

Research Article



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다양한 광원이 배추 내 Carotenoid와 Glucosinolate 함량에 미치는 영향

성호영, 조이경, 천진혁, 우현녕, 김선주*

Effects of Various Light Sources on the Carotenoid and Glucosinolate Contents in Chinese Cabbage (*Brassica rapa* L. ssp. *pekinensis*)

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Abstract

BACKGROUND: Chinese cabbage biosynthesizes various phytochemicals including carotenoids and glucosinolates. Environmental stress has a major effect on the growth and yields of vegetables, and can significantly affect nutritionally important phytochemicals. Phytochemicals of plants are influenced by light, temperature, carbon dioxide, and growing conditions. The aim of this study was to investigate the effect of various light sources on carotenoid and glucosinolate contents in Chinese cabbage.

METHODS AND RESULTS: [Experiment I] Set the control (field control, FC) on the ground. Using acrylic sunlight, experiments were set up transparency box (field transparency, FT), red box (field red, FR) and blue box (field blue, FB). [Experiment II] Set the control (chamber control, CC) in the greenhouse. Using plant growth chamber with artificial light, experiments were set up LED red (chamber red, CR), LED blue (chamber blue, CB), LED mixed red+blue (chamber red+blue, CRB) and fluorescent (chamber fluorescent, CF). After plant growth, Chinese

cabbage was harvested at 110 days after sowing (DAS). The status of plants growth (leaf length, width, fresh weight etc.) was immediately investigated. Carotenoid and GSL contents were analyzed by HPLC. [Experiment I] Results documented that the ranges of total carotenoid contents were 25.39 ~ 58.80 mg/kg dry wt for lutein, 0.84~ 4.22 mg/kg dry wt for zeaxanthin, and 3.85~18.71 mg/kg dry wt for β -carotene. Lutein was the highest for the content and the largest for the variation as well. [Experiment II] Results documented that the ranges of total carotenoid contents were 24.66~137.96 for lutein, 2.51~20.65 for zeaxanthin, and 8.40~49.80 mg/kg dry wt for β -carotene. The total carotenoid contents of CR (156.62) and CB (115.90) were 1.6~2.3 times larger than the other treatments, and β -carotene content was about twice as high as that of the other treatments on the CR (38.74 mg/kg dry wt.). [Experiment I] Total GSL content was the highest in FT (19.76) that was higher 1.7 times than the lowest treatment (11.39 μ mol/g dry wt.). [Experiment II] The total content of GSL was highest in CRB (4.19) and lowest in CF (2.88 μ mol / g dry wt.). In the CRB, total GSL contents (4.19 μ mol/g dry wt.) was the highest.

CONCLUSION: Total and individual carotenoid and GSL contents in Chinese cabbage show significant differences under different light sources. Red and blue lights contribute

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to significant carotenoids expression and antioxidant activity for nutrition and health benefits. These results concluded that the introduction of varying lights affected the synthesis of important nutrient compounds in Chinese cabbage. It is predicted that the application of good light source enhances the accumulation of functional compounds.

Key words: Carotenoids, Chinese cabbage, Glucosinolates, Light sources

서론

(*Brassica rapa* L. ssp. *pekinensis*)
(Brassicaceae)
25%
carotenoids glucosinolates(GSLs)
(Hwang, 2010).
LED (Light-emitting diode)
가 (Heo *et al.*, 2013). LED
carotenoid, GSL 가
(Lefsrud *et al.*, 2008).
(630 ~ 780 nm) 가
660 nm
LED 가
(Matsuda *et al.*, 2004;
Massa *et al.*, 2008). (450~500 nm)
, CO₂
(Schwartz and Zeiger, 1984).
가 (Goins *et al.*, 1997),
(Yorio *et al.*, 2001; Matsuda *et al.*, 2004).
Carotenoid 40 가
polyene chain 15 가
(Hirschberg, 2001). carotenoid 가
(Miglio *et al.*, 2008). Carotenoid (400~500 nm)
(light harvesting)
(Lee *et al.*, 2010).
GSLs

R 200
(Clarke, 2010). GSLs 7
(alanine, methionine, valine, leucine, isoleucine,
phenylalanine, tryptophan) (Fahay
et al., 2001), methionine aliphatic GSLs,
tryptophan indolic GSLs, phenylalanine
aromatic GSLs 3가
(Halkier and Du, 1997; Huseby *et al.*, 2013).
GSL
GSL
가
(Fenwick *et al.*, 1983).
가 가 LED
가 가 LED
가
carotenoid GSL
3 (, ,)
[I] (growth chamber)
LED(, , +)
[II] 2가

재료 및 방법

시약

Ethanol (C₂H₅OH), Hexane (C₆H₁₄) Fisher Scientific
Korea, Ltd. (Seoul, Korea) , dichloromethane (C₂H₅Cl₂)
Merck KGaA (Dermstadt, Germany)
Acetonitrile (CH₃CN), methanol (CH₃OH) J.T. Baker
Chemical Co. (Phillipsburg, NJ, USA) , ethyl acetate
(CH₃COOC₂H₅) Burdick & Jackson (Ulsan, Korea)
. Sodium acetate (NaC₂H₃O₂·3H₂O) Samchun
Pure Chemical Co., Ltd. (Pyeongtaek, Korea) ,
potassium hydroxide (KOH) Daejung Chemicals &
Metals Co., Ltd. (Siheung, Korea)
Sigma-Aldrich Chemical Co.
(St Louis, MO, USA) , α- β-
Wako Pure Chemical Industries, Ltd. (Osaka, Japan)
DEAE-Sephadex A-25
GE Healthcare Bio-Sciences AB (Uppsala, Sweden)
, Sinigrin (2-propenyl GSL) aryl sulfatase (type
H-1, EC 3.1.6.1) Sigma-Aldrich Chemical Co. (St
Louis, MO, USA)

아크릴 상자(field)를 이용한 태양광 실험 [실험 I]

(주)

2015 8 10



Fig. 1. Sunlight with acrylic treatment of experiment group. (a), red acrylic; (b), blue acrylic; (c), clear acrylic (Experiment I).

(plug tray, 50) (High, 卍) ,)
 ,)
 .
 30 (DAS, day after sowing) 50 48 (field control, FC) (field transparency, FT), (field red, FR), (field blue, FB) 4 (Fig. 1), 110 DAS (가 가 ,) -70°C (SFDSF 12, Samwon Freezing Engineering Co., Busan, Korea)

식물 생장기(growth chamber)를 이용한 인공광원 실험 [실험 II]

, 36 DAS (15×15×19 cm³) (chamber control, CC) (Growth Chamber) LED (chamber red, CR), LED (chamber blue, CB), LED + (chamber red+blue, CRB), (chamber fluorescent, CF) 7 (103 DAS~109 DAS)(Fig. 2). 160~180 μmol·m⁻²·s⁻¹, / 11/13 h, / 12/10°C 60~70% . 110 DAS (,) -70°C (SFDSF 12, Samwon Freezing Engineering Co., Busan, Korea)

Carotenoid 추출 및 HPLC 분석

500 mg 50 mL-Falcon tube ethanol 5 mL , (vortex) (75°C) 5 . 80% KOH 1.5 mL (75°C) 10 . hexane 2.5 mL (vortex) , (3,000 rpm, 3

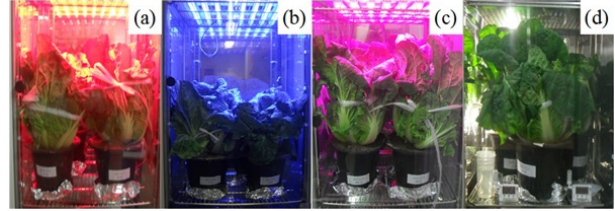


Fig. 2. Artificial light source (LED) treatment of experiment group. (a), chamber red light (CR); (b), chamber blue light (CB); (c), chamber red+blue light (CRB); (d), chamber fluorescent lamp (CF) (Experiment II).

min) (hexane) . 2 , 3 (4 0°C) , dichloromethane : methanol= 50:50 (v/v) 1 mL sonicator . 0.45 μm hydrophilic PTFE syringe filter (13 mm) , HPLC vial HPLC . Carotenoid YMC carotenoid C30 column (250×4.6 mm I.D., particle size 5 μm) HPLC (Perkin Elmer Flexar, Inc., MA, USA) (detective wavelength) 454 nm, (flow rate) 1.0 mL/min, (column temperature) 40°C , 10.0 μL . solvent A [water: methanol=25:75 (v/v)] solvent B (ethyl acetate) solvent B 60% 4 70% 가 , 9 75% 가 20 , 23 100% 가 28 , 28.1 60% 35 . 4가 (, , α- , β-) HPLC (area) .

GSL 추출 및 HPLC 분석

100 mg 2.0 mL-Eppendorf tube , 70%(v/v) boiling methanol 1.5 mL (vortex) . (75°C) 5 (crude) GSLs . 2.0 mL-Eppendorf tube (12,000 rpm, 4°C, 10 min) (test tube) . 2 , 3 . Mini-column (1000 μL pipet tip) DEAE Sephadex A-25 5 cm가 (crude extract) GSLs 가 pasteur pipet 가 2 mL pasteur pipet . Mini-column paraffin film 가 , aryl sulfatase solution 75 μL 16~18 , 2.0 mL-Eppendorf tube 0.5

Table 1. Plant growth of Chinese cabbage in all treatments

Treatment	leaf length (cm)	leaf width (cm)	leaf number	head length (cm)	head width (cm)	head weight (kg)	fresh weight (1/8, g)	dry weight (g)	water content (%)
FC	30.3±2.63a ^{a)}	23.3±1.16a	35.3±6.06a	23.3±1.32a	15.7±1.91a	1.34±0.33a	225±62.6a	17.0±2.1a	92.3±1.00a
FT	24.0±1.53a	14.3±1.31c	41.0±3.32a	18.0±1.03b	11.8±0.57b	0.39±0.06b	135±19.6a	10.0±0.2b	92.4±1.22a
FR	30.0±4.13a	18.0±1.94bc	42.3±3.96a	19.9±5.56a	12.8±1.71ab	0.73±0.46ab	150.5±63.4a	10.6±2.2b	92.8±1.03a
FB	27.8±3.83a	19.1±3.41ab	41.5±4.15a	19.1±1.07a	13.0±1.64ab	0.55±0.15b	149±66.8a	10.2±2.9b	92.7±1.11a
CC	39.6±3.622a	27.3±4.01a	41.8±3.77a	24.4±0.43ab	16.5±1.10a	2.80±0.40a	275.8±31.35a	14.8±1.99a	94.63±0.3a
CF	36.3±5.93a	24.4±4.30a	43.7±3.40a	23.1±1.44ab	13.6±1.15ab	2.10±0.21ab	280.2±15.92a	17.3±1.09a	93.81±0.3ab
CR	34.5±2.47a	25.78±10.20a	45.0±1.58a	19.2±2.11bc	11.3±1.66bc	1.40±0.38b	189.3±17.82b	13.4±1.95a	92.96±0.4ab
CB	33.6±4.09a	22.08±2.88a	43.5±3.50a	17.2±2.04c	8.8±0.65c	1.10±0.35b	170.0±29.83b	12.2±0.71a	92.7±0.8b
CRB	37.78±3.01a	25.82±4.48a	44.0±1.41a	25.8±4.48a	12.1±2.13b	1.50±0.66b	205.9±47.46ab	14.0±2.24a	93.01±1.1ab

^{a)} Within each column values follow by the same small letters are not significantly different at $P < 0.05$, using Tukey's multiple-range test. ($n=4$, except for CF $n=3$). Each means that FC, field control; FT, field transparency; FR, field red; FB, field blue; CC, chamber control; CF, chamber fluorescent; CR, chamber red; CB, chamber blue; CRB, chamber red+blue.

mL 3
hydrophilic PTFE syringe filter
vial HPLC
Inertsil ODS-3 column (150×3.0 mm I.d., particle size 3 μm), 가 Inertsil ODS-2 Cartridge Guard column E (10×2.0 mm I.d., particle size 5 μm)(GL Science, Tokyo, Japan) HPLC (Agilent Technologies, CA, USA)
(detection wavelength) 227 nm, (flow rate) 0.4 mL/min, (column temperature) 40°C
10.0 μL
solvent A () solvent B (acetonitrile, CH3CN)
27
B 2 0% 7 0% 10%
가 , 16 10% 31% 가 . 19
31% 21 31% 0% , 27
0% . GSL 3
sinigrin HPLC (area)
response factor
(ISO 9167-1, 1992).

통계 분석

carotenoid, GSL Microsoft Office Excel 2010 (average value) (SD, standard deviation) IBM SPSS[®] 21 Statistics (P) 0.05 Tukey

결과 및 고찰

배추의 생장 [I]

(field control, FC), (field transparency, FT), (field red, FR), (field blue, FB) FR
(30.0) 가 FT (24.0 cm) 가
(Table 1). FR (42.3) 가 FC (35.3) 가 . (640~690 nm) (420~470 nm) 가
(Bang *et al.*, 2012), [I] FR (18.0)
FB (19.1 cm)
FT (18.0 cm) (11.8 cm)
가 . FC (225)가 가
FT (135 g)가 가 , FC (17.0) 가 FT (10 g) 가
[II] (growth chamber) LED (, , +)
(chamber control, CC), (chamber fluorescent, CF), LED (chamber red, CR), LED (chamber blue, CB), LED + (chamber red+blue, CRB)
CC (39.6) 가 ,
CC (27.3) 가 . CR (45.0)
가 . CF (280.2) 가
LED

아크릴 상자의 파장 분석

가 , 가
20~30%
630~780 nm 90% (Fig. 3).
가
20~30% 430~490 nm
75~85%

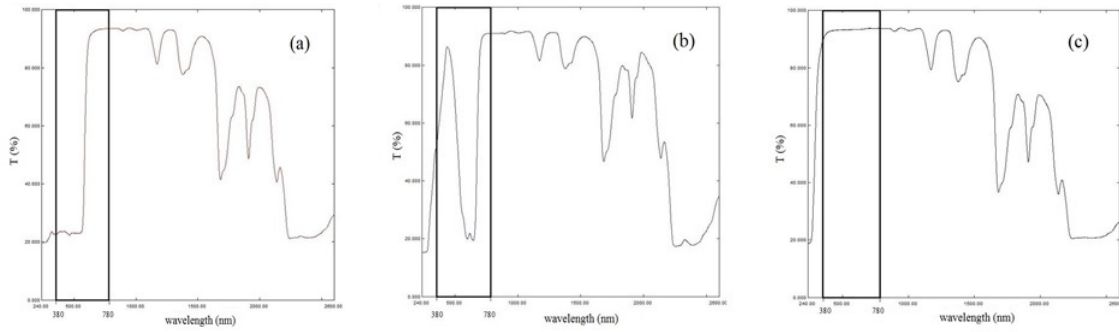


Fig. 3. Transmittance of acrylic box. (a), red acrylic box; (b), blue acrylic box; (c), transparent acrylic box.

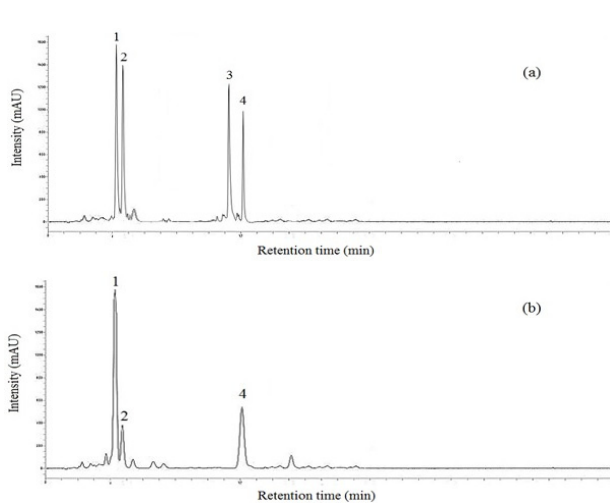


Fig. 4. HPLC chromatograms of carotenoids separated from Chinese cabbage. (a), Carotenoid standards; (b), CRB treatment. Peak 1, Lutein; 2, Zeaxanthin; 3, α -carotene; 4, β -carotene.

가 90%가 .
 가 ,
 가 가
 가 .
 광원에 따른 carotenoid 함량
 carotenoid HPLC , carotenoid
 3 (, , β -)가 (Fig. 4).
 [I] carotenoid
 25.39~58.80, 0.84~4.22, β - 3.85~18.71
 mg/kg dry wt. (Table 2). FC
 가 53.67 가 , FT 가 28.31 mg/kg dry wt.
 가 . β - FC 가
 (16.06), FB (13.12)가 FR
 (5.38), FT (5.79 mg/kg dry wt.) 2.4 .
 [I] carotenoid FC 가

Table 2. Carotenoid contents (mg/kg dry wt.) of various light source treatment in Chinese cabbage (Experiment I and II)

No.	Treatment	Lutein	Zeaxanthin	β -Carotene	Total
1	FC	53.67±3.30a ^{a)}	3.68±0.40a	16.06±1.83a	73.41±5.46a
2	FT	28.31±1.81c	2.03±0.42b	5.79±0.71b	36.12±2.04c
3	FR	40.24±4.61b	2.14±0.79b	5.38±1.10b	47.76±4.87b
4	FB	47.38±4.32ab	2.20±0.25b	13.12±2.74a	62.69±6.00ab
Ave		42.40±10.11	2.88±0.85	10.09±4.95	55.00±15.01
No.	Treatment	Lutein	Zeaxanthin	β -Carotene	Total
1	CC	35.41±12.58c	11.90±5.28a	21.84±9.61ab	69.15±23.63bc
2	CF	59.52±10.83bc	6.47±4.01a	14.96±0.71b	80.95±14.96b
3	CR	108.35±21.43a	9.53±2.40a	38.74±6.57a	156.62±24.99a
4	CB	81.35±14.69ab	8.91±3.99a	25.68±11.14ab	115.90±29.57a
5	CRB	69.25±5.54bc	6.94±3.09a	17.77±3.51b	93.96±5.87ab
Ave		71.37±28.37	8.87±4.32	24.26±11.21	104.49±38.06

^{a)} Within each column values follow by the same small letters are not significantly different at $P < 0.05$, using Tukey's multiple-range test. ($n=4$, except for CF $n=3$). Each means that FC, field control; FT, field transparency; FR, field red; FB, field blue. CC, chamber control; CF, chamber fluorescent; CR, chamber red; CB, chamber blue; CRB, chamber red+blue.

Table 3. Glucosinolates identified in Chinese cabbage with different light sources

No. ^{a)}	RT ^{b)}	Trivial names	Molecular weight (<i>m/z</i>) ^{c)}	Response factor ^{d)}
1	9.67	Progoitrin	309	1.09
2	11.75	Glucoalyssin	371	1.07
3	11.99	Gluconapoleiferin	323	1.00
4	13.15	Gluconapin	293	1.11
5	15.17	Glucobrassicinapin	307	1.15
6	16.07	Glucobrassicin	368	0.29
7	16.79	4-Methoxyglucobrassicin	398	0.25
8	17.14	Gluconasturtiin	343	0.95
9	18.46	Neoglucobrassicin	398	0.20

^{a)} No, the elution orders of HPLC analysis. ^{b)} RT,retentiontime (min).
^{c)} As a desulfo-glucosinolate. ^{d)} The international organization for standardization (ISO 9167-1,1992).

α β
α
(Susan and Olle, 1990)

가

[II] carotenoid
 24.66~137.96, 2.51~20.65, β 8.40~49.80
 mg/kg dry wt. (Table 2). 108.35
 mg/kg dry wt. 가 β CR
 38.74 가 , CF 14.96
 mg/kg dry wt. 가 .
 carotenoid CR (156.62) CB
 (115.90 mg/kg dry wt.)가 1.6~2.3

(Kim *et al.*, 2013). CR

β β
(Wu *et al.*, 2007)

II] carotenoid , LED
 가

가 가 (Heo *et al.*, 2010)

광원에 따른 GSL 함량
 GSLs HPLC , 9 GSLs
 (progoitrin, glucoalyssin, gluconapoleiferin, gluconapin, glucobrassicinapin, glucobrassicin, 4-methoxyglucobrassicin, gluconasturtiin, neoglucobrassicin)
 (Table 3 and Fig. 5). [I] GSL FT
 가 19.76 가 , FR 가 11.39 μmol/g dry

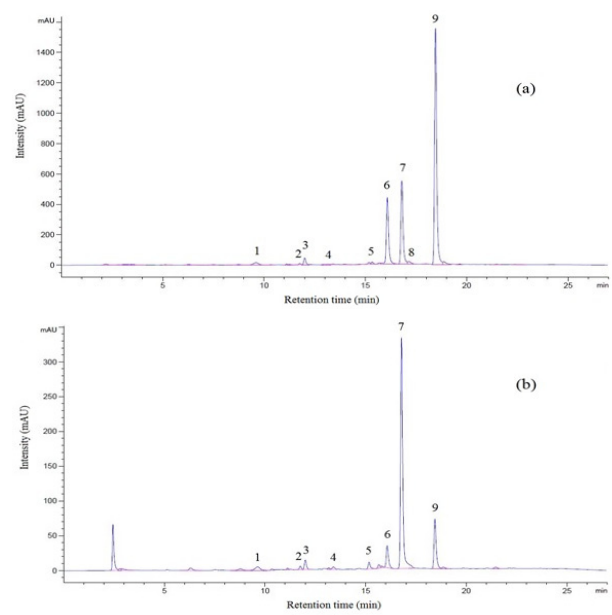


Fig. 5. HPLC chromatograms of glucosinolates separated from Chinese cabbage. (a), sun-light (field control) and (b), artificial-light (growth chamber control). Peak 1, Progoitrin; 2, Glucoalyssin; 3, Gluconapoleiferin; 4, Gluconapin; 5, Glucobrassicinapin; 6, Glucobrassicin; 7, 4-Methoxyglucobrassicin; 8, Gluconasturtiin; 9, Neoglucobrassicin.

wt. 가 (Table 4). FT glucobrassicin
 3.74 FR glucobrassicin 1.68 μmol/g
 dry wt. 2 . Glucobrassicin indole-
 3-carbinol , indole-3-carbinol
 (Zhang
et al., 1994).
 가 가
 (Brew *et al.*, 2009; Pedras *et al.*, 2006). FT
 neoglucobrassicin 8.58 μmol/g dry wt.
 3 . [I] GSL
 neoglucobrassicin FC 25%, FT

Table 4. Glucosinolate contents ($\mu\text{mol/g}$ dry wt.) of various light source treatment in Chinese cabbage (Experiment I and II)

No.	Trivial names	Sun-lights with acrylic treatment			
		FC	FT	TR	FB
1	Progoitrin	1.02±0.07ba)	1.16±0.04a	1.02±0.02b	0.98±0.04b
2	Glucoalyssin	0.22±0.00a	0.24±0.01a	0.17±0.01b	0.15±0.01b
3	Gluconapoleiferin	0.90±0.07b	1.21±0.05a	0.89±0.02b	0.93±0.08b
4	Gluconapin	0.20±0.02a	0.13±0.01b	0.18±0.02a	0.16±0.01ab
5	Glucobrassicinapin	0.70±0.01a	0.37±0.02c	0.57±0.01b	0.53±0.03b
6	Glucobrassicin	2.44±0.14b	3.74±0.10a	1.68±0.04c	1.89±0.08c
7	4-Methoxyglucobrassicin	2.67±0.15c	3.67±0.12a	3.31±0.10b	3.46±0.17ab
8	Gluconasturtiin	0.69±0.03a	0.67±0.03a	0.68±0.02a	0.60±0.02b
9	Neoglucobrassicin	2.93±0.21c	8.58±0.11a	2.88±0.06c	3.39±0.28b
	Total	11.75±0.64bc	19.76±0.42a	11.39±0.18c	12.10±0.17b

No.	Trivial names	LED-light treatment				
		CC	CF	CR	CB	CRB
1	Progoitrin	0.39±0.01a	0.17±0.01b	NDb)	0.18±0.01b	0.25±0.02b
2	Glucoalyssin	0.14±0.01a	0.05±0.00b	ND	0.05±0.00b	0.05±0.00b
3	Gluconapoleiferin	0.37±0.02a	0.19±0.01c	0.14±0.01c	0.26±0.01b	0.29±0.02b
4	Gluconapin	0.09±0.01b	ND	0.33±0.06a	ND	0.28±0.00b
5	Glucobrassicinapin	0.34±0.01a	0.10±0.02d	0.08±0.01d	0.13±0.01c	0.19±0.01b
6	Glucobrassicin	0.28±0.01c	0.22±0.00d	0.32±0.01b	0.41±0.02a	0.32±0.02b
7	4-Methoxyglucobrassicin	2.56±0.12a	1.74±0.03b	1.33±0.06c	1.82±0.04b	2.34±0.09a
8	Gluconasturtiin	ND	0.14±0.02a	0.18±0.03a	0.16±0.00a	0.16±0.01a
9	Neoglucobrassicin	0.43±0.01c	0.31±0.01c	0.57±0.02b	0.75±0.08a	0.56±0.04b
	Total	4.59±0.17a	2.88±0.03c	2.95±0.10c	3.76±0.08b	4.19±0.16a

^{a)} Within each column values follow by the same small letters are not significantly different at $P < 0.05$, using Tukey's multiple-range test ($n=4$). Each means that FC, field control; FT, field transparency; FR, field red; FB, field blue. CC, chamber control; CF, chamber fluorescent; CR, chamber red; CB, chamber blue; CRB, chamber red+blue.
^{b)} ND, not detected.

43% 가 , 4-methoxyglucobrassicin FR
 FB 29% 가 . 가 .
 [II] GSL CC (4.59) CRB
 (4.19) , CF (2.88 $\mu\text{mol/g}$ dry wt.)
 가 (Table 4). Gluconapin CR (0.33)
 CRB (0.28) CC (0.09 $\mu\text{mol/g}$ dry wt.)
 3.5 , isothiocyanate
 (Padilla *et al.*, 2007). CRB
 GSL , GSL (4.19 μ
 mol/g dry wt.) 1.4 . [II]
 GSL 4-methoxyglucobrassicin
 45~60% 가 , neoglucobrassicin 9~20%
 . [I] GSL FT
 가
 , [II] CRB CR,
 CB GSL .
 (+) 가 LED

Note

The authors declare no conflict of interest.

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