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EFFECTS OF DIFFERENT LIGHT SOURCES ON THE QUALITY AND SAFETY OF NON-HEADING CHINESE CABBAGE

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Abstract

Effects of different light sources on the quality of non-heading Chinese cabbage was investigated. Chinese cabbage was dealed with five light courses: red, blue, green, red plus blue light, and dysprosium lamp. The fresh and dry mass of the seedlings under red plus blue light were maximum but the content of vitamin C and crude protein were highest under blue light. The energy efficiency was highest under red plus blue light. The content of nitrogen, phosphorus, and potassium under blue and red plus blue light were significantly higher than others. All LED treatments reduced the content of nitrate and nitrite, which enhanced the safety of seedlings. While the red plus blue light, and blue light increased the activity of nitrate and nitrite reductase. The red plus blue light treatment was found to be effective for improving the nutritional quality mostly and safety of non-heading Chinese cabbage.

Introduction

Vegetables are indispensable foods in people's daily life, and they offer a variety of essential amino acids, rich vitamins, minerals and fiber for human. However, vegetables contain many nitrate, especially the leafy vegetables, which are the main source of nitrate consumed by humans. The nitrate content is seen as an important index of the quality of vegetables. As people living standards increase, the adverse effects of nitrate and nitrite on human health have been taken more seriously. Nitrate is a potential threat to human health (Bartsch *et al.*1998, Slob *et al.* 1995). If considered the reducing the nitrate accumulation in vegetables, and improving the utilization rate of nitrate, it will have great significance in vegetable production, human health, and the nitrogen utilization.

Light plays a very important role in plant nitrate metabolism, which is one of the main factors that controls the plant nitrate content (Deng *et al.* 2000), mainly due to the activity of nitrate reductase (NR) by light regulation. The strength of the reduction of nitrate mainly depends on the activity of nitrate reductase. Secondly, under the appropriate light, plants have good photosynthesis, which provides the energy for the conversion of nitrate to ammonia, thus reducing nitrate accumulation (Daniel-Vedele *et al.*1998, Hu *et al.* 2007). The nitrate content in leafy vegetables has become one of the important indexes of evaluating its nutritional value. Based on the characteristics of the facility cultivation, regulating facility environment becomes an important means to reduce the nitrate content. Light is one of the limiting environmental factors in facility cultivation, and is also one of the important factors affecting nitrate metabolism (Elia *et al.* 1998). Therefore, effect of light on nitrate metabolism can achieve a significant impact on the nutritional quality of vegetables. On the other hand, using the facility control technology of light source to obtain low nitrate accumulation products is also a very effective method.

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The present experiment showed the quality of non-heading Chinese cabbage cultured under different light treatments. How different light qualities affect quality and safety in the plants were also examined. The results will provide theoretical support for improving leafy vegetable nutrition and safety.

Materials and Methods

Seedlings of non-heading Chinese cabbage (*Brassica campestris* L.Te'aiqing) were planted in plastic pots containing a mixture of peat, vermiculite and perlite (1 : 1 : 1, v/v/v). When the second leaves were fully expanded, 120 seedlings were selected, randomized into 6 groups and were cultured under five light quality treatments for 30 days. Plants were fertigated using Garden Test Standard nutrient solution. There was ventilation in the controlled environment, so the CO_2 level was the same as the CO_2 level of atmosphere. The relative humidity (RH) was maintained at 70 ± 10%, with a 12 hrs photoperiod, and the growth temperature was at 18 ~ 20ºC. Three replications were performed for each phytochemical measurement. All data are expressed on a fresh weight (FW) basis.

All the LEDs were designed by College of Agriculture, Nanjing Agricultural University, China. The light treatments were designated as red LEDs (R), blue LEDs (B), green LEDs (G), a mixture of red plus blue LEDs (R : B = 6 : 1) and dysprosium lamp (CK). The spectral distributions of the green (peak at 530 nm), red (peak at 658 nm) and blue (peak at 460 nm) lights were measured using a spectroradiometer (OPT-2000, ABDPE CO, Beijing, China). All the treatments were irradiated with the same photosynthetic photon flux density (PPFD) of 150 µmol m^{-2} s^{-1}. PPFD was measured using a quantum sensor (LI-250, LI-COR, USA) and was separately controlled by adjusting both the electric currents and numbers of lighting bulbs. The parameters of the light in each treatment are shown in Table 1.

Table 1. Major technique parameters of different light spectral energy distribution.

Light treatment	Peak wavelength λp (nm)	Half wave width Δλ (nm)	PPFD µmol/(m^2•s)	Power (W)
CK	400	-	150	400
G	530	±20	150	81
R	658	±12	150	54
B	460	±11	150	54
R : B = 6 : 1	658+460	±11 and ±12	150	63

CK = Dysprosium lamp, G = Green LED light, R = Red LED light, B = Blue LED light, R : B = Red plus blue LED light.

A total of 20 seedlings for each treatment were selected for biomass analysis. To determine the dry mass, the seedlings were dried at 85ºC until a constant mass was obtained. The fresh mass and dry mass of the seedlings were measured using an electronic balance.

The content of nitrogen was measured by micro kjeldahl method and was used to calculate the crude protein concentration. The crude protein concentration was estimated by a factor of 6.25 (Li 2000, Zhou and Luo 2004).

Vitamin C content was estimated using a spectrophotometric method (Li 2000). Genesys 6 spectrophotometer was used for the analysis (Thermospectronic, USA). Leaves of plant (1 g) was homogenised in 5 ml of 15% trichloroacetic acid and centrifuged (10 min, 4000 r). The 1 ml of extract was mixed with 1 ml of trichloroacetic acid, 1 ml of ethyl alcohol, 0.5 ml of 0.4% phosphoric acid ethanol, 1 ml of 0.5% 1,10-phenanthroline and 0.5 ml of 0.03% chloride ferric. The solution was shaked gently and allowed to stand for 2 min. The coloured radical ion was measured at 534 nm against the radical blank.

The content of nitrogen was measured by Kjeldahl method (Li 2000). Determination of total phosphorus and total potassium content was done according to the method of Nanjing Agricultural University, the central laboratory of the college of life science: Leaves of plant (0.5 g, dry weight, W) were put in the digestion tank. Next, 5 ml HNO_3 and 2 ml H_2O_2 was added and the mixture was digested by microwave digestion. Then the solution was diluted to 10ml and was determined on the island ferry ICP- 1000 spectrometer.

Statistical analyses were conducted using statistical product and service solutions for Windows, version 16.0 (SPSS Inc, Japan). The data were analyzed using analysis of variance (ANOVA), and the differences between the means were tested using Duncan's Multiple Range Test ($p < 0.05$).

Results and Discussion

Effects of different light quality on the growth of non-heading Chinese cabbage are presented in Table 2. The fresh and dry mass under R:B treatment were highest 28.71 and 2.63 g, respectively. Meanwhile the fresh mass was found almost double in comparison to other light treatments. The R and B treatment also positively increased the fresh and dry mass in comparison to CK, whereas the G treatment did not.

The present study showed that the B and R : B treatment resulted significantly higher content of crude protein than CK (Table 2). Protein is the basic material of life, and is an important component of various kinds of enzyme. Blue light was reported to obviously promote the dark respiration of mitochondria, and to provide energy for nitrogen metabolism and protein synthesis (Kowallik 1982). Meanwhile, blue light has activated effect to nitrate reductase, which provides more nitrogen to synthesis of protein (Campbell 1996).

In the present study, the vitamin C content was also found to be markedly higher under B (1.6 times higher than CK) and R : B treatment (1.5 times higher than CK) (Table 2). Vitamin C is necessary to sustain human growth and keep healthy, and vegetable is an important source of vitamin C for human (Bian *et al.* 2015). Regulating light environment in facility is a very significant way to adjust vitamin C content in leaf vegetables. Previous study also found that the light treatment contain blue light spectrum which promotes vitamin C content in many plant species such as lettuce and spinach (Ohashi-Kaneko *et al.* 2007, Chen *et al.* 2011). Meanwhile, blue light can also increase the synthesis and accumulation of hexose and D-glucose which are ascorbic acid precursors and stimulate ascorbic acid synthesis via several metabolic pathways in higher plants (Toledo *et al.* 2003, Chen *et al.* 2011). Previous study also reported that galactose acid lactone dehydrogenase is one of the key enzymes in vitamin synthesis process, the blue light can improve the activity of vitamin C synthesis enzymes and obviously promote the synthesis of vitamin C (Xu *et al.* 2007, Yang *et al.* 2010).While the red light has inhibition to this enzyme activity (Chen *et al.* 2012), which reduces vitamin C content in non-heading Chinese cabbage.

After different LED lighting exposures, significantly positive effect was found in energy efficiency (Table 2), while the efficiency was highest under R : B treatment (20.8 times higher than CK). Therefore, LED light can promote non-heading Chinese cabbage to use energy more efficiently.

Present study revealed that the content of nitrogen under B and R : Btreatment were higher comparing to CK treatments (42.7 and 27.2% higher than CK respectively), and the effect of monochrome blue light (B treatment) was more significant (Table 3). It might be that blue light and combination of red and blue light can improve photosynthesis of plant, which provide more assimilatory power, NADH/NADPH and carbon skeleton to metabolism process of nitrogen. The metabolism of nitrogen in the plant is very sensitive to changes of light. In general, the blue light promote metabolism of nitrogen (Kowallik *et al.*1982). Previous studies found that total nitrogen content in leaf of garlic seedling is highest under blue light (Yang *et al.* 2010), while in the study of leek, they found the combination of red and blue light can improve the content of total nitrogen (Chen *et al.* 2012).

Table 2. Effect of different light sources on nutritional quality of non-heading Chinese cabbage.

Light treatment	Fresh mass (g/plant)	Dry mass (g/plant)	Crude protein (mg/g)	Vitamin C (mg/g)	Energy efficiency (g/kw)
CK	11.13d	1.12cd	189.35c	0.30b	2.23d
G	12.91c	1.07d	166.48d	0.17c	13.83c
R	13.71c	1.36c	240.08c	0.22bc	25.18b
B	16.96b	1.60b	364.42a	0.51a	29.63b
R : B = 6 : 1	28.71a	2.63a	284.06b	0.46a	41.75a

CK = Dysprosium lamp, G = Green LED light, R = Red LED light, B = Blue LED light, R : B = Red plus blue LED light. Different letters in columns indicate statistically significant differences ($p < 0.05$) according to Duncan’s multiple range test.

Phosphorus plays a vital role in sugar metabolism, energy metabolism and photosynthesis of plants. In this experiment, it was found that the B and R : B treatment increased content of phosphorus (8 and 21.6% higher than CK, respectively) (Table 3), which was consistent with the results on Chinese chives (Chen *et al.* 2012). In the study about wild arabidopsis, they found that blue light has important regulation effect to phosphorus absorption, and mutants *cryl* who lack of blue light receptor has inhibitory effect on phosphorus absorption (Yu 2009).

Table 3. Effect of different light sources on content of mineral element (N, P and K) of non-heading Chinese cabbage.

Light treatment	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)
CK	45.54c	5.38c	25.96c
G	31.29e	3.79cd	18.32e
R	39.54d	4.35c	20.78d
B	64.99a	5.82b	33.64b
R : B = 6 : 1	57.94b	6.54a	37.78a

CK = Dysprosium lamp, G = Green LED light, R = Red LED light, B = Blue LED light and R : B = Red plus blue LED light. Different letters in columns indicate statistically significant differences ($p < 0.05$) according to Duncan’s multiple range test.

Nitrate content is an important indicator for evaluating vegetable safety quality, and has a negative correlation with nutritional quality of vegetable. In recent years many studies about environment, food and medical have demonstrated that nitrate in the body can be reverted to nitrite by action of bacteria. The assimilation process of nitrate is a highly regulated process, and was mainly controlled by the nitrate reductase (NR) and nitrite reductase (NiR). Nitrate reductase (NR) is the rate-limiting enzyme in this process. Previous study reported that blue light has a direct stimulation to NR, and they surmised that the chromophores of blue light receptors contains flavin, adenine dinucleotide and the complementary base of nitrate reductase and also contains a flavin adenine dinucleotide (Campbell 1996, Lillo. 2004). Table 4 shows that, the nitrate content in non-heading Chinese cabbage was 61.8 and 49.5% lower than under R : B and B treatment, respectively than CK. While positive effect on activity of nitrate reductase was observed under R : B and B treatment (2.57 times and 2.0 times higher than CK, respectively). Therefore, combination of red and blue light promoted nitrate reductase activity but reduced the nitrate content.

Table 4. Effect of different LED light sources on safety quality of non-heading Chinese cabbage.

Light treatment	Nitrate (mg/g)	Nitrite (μg/g)	Nitrate reductase [μg/(g•h)]	Nitrite reductase [μg/(g•h)]
CK	4.34a	2.83ab	4.97c	1.49c
G	2.38b	2.61bc	2.97d	0.97d
R	2.69b	2.23c	4.16c	1.30c
B	2.19b	1.93d	10.15b	1.99b
R : B = 6 : 1	1.66b	1.25d	12.76a	2.49a

CK = Dysprosium lamp, G = Green LED light, R = Red LED light, B = Blue LED light and R : B = Red plus blue LED light. Different letters in columns indicate statistically significant differences ($p < 0.05$) according to Duncan's multiple range test.

It was found that the B light was also reported to improve the activity of nitrite reductase, since blue light induce expression of NII gene, which coded nitrite reductase (Goud and Sharma.1994, Migge *et al.*1998, Lillo. 2004). The present study showed that, R : B and B treatment reduced the nitrite content of plant significantly, (61.8 and 49.5%, relatively than CK), while the nitrite reductase activity was higher than CK (1.67 and 1.7-folds). These results showed that the light treatment containing blue light spectrum promote decomposition of nitrate. The mutual coordination of phytochrome and cryptochrome regulated enzyme activity and gene expression may be speculated.

The present study showed that different LED light wavelength can affect the nutritional quality and safety, such as the synthesis of many nutrients. From the results, it may be concluded that the B LED and R : B LED light increased the content of crude protein, vitamin C, nitrogen, phosphorus and potassium. At the same time, the B LED and R : B LED light also improved the photosynthetic rate of plant. Under R : B LED, the content of nitrate and nitrite was lowest while the nitrate reductase activity and nitrite reductase activity was highest. The red light plus blue light (6 : 1) treatment was more helpful for improving the nutritional quality and safety of non-heading Chinese cabbage but there was no substantial gain from this treatment.

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