	05/02	05/04	05/07	05/04	05/02	04/30	04/24	04/10	04/10
FFF	05/29	06/08	06/09	06/09	06/12	06/03	06/01	05/25	05/06	05/07
FSF	06/01	06/09	06/09	06/11	06/13	06/05	06/03	05/26	05/07	05/09
FTF	05/30	06/09	06/10	06/10	06/13	06/04	06/03	05/26	05/07	05/08
FFOF	05/31	06/09	06/11	06/10	06/12	06/05	06/03	05/27	05/07	05/10
FFIF	06/01	06/10	06/11	06/10	06/13	06/08	06/06	05/27	05/04	05/10
Flower-cut	05/30	06/09	06/10	06/10	06/12	06/05	06/03	05/26	05/07	05/08
FFW	06/23	07/07	07/08	07/09	07/02	06/29	06/30	06/16	05/14	05/22
SFW	06/25	07/07	07/08	07/09	07/02	06/30	07/01	06/16	05/15	05/24
TFW	06/24	07/07	07/09	07/09	07/02	06/30	07/01	06/16	05/15	05/23
FOFW	06/25	07/07	07/09	07/09	07/02	06/30	06/30	06/16	05/15	05/24
FIFW	06/26	07/07	07/09	07/10	07/02	07/05	07/04	06/14	05/13	05/26

[x] ELB_1: one energy-saving light bulb, 23 W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulbs, 23 W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; CK: no light treatment.

[y] FBF: floral bud formation.

[z] FFBF: first floral bud formation; FFF: flowering of the first flower; FSF: flowering of the second flower; FTF: flowering of the third flower; FFOF: flowering of the fourth flower; FFIF: flowering of the fifth flower; FFW; the first flower wilted; SFW: the second flower wilted; TFW: the third flower wilted; FOFW: the fourth flower wilted; FIFW: the fifth flower wilted.

日期(花朵之花開天數)亦後延，可見夜間照明也有延緩花蕾形成及開花的效果，並延長花開天數(Table 1 及 Table 3B)。

利用最小顯著性差異測驗(LSD)比較不同光源處理對'黃精競' 及'芬蘭小粉'生長及花朵性狀造成的差異，結果分列於 Table 2A 及 Table 2B。由大花種'黃精競'生長性狀統計值，顯示 R 及 W_{10W} 處理株具有最長的花莖高度，R、RB 及 ELB_2 處理下會有較多的葉位數，R 處理將使植株得到較高的地上部鮮重。花朵性狀的調查調查資料指出，Y_{10W} 處理株會有最長的花朵直徑，ELB_2 處理之花朵周長較大(Table 2A)。在小花種'芬蘭小粉'的生長性狀上，發現 W_{10W} 處理株之花莖高度、葉位數及地上部鮮重均最高，R 處理最能促進花莖周長。在花朵性狀部分，Y_{5W} 處理株之花朵直徑及花朵周長均最大(Table 2B)。令人注意的是，B 處理對此兩菊花栽培種的生長及

花朵性狀似無促進效果，調查數值與不照光對照處理植株之間無顯著差異(Tables 2A 及 2B)，值得未來深入探討。

如前述，不同波段光輻射的夜間光照處理可改變‘黃精競’及‘芬蘭小粉’兩種菊花植株生育的進展，造成從種植至見蕾、見蕾至開花及切花花開之天數間的差異(Tables 3A 及 3B)。除了 B 處理之外，W_{10W}、RB、ELB_2 及 R 等處理，相較於不照光對照處理，可明顯地延長‘黃精競’種植至見蕾所需天數約 15-18 天，W_{10W} 及 ELB_2 更可明顯增加達到開花所需天數至 23 天。切花後瓶插期間，以 RB 及 W_{10W} 處理延長花開天數的效果較佳，可使切花之‘黃精競’花朵延後萎凋時間約 9-11 天(Table 3A)。在多花的‘芬蘭小粉’，RB、ELB_2 及 R 等處理，相較於不照光對照處理組，可增加達到見蕾所需天數約 23-27 天。加上見蕾至開花所需的天數，W_{10W}、RB、ELB_2 及 R 等處理可比不照光對照處理的達到開花所需天數延長至 35 天。其最上位 5 朵花的平均花開天數，以 W_{10W}、RB 及 ELB_2 等處理較長，使小花種‘芬蘭小粉’的切花天數至約 14 天。惟無論‘黃精競’或‘芬蘭小粉’，由種植至見蕾、見蕾至開花及花開時間等徵狀，B 與不照光對照處理組之間無明顯差異(Tables 3A 及 3B)，顯示藍光波段對於參試兩夏菊栽培種的生育進展似無明顯作用，不適合利用於開花期的調節。

Table 2A. Effects of nighttime illumination treatments using LEDs (light-emitting diodes) and energy-saving light bulb (ELB) as light sources on growth traits and floral characters of *Chrysanthemum*, variety ‘Huang-Jing-Ching’, grown in summer season of 2011. Nighttime illumination treatment (22:00-02:00) started from planting till the formation of floral bud of plants with no light treatment (CK).

Light source	LS[x] (cm)	NLN (No. leaf^{-1})	CFS (mm)	AFW (g)	LDF (cm)	CF (cm)
Variety ‘Huang-Jing-Ching’						
ELB_1[y]	97.0	47.17	22.55	123.6	9.65	30.60
W_{10W}	123.2	53.75	20.73	144.5	11.45	37.85
RB	118.5	58.50	22.01	164.9	11.38	36.83
ELB_2	116.3	57.25	21.85	171.7	11.83	38.08
R	127.0	60.75	20.90	191.1	11.75	37.50
Y_{10W}	115.9	52.25	20.73	135.7	12.25	37.00
Y_{5W}	100.0	48.50	21.91	133.9	9.60	33.80
W_{5W}	101.3	51.50	22.75	132.7	11.25	35.00
B	85.7	42.25	17.50	81.8	9.98	31.63
CK	69.5	43.58	17.03	72.9	9.99	32.33
Mean	105.4	51.55	20.80	135.28	10.91	35.06
$LSD_{0.05}$	4.36	2.82	0.94	10.35	1.16	2.72

[x] LS: length of stem; NLN: number of leaf node; CFS: circumference of floral stem; AFW: aboveground fresh weight; LDF: longest diameter of flower; CF: circumference of flower. Values are the mean of four replicates.

[y] ELB_1: one energy-saving light bulb, 23W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulbs, 23W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; CK: no light treatment.

Table 2B. Effects of nighttime illumination treatments using LEDs (light-emitting diodes) and energy-saving light bulb (ELB) as light sources on growth traits and floral characters of *Chrysanthemum*, variety 'Finnish-Hsiao-Fen', grown in summer season of 2011. Nighttime illumination treatment (22:00-02:00) started from planting till the formation of floral bud of plants with no light treatment (CK).

Light source	LS[x] (cm)	NLN (No. leaf^{-1})	CFS (mm)	AFW (g)	LDF (cm)	CF (cm)
Variety 'Finnish-Hsiao-Fen'						
LB_1[y]	102.3	59.67	11.56	127.9	5.62	18.39
W_{10}	128.8	69.00	12.41	155.0	5.96	18.77
BR	114.5	61.75	12.57	139.3	5.76	18.78
LB_2	112.3	66.33	12.17	137.6	5.37	17.34
R	119.9	66.00	12.93	145.5	5.81	18.49
Y_{10}	113.3	61.75	12.23	132.9	5.99	18.89
Y_5	110.8	62.00	11.87	138.9	6.30	20.09
W_5	101.5	56.75	10.26	116.6	5.73	18.54
B	77.5	45.75	11.66	77.9	5.76	19.26
CK	67.9	39.80	10.44	65.9	6.21	19.51
Mean	104.9	58.88	11.81	123.75	5.85	18.81
$LSD_{0.05}$	4.66	3.52	0.97	8.81	0.34	0.97

[x] LS: length of stem having the first flower; NLN: number of leaf node at flowering of the first flower; CFS: circumference of floral stem having the first flower; AFW: aboveground fresh weight; LDF: the average of longest diameter of the first five flowers; CF: the average of circumference of the first five flowers. Values are the mean of five replicates.

[y] ELB_1: one energy-saving light bulb, 23W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulbs, 23W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; CK: no light treatment.

經檢視'黃精競'及'芬蘭小粉'於不同光輻射處理下之花開天數與生長性狀之迴歸分析結果(Fig 1)，除了花莖周長，在夜間光照處理之下植株的花莖高度、地上部鮮重及葉位數等性狀皆與花開天數呈顯著二次曲線正相關。由此推知，如果經過夜間光照處理可以促進此 3 個生長性狀，將有利於延長花開天數。由花朵性狀與花開天數的迴歸分析(Fig 2)，僅有大花種'黃精競'呈現顯著二次曲線正相關，而小花種'芬蘭小粉'則無。因此，夜間光照處理果能增大花莖直徑及花朵周長，可有助於增加花開天數。另探討生育進展與花開天數之相關(Fig 3)，在本試驗的條件下，發現達到開花所需天數(開花期)與花開天數之間為二次曲線關係，開花期愈長則其花朵萎凋速度愈慢，顯然較長的開花所需天數具有延長花開天數的正向效應。再進一步比較不同生育期的影響，發現種植至見蕾所需天數的長短在兩參試菊花栽培種皆具有正面效果，可能較長營養生長期有利於後續生殖生長，進而加大了花朵、也增加了花開天數(Figs. 1 及 2)。經由這些試驗結果，促進具有正向

Table 3A. Effects of nighttime illumination treatments using LEDs (light-emitting diodes) and energy-saving light bulb (ELB) as light sources on flower development of *Chrysanthemum*, variety 'Huang-Jing-Ching', grown in summer season of 2011. Nighttime illumination treatment (22:00-02:00) started from planting till the formation of floral bud of plants with no light treatment (CK).

Light source	DRFBF[x]	DRFBFF	DRF	FDCF
	---------- days ----------			
Variety 'Huang-Jing-Ching'				
ELB_1[y]	56.0	37.5	92.5	6.8
W_{10W}	72.5	33.8	105.3	21.3
RB	71.5	30.8	101.3	23.0
ELB_2	71.0	35.0	105.0	19.2
R	69.8	31.8	100.5	19.5
Y_{10W}	65.5	32.0	96.5	20.3
Y_{5W}	60.8	34.3	94.0	10.5
W_{5W}	60.3	33.8	93.0	9.5
B	51.0	31.0	81.0	9.8
CK	53.8	29.5	82.3	11.6
Mean	63.2	32.9	95.1	15.1
$LSD_{0.05}$	3.44	1.30	3.49	2.50

[x] DRFBF: days required to floral bud formation; DRFBFF: days required from floral bud formation to flowering; DRF: days required to flowering; FDCF: flowering duration of cut flower. Values are the mean of four replicates.

[y] ELB_1: one energy-saving light bulb, 23 W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulbs, 23 W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; CK: no light treatment.

功用的生長及花朵性狀或生育進展階段，將因為增大花朵與延長花開天數而提升菊花的開花品質。檢視各種夜間光照處理，發現此兩種菊花概以 W_{10W}、RB、ELB_2、R 及 Y_{10W} 等光源處理的效果較佳。

根據文獻研究報告，光質、光強度及光照時間等照明因子會影響花芽的分化與形成 (Cathey and Borthwick 1964, Cathey and Borthwick 1970, Huang and Chu 1984)，Appelgren (1991)研究更指出藍光與紅光處理的差異，藍光將使得天竺葵 (*Pelargonium*) 莖的伸長受到抑制而紅光則加速莖桿延長。本試驗藉由不同波段光輻射的夜間光照處理，證實了紅光波段 LED 光源會促進參試菊花栽培種在夏季生育期莖桿的生長高度，卻抑制花芽分化及開花現象，而本研究使用的藍光波段 LED 光源則無這些處理結果，因而不適合利用於菊花開花期的調節。Stack and Drummond (1998)之研究指出藍光的光強度若低於 3.5 μmol m^{-2} s^{-1} 時，將不會影響菊花的花芽分化及發育，此可能為本試驗未見藍光處理效果的可能原因之一。此外，將本試驗人工光源皆置於距離菊花植株在相同高度 (150 公分)下，ELB_2 (1.48 μmol m^{-2} s^{-1})、W_{10W}

Table 3B. Effects of nighttime illumination treatments using LEDs (light-emitting diodes) and energy-saving light bulb (ELB) as light sources on flower development of *Chrysanthemum*, variety 'Finnish-Hsiao-Fen', grown in summer season of 2011. Nighttime illumination treatment (22:00-02:00) started from planting till the formation of floral bud of plants with no light treatment (CK).

Light source	ADRFBF[x]	ADRFBFF	ADRF	ADCFD
	---------- days ----------			
Variety 'Finnish-Hsiao-Fen'				
ELB_1[y]	77.8	33.0	109.8	25.7
W_{10W}	81.0	39.5	119.5	28.6
RB	83.8	37.7	120.5	29.9
ELB_2	86.8	34.5	120.3	29.8
R	83.0	40.9	122.9	21.6
Y_{10W}	81.0	35.2	115.2	25.5
Y_{5W}	79.0	35.0	113.0	29.0
W_{5W}	73.0	33.4	105.4	21.6
B	59.0	28.2	86.2	8.9
CK	59.4	29.1	87.5	15.4
Mean	76.4	34.6	110.0	23.6
$LSD_{0.05}$	3.26	1.16	2.95	2.09

[x] DRFBF: days required to the first floral bud formation; DRFBFF: days required from the first floral bud formation to its flowering; DRF: days required to flowering of the first flower; FDCF: the average of flowering duration of the first five flowers on the same plant. Values are the mean of five replicates.

[y] ELB_1: one energy-saving light bulb, 23 W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulbs, 23 W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; CK: no light treatment.

(0.8 μmol m^{-2} s^{-1})及 Y_{10W} (1 μmol m^{-2} s^{-1})等處理效果分別大於相對應的 ELB_1 (0.73 μmol m^{-2} s^{-1})、W_{5W} (0.54 μmol m^{-2} s^{-1})及 Y_{5W} (0.55 μmol m^{-2} s^{-1})等處理，故推測光照強度會影響本試驗參試菊花栽培種'黃精競'及'芬蘭小粉'的表現，關連於生長性狀、花朵性狀及生育進展出現的差異(Tables 2A、2B、3A 及 3B)。又本試驗選用各光源之光輻射強度概低於 2.5 μmol m^{-2} s^{-1}，顯見光照對於開化現象的調節效果在於改變光週期，對於生長性狀及花朵特性的促進作用可能在於額外夜間光照或其他未知因素造成，需要另予研究解釋。至於將夜間光照時數由現行 4 小時縮短是否顧以得到類似結果，或具成劑量效應、光質差異等，亦為可供探討的課題。然而無論如何，在本研究結果的支持之下，將可利用於使用節能光源 LED (10 W)取代耗能的白熾鎢絲燈(100 W 或 60 W)於現行菊花生產光照作業流程，甚至取代節能燈泡(23 W)，獲得更大的省電及減碳的的效益。

其次，綜合 Fig. 1、Fig. 2 及 Fig. 3 之迴歸分析結果，兩個參試菊花栽培種在夜間光照處理下的生長性狀、花朵性狀及生育進展皆可能與花開天數有關，其中植株花莖高

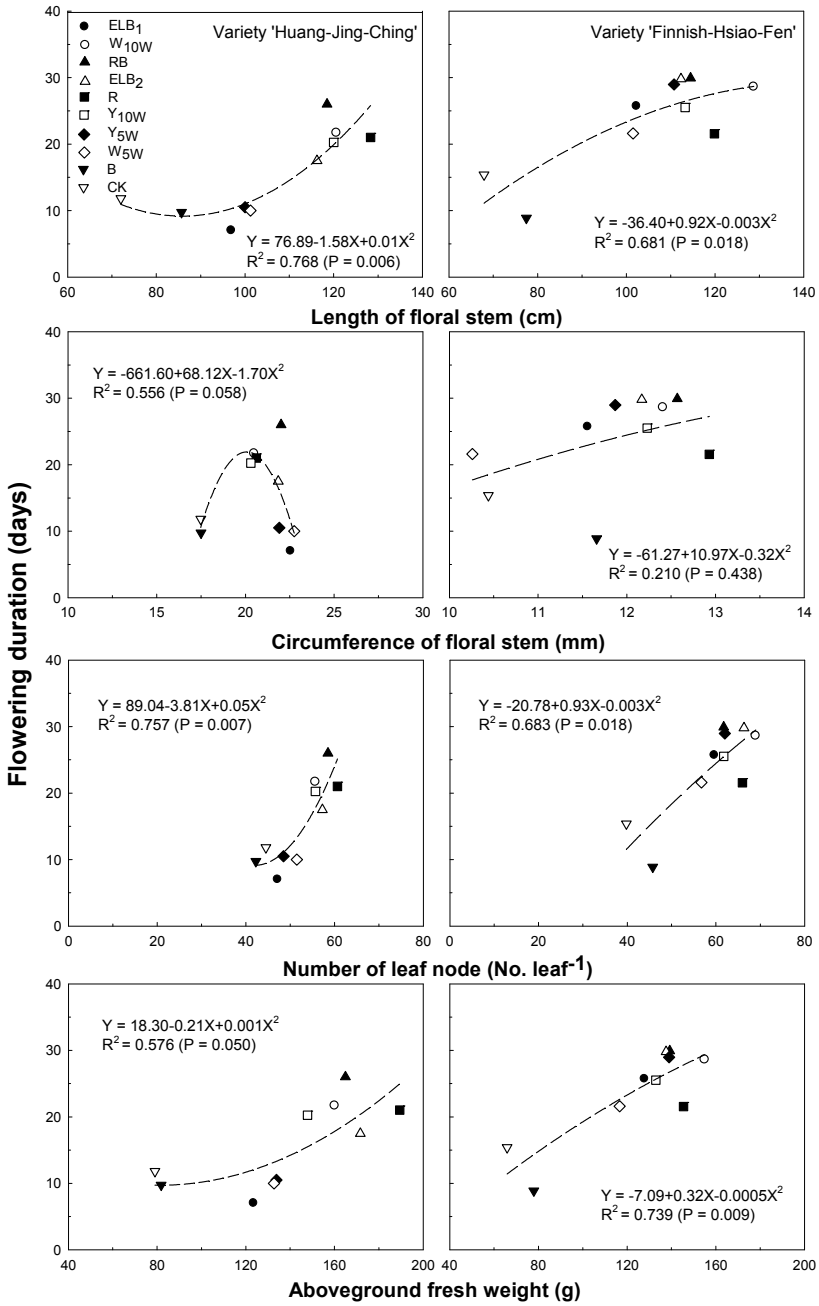


Fig 1. Changes of flowering duration of cut-flower to growth traits in plants of *Chrysanthemum*, varieties of 'Huang-Jing-Ching' and 'Finnish-Hsiao-Fen', grown under nighttime illumination treatments using LEDs (light-emitting diodes) and ELB (energy-saving light bulb) as light sources. ELB_1: one energy-saving light bulb, 23W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulb, 23W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; and CK: no light treatment.

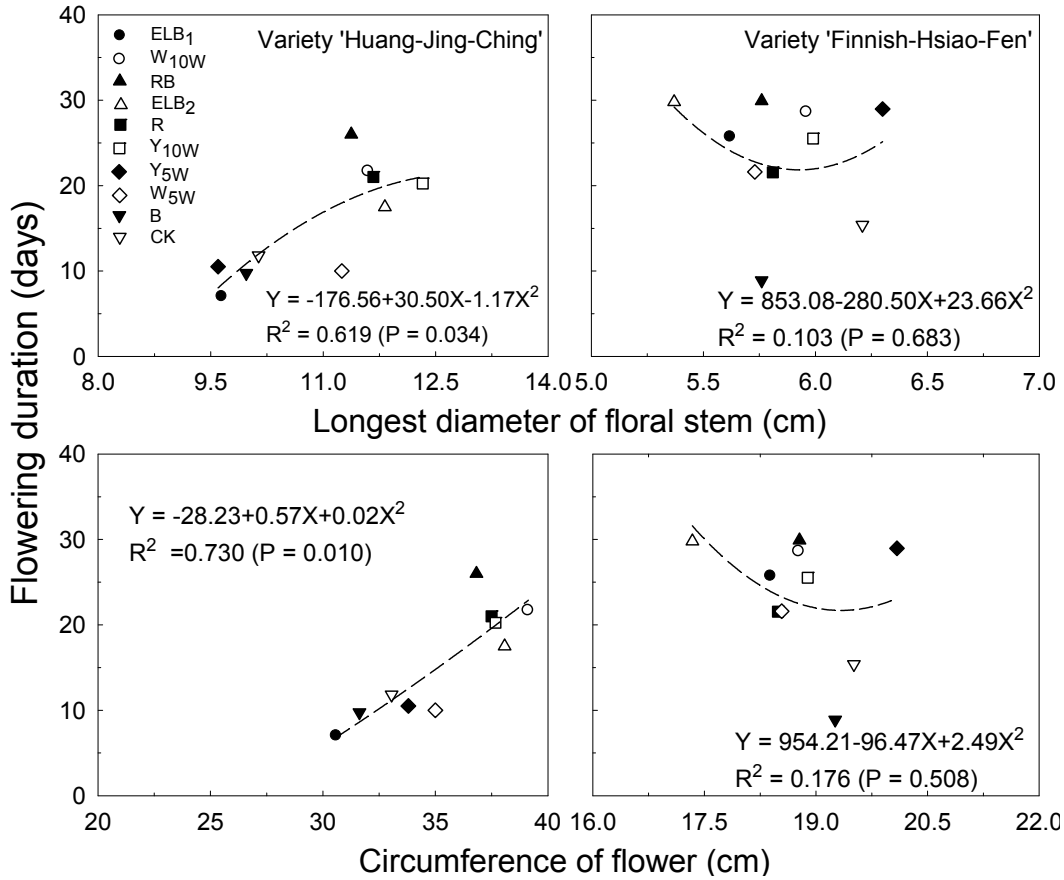


Fig 2. Changes of flowering duration of cut-flower to floral characters in plants of *Chrysanthemum*, varieties of 'Huang-Jing-Ching' and 'Finnish-Hsiao-Fen', grown under nighttime illumination treatments using LEDs (light-emitting diodes) and ELB (energy-saving light bulb) as light sources. ELB_1: one energy-saving light bulb, 23W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulb, 23W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; and CK: no light treatment.

度、地上部鮮重及葉位數愈高者，則其花開天數相對也會增加；大花種'黃精競'的花朵直徑與周長，亦密切相關於花開天數；而達到開花所需天數多寡，尤其是達到見蕾所需天數長短，也是花開天數顯著相關的影響因子。因此，一如上述，凡可促進這些性(徵)狀的不同波段(包括紅光、白光、黃光、省電燈泡等)人工光源，均可利用於調節開花期及提升切花('黃精競')或花朵('芬蘭小粉')品質。而光照強度的量化差異，從節能角度，可再予探討。雖然本研究並未考量溫度效應，事實上除了光照因素之外，文獻研究亦指出溫度對於包括菊花在內許多花卉植物的影響力(Coorts 1973, De Jong 1984, Lepage *et al.* 1984, Whealy *et al.* 1987, Cockshull and Kofranek 1994)，可作為未來研究主題。

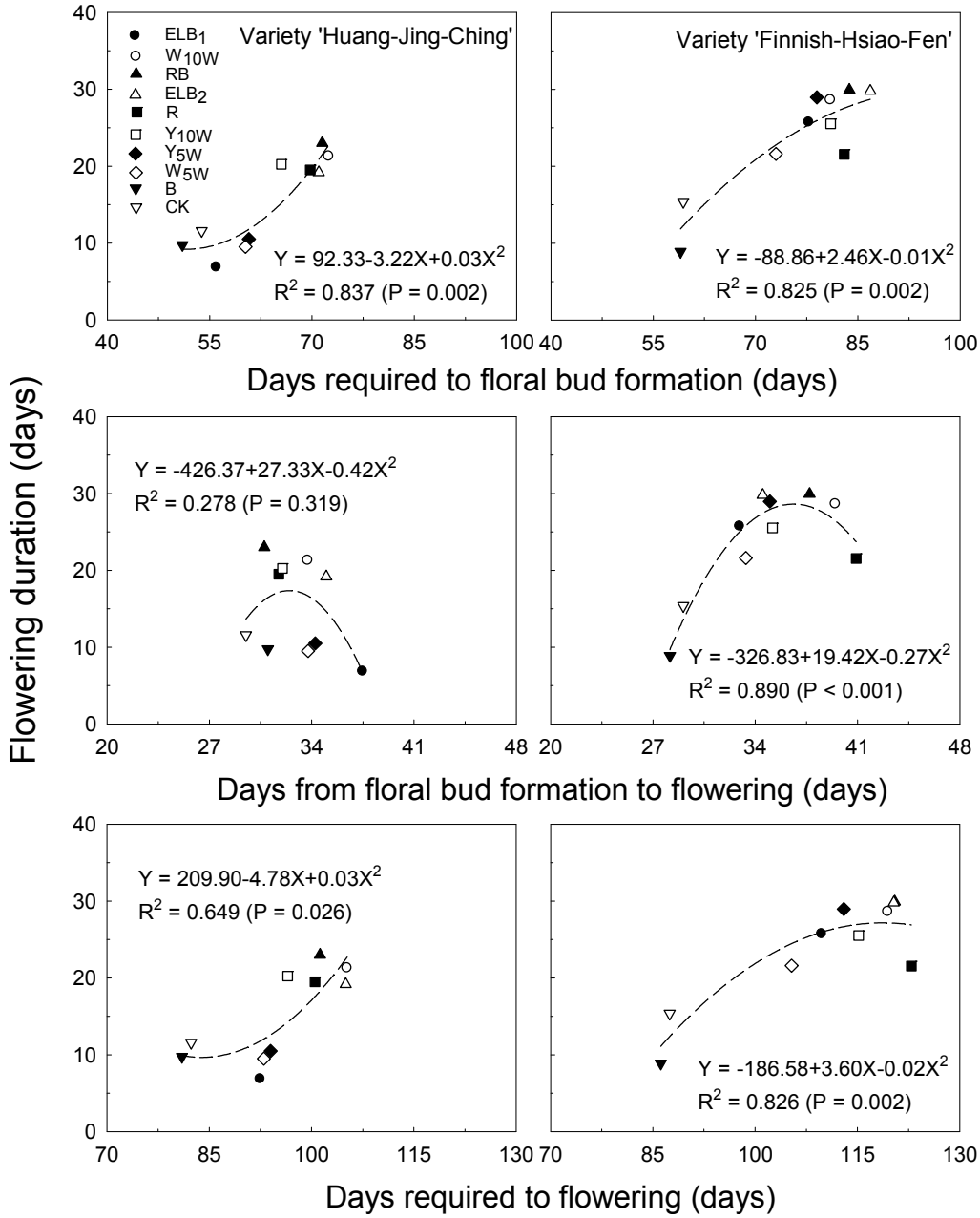


Fig 3. Changes of flowering duration of cut-flower to flower development in plants of *Chrysanthemum*, varieties of 'Huang-Jing-Ching' and 'Finnish-Hsiao-Fen', grown under nighttime illumination treatments using LEDs (light-emitting diodes) and ELB (energy-saving light bulb) as light sources. ELB_1: one energy-saving light bulb, 23W; W_{10W}: white light LED, 10W; RB: red and blue light combined LED, 10W; ELB_2: two energy-saving light bulb, 23W; R: red light LED, 10W; Y_{10W}: yellow light LED, 10W; Y_{5W}: yellow light LED, 5W; W_{5W}: white light LED, 5W; B: blue light LED, 10W; and CK: no light treatment.

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