International Journal of Food Science +Technology

Institute of Food Science +Technology ifst

Original article

Effects of artificial lighting on bioactivity of sweet red pepper (*Capsicum annuum* L.)

Jong-Hyang Bae,[1,2] Yun-Jum Park,[1,2] Jacek Namiesnik,[3] Ilhami Gülçin,[4,5] Tae-Choon Kim,[1,2] Ho-Cheol Kim,[1,2] Buk-Gu Heo,[6] Shela Gorinstein[7]* & Yang-Gyu Ku[1,2]*

1 Department of Horticulture Industry, College of Life Science and Resource, Wonkwang University, Iksan 54538, Korea
2 Institute of Life Science and Natural Resources, Wonkwang University, Iksan 54538, Korea
3 Department of Analytical Chemistry, Chemical Faculty, Gdańsk University of Technology, Gdańsk 80 952, Poland
4 Department of Chemistry, Faculty of Sciences, Atatürk University, Erzurum, Turkey
5 Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia
6 Naju Foundation of Natural Dyeing Culture, Naju 58280, Korea
7 Institute for Drug Research, School of Pharmacy, Hadassah Medical School, the Hebrew University, Jerusalem 91120, Israel

(Received 14 January 2016; Accepted in revised form 14 March 2016)

Summary Recent studies have shown that artificial light effectively promotes the growth and development of red peppers when light spectra, intensities and duration are controlled. Cited reports deal mostly with studies involving with the growth stages of pepper. Changes in the biochemical status of plants were not studied. Therefore, this study focuses on the changes in the content of some bioactive compounds (polyphenols, flavonoids, tannins, ascorbic acid and antioxidant capacities) after artificial lightening [high-pressure sodium and light-emitting plasma (LEP) lamps] during the cultivation of sweet red pepper. The bioactive compounds differ slightly, depending on the source of light. Fluorescence spectra showed higher binding properties of LEP polyphenol extracts to human serum albumin (HSA) than other samples. FTIR peaks were similar in their polyphenols region for all investigated samples.

Keywords Ascorbic acid, bell pepper, binding properties, flavonoids, health-promoting compounds, light quality, polyphenols.

Introduction

Sweet peppers (*Capsicum* annuum L.) are an excellent source of phenolic compounds, which are important antioxidant components that may reduce the risk of diseases (Sim & Sil, 2008; Yazdizadeh Shotorbani *et al*., 2013). Supplementary lighting is frequently applied in the winter season for crop production in greenhouses (Hao & Papadopoulos, 1999; Li *et al*., 2015). Fluorescent, metal halide, high-pressure sodium and incandescent lamps are generally used for plant cultivation as conventional light sources (Lin *et al*., 2013). These lamps increase photosynthetic photon flux levels, but they contribute little to plant growth. Plant development is strongly influenced by the light quality, which refers to the colour or wavelength reaching a plant's surface (Johkan *et al*., 2010; Peng *et al*., 2015). While it is widely understood that light intensity can positively affect photochemical accumulation (Li & Kubota, 2009), the effects of light quality are more complex, and mixed results are often reported. There are many studies dealing with the light sources applying to peppers and other vegetables. The cultivation of sweet pepper transplants under light-emitting diode (LED) lamps that were developed to supplement high-pressure sodium lamps (HPS) used in greenhouses was investigated by Bagdonaviciene *et al*. (2015). Green light diode emitters were used as a radiation source to illuminate broccoli, asparagus and green pepper in the shelf temperature, where the quality of the three vegetables was tested in the storage period (Liu *et al*., 2013). The effect of influence of four different light-emitting diode lights on flowering and polyphenol variations in the leaves of chrysanthemum was studied by Jeong *et al*. (2012). Samuoliene *et al*. (2013) showed the effect of light quality of LED and HSP on lettuce bioactivity. The influence of light wavelength on the mycelial growth and conidial germination of C. *acutatum* was investigated using red, green, blue and white light sources (Yu *et al*., 2013). During the fully fruiting stage, tomato plants are source-limited and the extent of source limitation of a cultivar is positively correlated with its potential fruit

*Correspondent: Faxs: +972 2 675 7076; +82-63-850-7308; e-mails: shela.gorin@mail.huji.ac.il; ygku35@wonkwang.ac.kr

doi:10.1111/ijfs.13116

size (Li *et al*., 2015). The light quality could influence the growth and metabolism of *Ganoderma lucidum mycelium* (Kim *et al*., 2011). To increase the production capacity, controlled growing systems using artificial lighting were taken into consideration. Recent development of LED technologies presents an enormous potential for improving plant growth and making systems more sustainable. Changes in intensity and wavelength of LED can influence the quality of plants with their future use for functional foods (Darko *et al*., 2014). As it was mentioned above, there are a number of publications on the effect of light quality on growth, production and other aspects, but no studies were found about the antioxidant and binding properties of sweet red pepper. The results of supplementary lightening (HPS and LEP lamps) on growth and fruit characteristics of sweet pepper (*C. annuum* L.) during low radiation were also shown in our recent study. Lee *et al*., 2014 investigated the effect of HPS and LEP lamps supplemental lighting on the antioxidant and binding properties of sweet red pepper. Antioxidant scavenging assays, fluorescence and FTIR were applied in this study.

Materials and methods

Chemicals

6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2-azinobis-(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS), 1,1-diphenyl-2-picryl-hydrazl (DPPH), 2,9-dimethyl-1,10-phenanthroline (neocuproine), and Folin–Ciocalteu reagent were purchased from Sigma Chemical Co., St. Louis, MO, USA, and 2,4,6,-tripyridyl-s-triazine (TPTZ) was purchased from Fluka Chemie, Buchs, Switzerland. All reagents were of analytical grade.

Samples

In this study, two artificial light sources (HPS and LEP lamps) were placed in the glass greenhouse (Venlo-type, JeonBuk province, South Korea) to investigate the growth and fruit setting properties of red sweet pepper (Red, De Ruiter, NL, USA). Specifications for the lamps were the following: HSP (HSE Daylight model; 315 watt (W); energy consumption = 1.5 ampere (A)/230 volt (V); colour rendition index >90; manufacturer Hortilux Schréder, the Netherlands) and LEP (Gavita-Pro 300 model; 300 W; energy consumption= 1.3 A/230V; colour rendition index 94; manufacturer Gavita, the Netherlands); index compared with CRI (=100 index) of sunlight. Control samples were grown in natural light (sunlight). The experiment was carried out from 12 August 2012 until 28 February 2013. Usually, HPS and LEP were not provided from 12 August 2012 till 11 October 2012, because of enough light intensity. HPS and LEP lamps were provided from 12 October 2012 till 28 February 2013. These periods required supplemental of lighting because light intensity is very low in winter season in Korea. At 20th week (28 February 2013) after the provision of supplemental lighting, mature sweet pepper fruits (*C. annuum* L.) with ≥90% coloration were harvested to investigate their bioactive properties. Three replications (HPS, LEP and natural light) were used. Two experiments were conducted at the same time in the same place. We used completely randomised design. The generated photosynthetic photon flux density (PPFD) of HPS lamps was about 235.7 ± 82.7 μmol m^{-2} s^{-1}, for LEP – 539.3 ± 77.2 μmol m^{-2} s^{-1} and control samples at 171.3 ± 21.6 μmol m^{-2} s^{-1}. Paprika plants were grown on the slab that had three holes (a paprika plant was grown each hole), then (four Slabs) × (three plants per slab) per lamp (total twelve plants). All details are described in the study by Lee *et al*. (2014).

Determination of bioactive compounds and total antioxidant capacities

Polyphenols were extracted from lyophilised red sweet pepper with methanol (concentration 25 mg mL^{-1}) at room temperature twice during 3 h. Polyphenols were determined by Folin–Ciocalteu method with measurement at 750 nm using a spectrophotometer (Hewlett-Packard, model 8452A, Rockville, MD, USA). The results were expressed as mg of gallic acid equivalents (GAE) per g DM (Singleton *et al*., 1999). Flavonoids, extracted with 5% $NaNO_2$, 10% $AlCl_3 \times H_2O$ and 1 M NaOH, were measured at 510 nm. The extracts of condensed tannins (procyanidins) with 4% vanillin solution in MeOH were measured at 500 nm. (+) Catechin served as a standard for flavonoids and tannins, and the results were expressed as catechin equivalents (CE).

Total antioxidant capacity was determined with utilisation of four complementary assays: (i) 2, 2′-azinobis (3-ethyl-benzothiazoline-6-sulphonic acid) diammonium salt ($ABTS^{\bullet+}$) was generated by the interaction of ABTS (7 mM) and $K_2S_2O_8$ (2.45 mM). This solution was diluted with methanol until the absorbance in the samples reached 0.7 at 734 nm (Re *et al*., 1999). (ii) Ferric reducing/antioxidant power (FRAP) assay measures the ability of the antioxidants in the investigated samples to reduce ferric-tripiridyltriazine (Fe^{3+}-TPTZ) to a ferrous form (Fe^{2+}), which absorbs light at 593 nm (Benzie & Strain, 1996). (iii) Scavenging free radical potentials were tested in a methanolic solution of DPPH method. In its radical form, DPPH has an absorption band at 515 nm which disappears upon reduction by antiradical compounds (Brand-Williams *et al*., 1995). (iv) Cupric reducing antioxidant

(CUPRAC): this study is based on utilising the cooper (II) – neocuproine reagent as the chromogenic oxidising agent. To the mixture of 1 mL of cooper (II) – neocuproine and NH_4Ac buffer solution, acidified and nonacidified methanol extracts of fruits (or standard) solution (x, in mL) and H_2O [(1.1 – x) mL] were added to make the final volume of 4.1 mL. The absorbance at 450 nm was recorded against a reagent blank (Apak *et al*., 2004). Total ascorbic acid was determined by CUPRAC assay (Ozyurek *et al*., 2007) in water extract (100 mg of lyophilised sample and 5 mL of water).

Fluorometric and FTIR measurements

Fluorometric measurements were used for the evaluation of binding properties of red pepper fruit extracts to human serum albumin (HSA). Two-dimensional (2D-FL) and three-dimensional (3D-FL) fluorescence measurements were recorded on a model FP-6500, Jasco spectrofluorometer, serial N261332, Japan. The corresponding fluorescence emission spectra were recorded in the range of 300–500 nm upon excitation at 280 nm. The 3D-FL spectra were measured under the emission wavelength between 200 and 795 nm. The initial excitation wavelength was set at 200 nm. All solutions for protein interaction were prepared in 0.05 mol L^{-1} Tris–HCl buffer (pH 7.4), containing 0.1 mol L^{-1} NaCl (Park *et al*., 2014). The presence of polyphenols in the investigated pepper fruit samples was studied by Fourier transform infrared (FTIR) spectroscopy. A Nicolet iS 10 FTIR Spectrometer (Thermo Scientific Instruments LLC, Madison, WI, USA), with the smart iTRTM ATR (Attenuated Total Reflectance) accessory, was used to record IR spectra (Derenne *et al*., 2013).

Statistical analysis

To verify the statistical significance, means ± standard deviation of five independent measurements were calculated. One-way analysis of variance (ANOVA) for statistical evaluation of results was used, followed by Duncan's multiple range test to assess differences between group's means. P values of <0.05 were considered to be significant.

Results and discussion

Bioactive compounds in pepper samples

The effect of different light treatments on the antioxidant and bioactive compounds of pepper is presented in Table 1. The amount of polyphenols, tannins and flavonoids in red pepper cultivated in Korea before and after light treatment (control, HPS, LEP) was analysed in methanol extracts (Me). The strongest antioxidant capacity (μg TE per g DW) in a 2, 2′-azino-bis (3-ethyl-benzothiazoline-6-sulphonic acid) diammonium salt ($ABTS^{\bullet+}$) assay was in control (62.72 ± 5.44) and in a CUPRAC in LEP (66.51 ± 5.78). Our results are in line with others showing that the bioactive compounds correlated with the antioxidant activity (Kim *et al*., 2011). The obtained results of red pepper were close to the antioxidant enzyme activities of *Ganoderma lucidum* under the effect of LED light quality on growth and quality of the plant. According to Table 1, all bioactive compounds and their antioxidant capacities slightly differ, but not significantly, with small preference for the control, followed by LEP samples. Our results are in line with Marin *et al*. (2008) where the total phenolic content of sweet peppers ranged from 1.2 to 4.1 mg/100 g FW. Previous studies showed (Lee *et al*., 2014) that LEP wavelengths ranged from 300 nm to 750 nm with valid wavelengths of blue (430–450 nm) and red colours (650–670 nm), which have to be activated. LED has narrow range of wavelength. Wavelength of some LED lamps is set at 660 nm. The PPFD of LEP lamps were twice as high as that of the HPS lamp per unit distance, but the rate of decreased PPFD of the LEP per unit distance was higher than that of HPS lamp. Radiation of HPS and LEP lighting was 137% and 315% higher than control. Connected with our results Gómez *et al*. (2013) showed that the energy consumption metrics indicated that the electrical conversion efficiency for light-emitting diode intracanopy lighting (LED-ICL) into fruit biomass was 75% higher than that for HPS-OHL. Our results are in line with Samuoliene *et al*. (2013) that wavelength control using LED technology affects the production of secondary

Table 1 Bioactivity of methanol extracts of red sweet paprika

Indices	Control	LEP	HPS
Polyphenols, mgGAE/gDW	19.21 ± 1.32^{a}	19.89 ± 1.18^{a}	18.98 ± 1.31^{b}
Tannins, mg CE/gDW	3.34 ± 0.28^{a}	3.37 ± 0.31^{a}	3.26 ± 0.32^{a}
Flavonoids, mg CE/gDW	1.67 ± 0.14^{a}	1.75 ± 0.16^{a}	1.59 ± 0.11^{a}
ABTS, μMTE/gDW	62.72 ± 5.44^{ab}	64.13 ± 4.28^{a}	55.19 ± 3.41^{b}
DPPH, μMTE/gDW	13.16 ± 1.12^{a}	13.97 ± 1.09^{a}	12.67 ± 1.2^{b}
FRAP, μMTE/gDW	25.85 ± 2.43^{a}	25.87 ± 2.53^{a}	24.09 ± 1.87^{b}
CUPRAC, μMTE/gDW	60.35 ± 5.67^{b}	66.51 ± 5.78^{a}	62.00 ± 6.1^{ab}
Vit. C, mgAA	2.23 ± 0.21^{a}	2.08 ± 0.18^{a}	1.72 ± 0.12^{b}

Mean ± standard deviation of five measurements. Average in rows marked with different letters differ significantly ($P < 0.05$)
ABTS, 2, 2′-Azino-bis (3-ethyl-benzothiazoline-6-sulfonic acid) diammonium salt; FRAP, Ferric-reducing/antioxidant power; DPPH, 1, 1-diphenyl-2-picrylhydrazyl; CUPRAC, Cupric reducing antioxidant capacity; CE, catechin equivalent; GAE, gallic acid equivalent; DW, dry weight; TE, Trolox equivalent; LEP, HPS, light-emitting plasma and high-pressure sodium lamps; fluorescence shift in nm/nm; fluorescence intensity, arbitral units; Vit. C, vitamin C; AA, ascorbic acid.

Table 2 Three-dimensional fluorescence spectral characteristics of polyphenol pepper extracts, HSA and HSA-polyphenol complex

	Peak a		Peak b		Peak c		Peak d	
Samples	$\lambda_{ex}/\lambda_{em}$	**FI**	$\lambda_{ex}/\lambda_{em}$	**FI**	$\lambda_{ex}/\lambda_{em}$	**FI**	$\lambda_{ex}/\lambda_{em}$	**FI**
C	282/344	189.81	339/412	239.31	261/421	125.02	406/670	47.70
LEP	280/340	186.54	257/439	256.99	249/442	261.84	406/667	53.89
HPS	285/341	249.46	340/414	645.47	249/431	228.32	406/670	155.69
HSA	226/344	718.72	280/352	856.74	280/674	112.17	–	–
C + HSA	278/357	544.73	342/422	494.36	278/660	76.18	–	–
LEP + HSA	278/356	484.76	346/424	448.13	280/670	79.86	–	–
HPS + HSA	278/357	488.23	346/424	421.47	278/677	92.28	410/673	97.15
CA + HSA	228/354	249.86	278/687	759.12	278/687	84.15	–	–

C, control; LEP, HPS, light-emitting plasma and high-pressure sodium lamps; $\lambda_{ex}/\lambda_{em}$, fluorescence shift in nm/nm; FI, fluorescence intensity, arbitral units; HSA 2 mM $\times$ 10^{-5}, pepper extracts in methanol 100 μL from 25 mg mL^{-1} (0.83 mg mL^{-1} in fluorescence cuvette); HSA, human serum albumin; CA, caffeic acid.

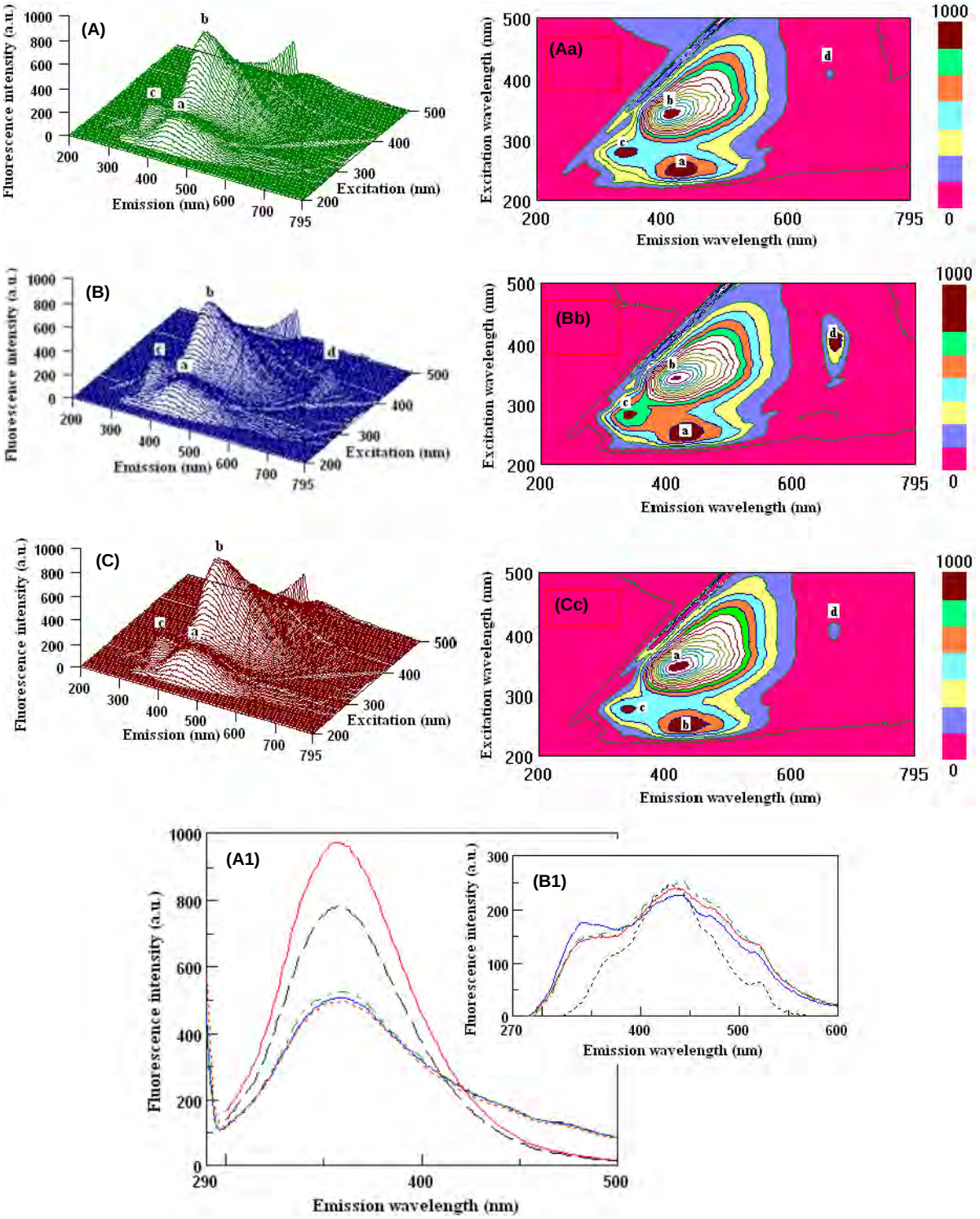
metabolites, because the metabolism of nutrients is light-dependent. It was shown that LEDs at 622 nm enhanced phenolic compounds. HPS lighting supplemented with different LEDs was not efficient, because the increase in some compounds did not influence the overall decrease in main bioactive phytochemicals (Samuoliene *et al*., 2013). The major compound in red sweet pepper is capsaicin, but this compound was not determined in the present report. The capsaicinoid contents of nine peppers showed a large variability (Zhuang *et al*., 2012). Also the sweet peppers are rich in ascorbic acid and it has been proven by the research conducted by the other researchers that a correlation exists between the ascorbic acid and the antioxidant scavenging activity (Deepa *et al*., 2007). Our present results are in accordance with Deepa *et al*. (2007), showing the highest phenolic content of 852.0 mg/100 g and the maximum content of ascorbic acid (3030 mg/100 g) at the green stage. The obtained results on ascorbic acid showed that light supplementation even decreased the amount of ascorbic acid by LEP and statistically decreased after treatment with HSP. Our results about the changes in ascorbic acid follow the conclusion of Samuoliene *et al*. (2013) that all supplemental LED colours had a negative effect on ascorbic acid levels. The correlation coefficients between antioxidant scavenging activity values of the four assays and ascorbic acid were from 0.17 to 0.73. Seven phenolics were identified in four pepper samples, while six phenolics were detected in other samples by Zhuang *et al*. (2012). Antioxidant activities of nine peppers correlated well with their total phenolic contents. This is in line with our obtained results after the light supplementation. The correlation coefficients between flavonoids and antioxidant activities varied between 0.44 and 0.98 and between polyphehols and antioxidant scavenging values between 0.39 and 0.73. Antioxidant activities found by DPPH and ABTS and total polyphenols content in raw pepper were in line with Hwang *et al*. (2012) and Sun *et al*. (2007), where the total phenolics content of red peppers were 4.2 μM CE/g FW, and DPPH values were 2.1 μMTE g^{-1}. Flavonoids represented 15% and 85% of the total phenolic content, respectively. Total phenolic content, which ranged from 1.2 to 4.1 mg/100 g FW, was significantly affected by the harvest time, but not by the production system assayed (Marin *et al*., 2008). Our results are in line with Hernandez-Carrion *et al*. (2015), where the amount of polyphenols in fresh sweet peppers (red, green and yellow) was similar to our results.

Fluorescence and FTIR properties

Table 2 and Fig. 1A, B, C, Aa, Bb, Cc show the fluorescence characteristics of the investigated samples. Control and LEP samples (150 vs. 190) were similar in their fluorescence intensity [arbitral units (a.u.)] and differ from HSP (320). According to the fixed peaks a and b, the fluorescence intensity of these peaks was similar in control and LEP samples (190 vs. 187 and

Figure 1 3D-fluorescence spectra of methanol (Me) pepper extracts: A, B, C, ControlMe, HSPMe, LEPMe; Aa, Bb, Cc, corresponding 3D-FL cross-spectral images of ControlMe, HSPMe, LEPMe. Excitation and emission wavelengths scan: wavelength scans are: 200–500 nm and 200–795 nm, respectively. In each sample, several peaks are shown (see Table 2). 2-D emission spectra of human serum albumin (HSA) in the presence of pepper polyphenols methanol extracts (A1) and in the absence (B1): A1, lines from the top: (1) HSA in methanol [λ_{em} = 357 nm, fluorescence intensity (FI) = 976.44], (2) HSA + 'caffeic acid (CA)' (λ_{em} = 354 nm, FI = 778.34), (3) HSA + 'HSP' (λ_{em} = 359 nm, FI = 526.54), (4) HSA + 'LEP' (λ_{em} = 358 nm, FI = 507.47; (5) HSA + 'Control' (λ_{em} = 360 nm, FI = 496.51). B1, lines from the top: (1) 'ControlMe' 9λ_{em} = 344 nm, FI = 152.86; λ_{em} = 443 nm, FI = 253.51); (2) 'LEPMe' (λ_{em} = 362 nm, FI = 150.59; λ_{em} = 435 nm, FI = 240.53); (3) 'HSPMe' (λ_{em} = 344 nm, FI = 176.75; λ_{em} = 439 nm, FI = 228.22); (4) CA (0.1 mM, λ_{em} = 432 nm, FI=247.70). At 2-D HSA at 2 mM $\times$ 10^{-5}; λex 280 nm and λ_{em} 300 nm; CA 0.1 mM; pepper extracts 0.83 mg mL^{-1}. HPS, LEP, high-pressure sodium and light-emitting plasma lamps.

239 vs. 257) and then in HSP sample. The interaction of polyphenols of the same samples with HSA (Fig. 1A1) showed the changes in the fluorescence intensity. The binding ability (%) of the polyphenols was in the following order: C (49.2)>LEP (48.0)>HSP (46.1)> caffeic acid (CA) (20.3). The measured fluores-



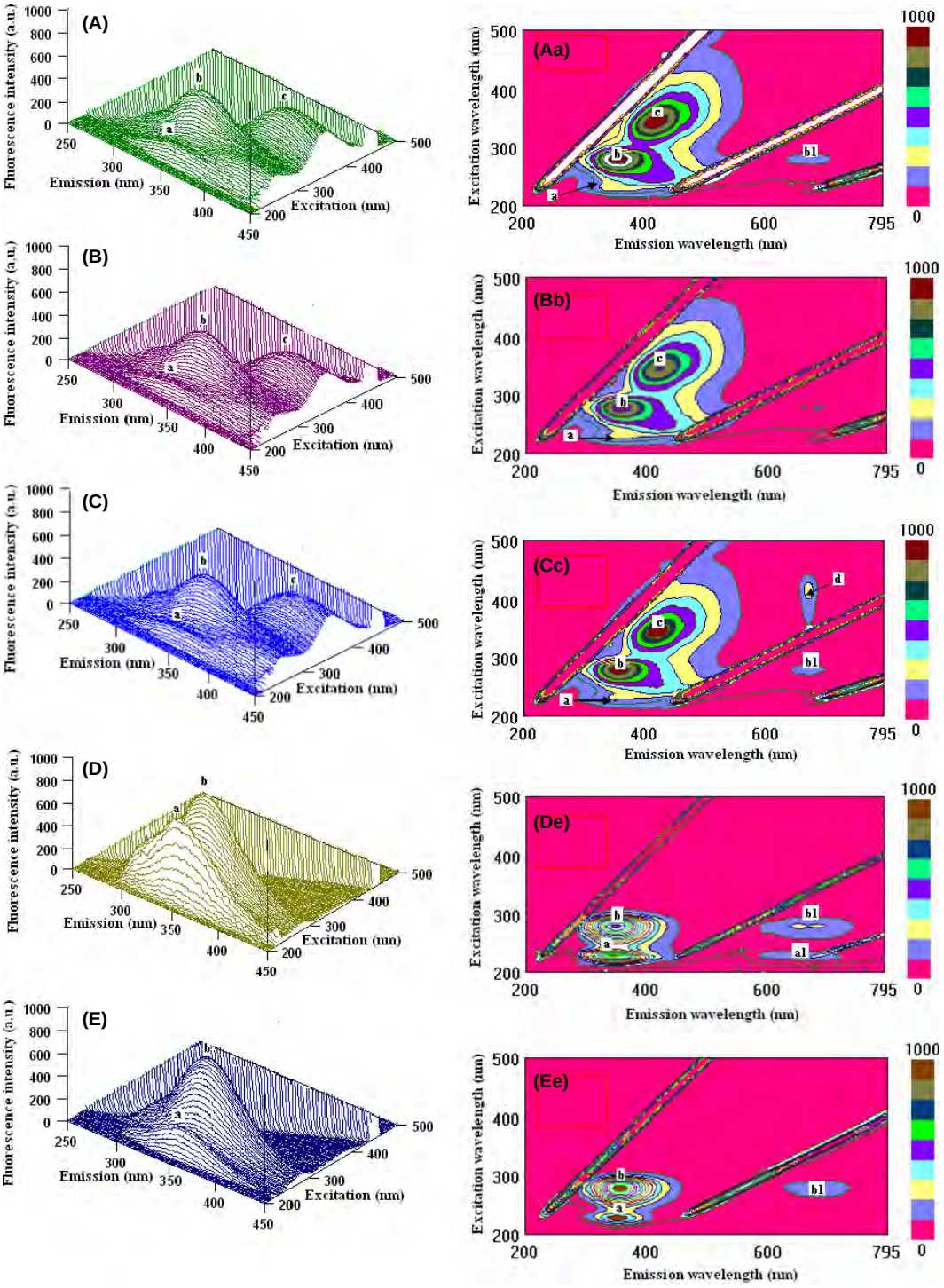


Figure 2 3D-fluorescence spectra of methanol (Me) pepper extracts with interaction of human serum albumin (HSA): A, B, C, D, E, ControlMe + HSA, HSPMe + HSA, LEPMe + HSA; HSA + Me; caffeic acid (CA) + HSA; Aa,Bb, Cc, De, Ee, corresponding 3D-FL cross-spectral images of ControlMe + HSA, HSPMe + HSA, LEPMe + HSA; HSA + Me; CA + HSA. Excitation wavelength scan: 200–500 nm. To 20 μL HSA were added 20 μL of 0.17 mg mL^{-1} of pepper methanol extract. The reaction was during 1 h at room temperature. Emission wavelength scan: 200–795 nm. In each sample, several peaks are shown (see Table 2). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

cence parameters varied not only in the intensity of the peaks but also in their maximum shift. The interaction of polyphenols of the same samples with HSA (Fig. 2, A–E) showed the changes in the fluorescence intensity. The binding ability (%) of the polyphenols were in the following order: LEP (80.4)> C (63.8)> HSP (58.0)> CA (36.) These numbers showed preference of the antioxidant properties of LEP sample, which were correlated with the binding results. The polyphenol extracts of all investigated samples showed higher binding properties than the pure caffeic acid. This can be explained by synergism of some phenolic acids found in the samples. The obtained results with the use in the calculation of all found fluorescence peaks showed that the 3D-FL can be used as a very precise analytical tool in the interaction of plant polyphenols with proteins. In FTIR spectra of three investigated samples, most of the bands were between 1637 and 777 cm^{-1}. These numbers are typical for the different hydroxyl-aromatic molecules that constitute the tannin extracts (Cui *et al.*, 2012). The tannins showed intense absorptions in the region of the C = O at around 1637 cm^{-1} and also two major bands 1342 and 1112 cm^{-1} to be assigned to aromatic C–O. Condensed tannins presented an overall structured profile, especially in the region between 1445 and 1107 cm^{-1}, where small differences were found between the samples. Most of the mentioned bands appeared as well in caffeic acid spectra, showing that the pepper samples did not change drastically during the light treatment. LEP and HSP spectra were similar in comparison with the control sample, where the same bands were only with lower intensity. Our results are in strong correspondence with Zhang *et al.* (2012), where the strong peaks at 1621, 1500 and 751 cm^{-1} in FTIR spectra in red paprika appeared. Table 3 in two regions 2007–1258 and 1258–750 cm^{-1} showed the matching between control and LEP samples of about 46% and control and HSP – 35%. Our results are in agreement with Bagdonaviciene *et al.* (2015). It was shown that different responses to supplemental LED lighting depend on the cultivar. The supplemental 470 nm illumination with HPS lamps resulted in increases in leaf area, fresh and dry weight, and the photosynthetic pigment content of the sweet pepper, but all of the supplemental LED lights suppressed their growth and development. The results depend on the LED light spectrum and relatively low irradiances (Trouwborst *et al.*, 2010). For the first time were determined the changes in bioactivity of red sweet pepper after the lightening. Among nine identified polyphenols found in chrysanthemum, three were yielded under green light, four were the greatest under red light, and two were produced in similar concentrations under both light types. The white and blue light appeared inefficient for polyphenol production. Our results were in accordance with Jeong *et al.* (2012), where it was stated that the chrysanthemum flowering and polyphenol production are influenced by light quality composition. Growth characteristics and phytochemical content of pepper seedlings were greatly influenced by supplemental LED light compared to control treatment. Red light increased the number of leaves, number of nodes, leaf width and plant fresh weight by 34%, 27%, 50% and 40%, respectively. Blue light increased the leaf length by 13%, and stem length and length of internode were increased by 17% and 34%, respectively, under grown far red light. After 15 days of light treatments, phytochemical concentrations of pepper plants were significantly changed. Blue light enhanced the total anthocyanin and chlorophyll concentration by six times and two times, respectively. Red light increased the total phenolic compound at least twofold; meanwhile, far red light reduced the ascorbic acid and antioxidant activity 31% and 66%, respectively, compared to control treatment (Chun *et al.*, 2011).

Table 3 Matching of the peaks (%) in the FTIR spectrum of extracted pepper polyphenols in MeOH and caffeic acid (CA)

	Matching of standard/sample (%)								
Range of bands	3015–2007 cm^{-1}			2007–1258 cm^{-1}			1258–750 cm^{-1}		
Samples	HPS	LEP	C	HPS	LEP	C	HPS	LEP	C
CA	14	14	10	7	6	12	8	7	7
HPS	100	93	26	100	96	31	100	98	35
LEP	93	100	37	96	100	46	98	100	45
C	26	37	100	31	46	100	35	45	100

C, control; LEP, HPS, light-emitting plasma and high-pressure sodium lamps.

Conclusions

Artificial light has changed the biological properties of red sweet pepper, which was found using 3D-FL and FTIR spectroscopy. LEP samples showed higher antioxidant and binding properties than HSP treatment. These results influence the quality of the plant.

Acknowledgments

This research was supported by the Wonkwang University research grants in 2014.

The authors are thankful to Dr. Elena Katrich (School of Pharmacy, Hebrew University of Jerusalem) for her technical assistance in determination of antioxidant activity and fluorescence. Special thanks to Judy Siegel-Itzkovich, The Jerusalem Post's Health & Science Editor, for her help in improving the English style of the manuscript. We confirm that we do not have any conflict of interest.

References

Apak, R., Guclu, K., Ozyurek, M. & Karademir, S.E. (2004). Novel total antioxidant capacity index for dietary polyphenol and witamin C and E, using their cupric ion reducing capacity in the presence of neocuproine: CUPRAC method. *Journal of Agricultural and Food Chemistry*, **52**, 7970–7981.

Bagdonaviciene, A., Brazaityte, A., Virsile, A. *et al*. (2015). Cultivation of sweet pepper (*Capsicum annuum L.*) transplants under high pressure sodium lamps supplemented by light-emitting diodes of various wavelengths. *Acta Scientiarum Polonorum-Hortorum Cultus*, **14**, 3–14.

Benzie, I.F.F. & Strain, J.J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of antioxidant power: the FRAP assay. *Analytical Biochemistry*, **239**, 70–76.

Brand-Williams, W., Cuvelier, M.E. & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *Food Science and Technology (Lond.)*, **28**, 25–30.

Chun, I.-J., Kwon, S.T., Moon, H.J., Azad, M.D. & Obyedul, K. (2011). Response of the growth characteristics and phytochemical contents of pepper (*Capsicum annuum L.)* seedlings with supplemental LED light in glass house. *Protected Horticulture and Plant Factory*, **20**, 182–188.

Cui, X.X., Zhang, X.L., Tang, H.W., Zhang, L.P., Xu, C.H. & Sun, S.Q. (2012). Study on extracts of active substances from larch bark by FTIR spectroscopy. *Spectroscopy and Spectral Analysis*, **32**, 1810–1814.

Darko, E., Heydarizadeh, P., Schoefs, B. & 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**, 20130243/1–20130243/7.

Deepa, N., Kaur, C., George, B., Singh, B. & Kapoor, H.C. (2007). Antioxidant constituents in some sweet pepper (*Capsicum annuum L.)* genotypes during maturity. *LWT-Food Science and Technology*, **40**, 121–129.

Derenne, A., Van Hemelryck, V., Lamoral-Theys, D., Kiss, R. & Goormaghtigh, E. (2013). FTIR spectroscopy: a new valuable tool to classify the effects of polyphenolic compounds on cancer cells. *Biochimica et Biophysica Acta*, **1832**, 46–56.

Gómez, C., Morrow, R.C., Bourget, C.M., Massa, G.D. & Mitchell, C.A. (2013). Comparison of intracanopy light-emitting diode towers and overhead high-pressure sodium lamps for supplemental lighting of greenhouse-grown tomatoes. *Horttechnology*, **23**, 93–98.

Hao, X. & Papadopoulos, A.P. (1999). Effects of supplemental lighting and cover materials on growth, photosynthesis, biomass partitioning, early yield and quality of greenhouse cucumber. *Scientia Horticulturae*, **80**, 1–18.

Hernandez-Carrion, M., Hernando, I. & Quiles, A. (2015). Tissue microstructure, physicochemical properties, and bioactive compound locations in different sweet pepper types. *Food Science and Technology International*, **21**, 3–13.

Hwang, I.G., Shin, Y.J., Lee, S., Lee, J. & Yoo, S.M. (2012). Effects of different cooking methods on the antioxidant properties of red pepper (*Capsicum annuum* L.). *Preventive Nutrition and Food Science*, **17**, 286–292.

Jeong, S. W., Park, S., Jin, J. S. *et al*. (2012). Influences of four different light-emitting diode lights on flowering and polyphenol variations in the leaves of chrysanthemum (*Chrysanthemum morifolium*). *Journal of Agricultural and Food Chemistry*, **60**, 9793–9800.

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

Kim, Y. H., Bae, H., Lee, G. *et al*. (2011). [Effect of different light of LED light quality on growth and antioxidant enzyme activities of *Ganoderma lucidum*]. *Zhongguo Zhong Yao Za Zhi*, **36**, 2471–2474.

Lee, J.-W., Kim, H. C., Jeong, P. H., Ku, Y.-G. & Bae, J. H. (2014). Effects of supplemental lighting of high pressure sodium and lighting emitting plasma on growth and productivity of paprika during low radiation period of winter season. *Korean Journal of Horticultural Science and Technology*, **32**, 346–352.

Li, Q. & Kubota, C. (2009). Effects of supplemental light quality on growth and phytochemicals of baby leaf lettuce. *Environmental and Experimental Botany*, **67**, 59–64.

Li, T., Heuvelink, E. & Marcelis, L.F. (2015). Quantifying the source-sink balance and carbohydrate content in three tomato cultivars. *Frontiers in Plant Science*, **6**, 416 (10 pages).

Lin, K.-H., Huang, M.-Y., Huang, W.-D., Hsu, M.-H., Yang, Z.-W. & 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.

Liu, R.-R., Kou, L.-P. & Yan, R.-X. (2013). Effects of LED green light irradiation on quality of vegetables in shelf life. *Beifang Yuanyi*, **8**, 5–9.

Marin, A., Gil, M. I., Flores, P., Hellin, P. & Selma, M. V. (2008). Microbial quality and bioactive constituents of sweet peppers from sustainable production systems. *Journal of Agricultural and Food Chemistry*, **56**, 11334–11341.

Ozyurek, M., Guclu, K., Bektasoglu, B. & Apak, R. (2007). Spectrophotometric determination of ascorbic acid by the modified CUPRAC method with extractive separation of flavonoids–La (III) complexes. *Analytica Chimica Acta*, **588**, 88–95.

Park, Y.S., Namieśnik, J., Vearasilp, K. *et al*. (2014). Bioactive compounds and the antioxidant capacity in new kiwi fruit cultivars. *Food Chemistry*, **165**, 354–361.

Peng, L.-X., Zou, L., Fan, Y. & Zhao, G. (2015). Effects of light on growth, levels of anthocyanin, concentration of metabolites in *Fagopyrum tataricum* sprout cultures. *International Journal of Food Science & Technology*, **50**, 1382–1389.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M. & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology & Medicine*, **26**, 1231–1237.

Samuoliene, G., Brazaityte, A., Sirtautas, R. *et al*. (2013). LED illumination affects bioactive compounds in romaine baby leaf lettuce. *Journal of the Science of Food and Agriculture*, **93**, 3286–3291.

Sim, K. H. & Sil, H. Y. (2008). Antioxidant activities of red pepper (*Capsicum annuum*) pericarp and seed extracts. *International Journal of Food Science & Technology*, **43**, 1813–1823.

Singleton, V.L., Orthofer, R. & Lamuela-Raventos, R.M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods of Enzymology*, **299**, 152–178.

Sun, T., Xu, Z., Wu, C.T., Janes, M., Prinyawiwatkul, W. & No, H.K. (2007). Antioxidant activities of different colored sweet bell peppers (*Capsicum annuum L.*). *Journal of Food Science*, **72**, S98–102.

Trouwborst, G., Oosterkamp, J., Hogewoning, S. W., Harbinson, J. & van Ieperen, W. (2010). The responses of light interception, photosynthesis and fruit yield of cucumber to LED-lighting within the canopy. *Physiologia Plantarum*, **138**, 289–300.

Yazdizadeh Shotorbani, N., Jamei, R. & Heidari, R. (2013). Antioxidant activities of two sweet pepper *Capsicum annuum L.* varieties phenolic extracts and the effects of thermal treatment. *Avicenna Journal of Phytomedicine*, **3**, 25–34.

Yu, S.M., Ramkumar, G. & Lee, Y.H. (2013). Light quality influences the virulence and physiological responses of *Colletotrichum acutatum* causing anthracnose in pepper plants. *Journal of Applied Microbiology*, **115**, 509–516.

Zhang, W.W., Liu, L.L., Wu, Y.W., Ouyang, J. & Sun, S.Q. (2012). Rapid determination of Sudan dyes adulterated in natural paprika red by FTIR. *Spectroscopy and Spectral Analysis*, **32**, 958–961.

Zhuang, Y., Chen, L., Sun, L. & Cao, J. (2012). Bioactive characteristics and antioxidant activities of nine peppers. *Journal of Functional Foods*, **4**, 331–338.