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RESEARCH ARTICLE

Combined effects of enhanced ultraviolet-B radiation and doubled CO_2 concentration on growth, fruit quality and yield of tomato in winter plastic greenhouse

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Abstract Five different doses of ultraviolet-B (UV-B) radiation were supplied to tomato (*Lycopersicon esculeutum.* Mill) with the doubled CO_2 concentration (700 $\mu mol \cdot mol^{-1}$) in the winter plastic greenhouse. The influences on the seedling growth, fruit quality and yield of tomato were investigated. Results showed that the seedling growth, and the contents of UV absorbing compounds, soluble sugar, organic acid, vitamin C and lycopene of tomato fruits, and yield of tomato increased under doubled CO_2 concentration. Under the doubled CO_2 concentration the effects of lost doses of UV-B radiation could further promote the effects of doubled CO_2 concentration. However, there is no significant increase in yield of tomato. The best dose of UV-B radiation is about 1.163 $kJ \cdot m^{-2}$. When the dose of UV-B radiation is more than it, the effects of UV-B will be reduced.

Keywords UV-B, CO_2, plastic greenhouse, tomato, fruit quality, yield of tomato

1 Introduction

The plastic greenhouse vegetable industry has been flourishing in the last twenty years, which solved the problem that the fresh vegetables have been in short supply in winter for many areas in North China. However, it is prevalent that the plastic greenhouse vegetables have disadvantages in the quality and yield, such as colour and lustre of tomato being tarnished, its taste being distasteful and the yield being lower. The main reasons can be attributed to the following two aspects. On the one hand, there lacks the illumination in winter plastic greenhouse, especially ultraviolet. On the other hand, CO_2 concentration in winter plastic greenhouse is always scarce, which could restrain the photosynthesis and the growth of the vegetable (Hou and Xing, 1997; Wang et al., 2000). Maybe these problems will be solved by enhanced Ultraviolet-B (UV-B) radiation and CO_2 concentration in winter plastic greenhouse. Ultraviolet-B (UV-B) radiation is one of the important ecological factors for the growth of the vegetable, and reasonable dose of which can enhance the contents of vitamin C and lycopene of tomato fruits and improve the quality of tomato fruits consequently (Chen and Wang, 1999; Li et al., 2000; Wang et al., 2000). It is well known that CO_2 is the necessary precondition in the photosynthesis of the vegetable. Numerous studies have shown that the photosynthesis, dry weight and yield of the vegetable are all increasing when enhancing the CO_2 concentration reasonably (Wang et al., 1994; Fang et al., 1996; Guo and Li, 2003). Waton et al. (1990) reported that the CO_2 concentration in the atmosphere will be doubled to reach 700 $\mu mol \cdot mol^{-1}$ during the last period of the 21st century, because the coal and oil are overspended, and the forests are disafforested excessively with the development of industry. Therefore, many studies on the effects of CO_2 concentration enhancement were carried out in the last decade (Jiang and Han, 1997; Xu et al., 2004).

Although the studies on enhanced UV-B radiation or CO_2 concentration in winter plastic greenhouse were often reported, to study the complex effects of the enhanced UV-B radiation and CO_2 concentration must be the first report in China in order to find a new way to improve the quality and yield of the plastic greenhouse vegetable (Zhao et al., 2003; Wang et al., 2004).

2 Materials and methods

2.1 Plant materials

The seeds of uniform-sized tomato (*Lycopersicon esculeutum.* Mill., Zhong Za 9), provided by Northwest Sci-Tech of

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Agriculture and Forestry University, were selected for the experiments. They grew in plastic greenhouse (50 m in length and 8 m in width) and then they were treated with UV-B radiation and doubled CO_2 concentration during the sixth leaf outgrowing.

2.2 UV-B treatment and CO_2 treatment

The UV-B radiation was provided by filter Qin brand (Baoji Lamp Factroy, China) 30-W fluorescence sunlamps. The lamps were suspended above the plant at the height of 90 cm, perpendicular to the ground and filtered with 0.13-mm thick cellulose diacetate (transmission down to 290 nm) for UV-B radiation. The five levels of UV-B irradiation were 0.581, 0.872, 1.163, 1.454 and 1.744 $kJ \cdot m^{-2}$ per day from September 20 to December 20, 2002 with the treatment of doubled CO_2 concentration (see Table 1), while all the treatments should be ceased during the cloudy, rainy, snowy days.

Table 1 Treatment of CO_2 and UV-B

Treatment	Time (h/d)	UV-B supplements /($kJ \cdot m^{-2}$)	CO_2 Concentration /($\mu mol \cdot mol^{-1}$)
CK	–	–	350
C	–	–	700
B_1C	1	0.581	700
B_2C	1.5	0.872	700
B_3C	2	1.163	700
B_4C	2.5	1.454	700
B_5C	3	1.744	700

The gas of doubled CO_2 concentration was released using a steel bottle filled with liquid CO_2 (700×10^{-6}) and the concentration was controlled by a rotor flowmeter.

2.3 Effects test

The leaves for measuring the content of UV-B absorbing compounds were sixth leaf of the tomato which expanded entirely and healthily. The prophase mature fruits were selected for measuring the content of the soluble sugar and other indexes. All the tests were done in triplicate on January 18, 2003.

The measure items of morphological indexes included the plant length and stem diameter. The UV-B absorbing compounds were measured according to Mirechi and Teramura (1984). The method for measuring the content of the soluble sugar was anthracene ketone method according to Zhang (1985). Both the methods for measuring the origanic acid and lycopene contents of tomato fruits were according to Wang et al. (2000). Vitamin C was measured according to Xu et al. (1993). The yields of tomato, such as fruit number, single fruit mass and yield per plant, were measured from January 17 to 23, 2003.

2.4 Statistical analysis

Statistical significance was calculated at $P < 0.05$ according to Duncan's multiple range test.

3 Results

3.1 Effects of different doses of UV-B radiation on the growth of the seedling tomato under doubling CO_2

Table 2 showed that only fresh weight of tomato seedling in all treatment groups was significantly ($P < 0.05$) higher than that of the control group for 15-day-treatment. Moreover, fresh weight, dry weight and plant length in all treatment groups were significantly ($P < 0.05$) higher than those of the control group, while stem diameter only in UV-B treatment groups was significantly ($P < 0.05$) higher than that of the control group for 30-day-treatment.

Table 2 Effects of different doses of UV-B radiation on the growth of the seedling tomato under doubling CO_2

Time	Treatment	Fresh weight /(g/seedling)	Dry weight /(g/seedling)	Plant length /(cm/seedling)	Stem diameter /(mm/seedling)
15(*d*)	CK	124.3a	32.5a	28.2±1.1a	3.60±0.22a
	C	140.4b	34.8a	28.8±0.9a	3.67±0.21a
	B_1C	142.9b	35.1a	29.0±1.2a	3.65±0.28a
	B_2C	150.6b	35.9a	28.7±1.4a	3.77±0.24a
	B_3C	145.6b	35.5a	28.8±1.1a	3.65±0.18a
	B_4C	149.5b	36.3a	28.9±1.2a	3.72±0.22a
	B_5C	148.9b	35.4a	28.9±0.7a	3.71±0.20a
30(*d*)	CK	250.6a	67.7a	40.2±3.0a	4.15±0.28a
	C	270.1b	85.3b	47.3±2.8b	4.07±0.31a
	B_1C	275.8b	85.0b	48.0±2.0b	5.21±0.19b
	B_2C	279.3b	85.7b	47.7±1.8b	5.29±0.22b
	B_3C	290.3c	93.2c	48.1±1.9b	6.05±0.23c
	B_4C	293.4c	93.5c	48.0±2.2b	6.12±0.18c
	B_5C	288.5c	92.7c	47.9±1.7b	6.20±0.27c

Note: different letters followed the data of the same index at the same treatment time indicate significant difference among treatments ($P < 0.05$).

The fresh weight, dry weight, plant length and stem diameter of the seedling grown under all the treatments were measured corresponding to 15-day-treatment and 30-day-treatment.

3.2 Effects of different doses of UV-B radiation on tomato UV absorbing compounds content under doubling CO_2

Compared with the control group, all the treatment groups induced subsequently a significant increase in the contents of UV absorbing compounds ($P < 0.05$), for example, a 9% increase in C treatment group, a 13% increase in B_1C treatment group, a 46% increase in B_2C treatment group, a 63% increase in B_3C treatment group, an 87% increase in B_4C treatment group, a 100% increase in B_5C treatment group, respectively (Fig. 1).

3.3 Effects of different doses of UV-B radiation on tomato soluble sugar content under doubling CO_2

It can be seen from Fig. 2 that the soluble sugar content of all the treatment groups was significantly ($P < 0.05$) higher than

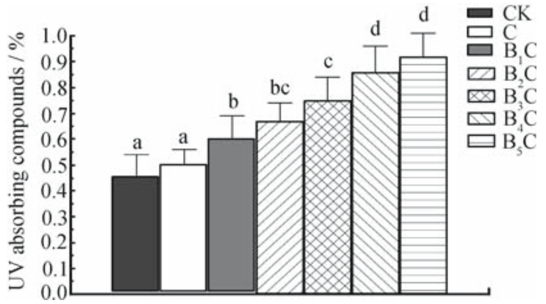

Fig. 1 Effects of different doses of UV-B radiation on tomato UV absorbing compounds content under doubling CO_2

Note: different letters above the data bar of the same index indicated significant difference among treatments at 0.05 level.

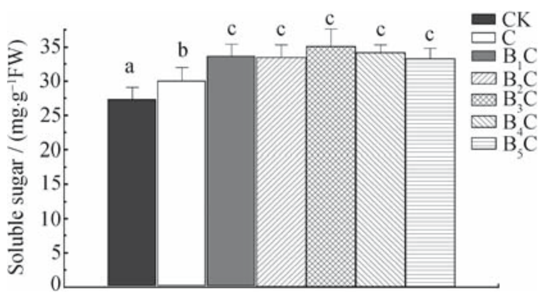

Fig. 2 Effects of different doses of UV-B radiation on tomato soluble sugar content under doubling CO_2

See notes of Fig. 1.

that of the control group. In the result, the increase effect of B_3C treatment group is the highest.

3.4 Effects of different doses of UV-B radiation on tomato organic acid content under doubling CO_2

Compared the result of Fig. 3 with that of Fig. 2, it can be concluded that the trend of the organic acid content is similar to that of the soluble sugar content.

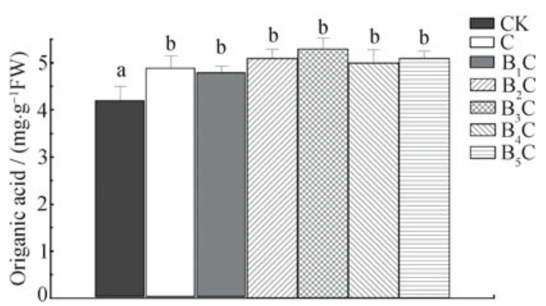

Fig. 3 Effects of different doses of UV-B radiation on tomato organic acid content under doubling CO_2

See notes of Fig. 1.

3.5 Effects of different doses of UV-B radiation on tomato ascorbate acid content under doubling CO_2

The result shows that the ascorbate acid content in the C, B_1C, B_2C, B_3C and B_4C treatment groups was significantly

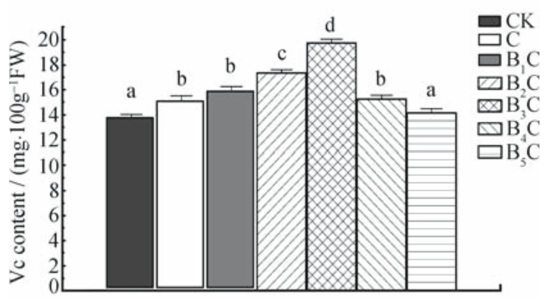

Fig. 4 Effects of different doses of UV-B radiation on tomato ascorbate acid content under doubling CO_2

See notes of Fig. 1.

($P < 0.05$) higher than that of the control group, while that in B_5C treatment groups was not significant. Moreover, the increase effect of B_3C treatment group is also the highest.

3.6 Effects of different doses of UV-B radiation on tomato lycopene content under doubling CO_2

It can be concluded from Fig. 5 that the tomato lycopene content of all the treatment groups was significantly ($P < 0.05$) higher than that of the control group, for example, a 7% increase in C treatment group, a 17% increase in B_1C treatment group, a 27% increase in B_2C treatment group, a 48% increase in B_3C treatment group, a 15% increase in B_4C treatment group, an 8% increase in B_5C treatment group, respectively. In the result, the increase effect of B_3C treatment group is consistently the highest.

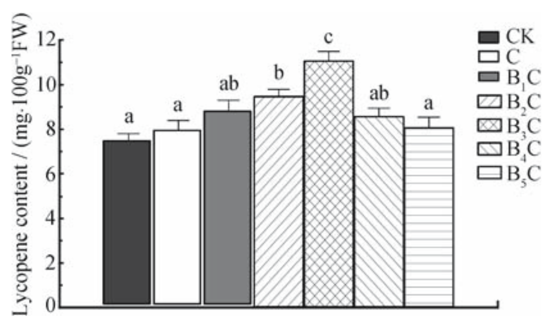

Fig. 5 Effects of different doses of UV-B radiation on tomato lycopene content under doubling CO_2

See notes of Fig. 1.

3.7 Effects of different doses of UV-B on the yields of the tomato fruits under doubling CO_2 during the first week

The improvement effects on the yield of doubled CO_2 concentration and enhanced UV-B radiation are obvious (as shown in Table 3).

4 Discussion

Doubled CO_2 concentration may exert a favorable influence on the physiological and biochemical processes of plants,

Table 3 Effects of different doses of UV-B on the yields of the tomato fruits under doubling CO_2 during the first week

Treatment	Fruit number (individual)	Single fruit mass (g)	Yield per plant (g)
CK	12.4±1.0a	109.0±8.6a	1,351.6a
C	14.0±0.7b	133.3±8.4b	1,866.2b
B_1C	14.1±0.9b	131.8±7.6b	1,858.4b
B_2C	14.4±1.3b	132.8±10.2b	1,912.3b
B_3C	14.9±1.3b	132.8±15.4b	1,978.7b
B_4C	14.4±1.3b	133.0±8.5b	1,915.2b
B_5C	14.1±1.8b	130.3±10.9b	1,837.2b

Note: different letters followed the data of same index at the same treatment time indicate significant difference among treatments ($P<0.05$).

such as promoting the growth of crops obviously (Wang et al., 1997). Enhanced UV-B radiation could restrain the plant length, but increase the stem diameter (Li and Wang, 1998; Yue and Wang, 1998). The experiments showed that fresh weight, dry weight and plant length of tomato seedling in doubled CO_2 concentration treatment were all increased, while stem diameter was unaltered for 30-day-treatment. Under the doubled CO_2 concentration the effects of lost doses of UV-B radiation could further promote the effects of doubled CO_2 concentration on fresh weight, dry weight and plant length of tomato seedling, at the same time, increase the stem diameter. It is inferred that the growth of tomato seedling in winter plastic greenhouse will be promoted by supplying with UV-B radiation and CO_2 concentration which were the two necessary conditions in the processes of photosynthesis. Moreover, the effects of them will be cumulated.

The UV-B absorbing compounds are the important pigments in leaves to absorb UV-B radiation and protect the foliar tissue (Cen and Bomman, 1993). The UV-B exposure could increase UV-B absorbing compounds in plant, which is a self protect feedback (Tevini et al., 1991). Those reports were consistent with the experimental results in this paper (Fig. 1). It was found that contents of UV-B absorbing compounds increased remarkably with the enhancment of UV-B radiation dose under the complex treatment. The UV-B absorbing compounds could also eliminate active oxygen and prevent lipid peroxidation in plants (Klironomos and Allen, 1995).

Wang et al. (2000) reported that UV-B radiation did not affect the contents of soluble sugar and organic acid in tomato fruits. The experiments showed that doubled CO_2 concentration increased the contents of soluble sugar and organic acid, which was consistent with the results that high CO_2 concentration could increase the contents of soluble solid in tomato (Fang et al., 1996). Under the complex treatment, the effects of lost doses of UV-B radiation could further promote the effects of doubled CO_2 concentration on soluble sugar and organic acid.

Ambasht and Agrawal (1995) brought forward that reasonable UV-B radiation dose could promote the accumulation of secondary metabolites matter, such as carotenoid. And Wang et al. (2000) reported that the reasonable UV-B radiation dose could promote the contentsof vitamin C and lycopene of tomato fruits. It was found in experiments that the effects of UV-B radiation and doubled CO_2 concentration were cumulated under the complex treatment. When the cells of plants were irradiated by UV-B radiation, it led to the accumulation of poisonous active oxygen free radicals. In order to eliminate active oxygen and prevent lipid peroxidation in plants, that the higher contents of UV absorbing compounds, vitamin C and lycopene will be produced in plants. However, if plants grow under UV-B exposure for a long period, the cells of plant must be damaged by the excessive poisonous active oxygen free radicals.

Hou and Xing (1997) reported that doubled CO_2 concentration affected the plant yield on fruit number and single fruit mass, which were consistent with the experimental results (Table 3). The reason is inferred that doubled CO_2 concentration can improve the photosynthesis, restrain respiration, reduce the carbon consume in the process of photorespiration and increase the content of carbohydrate which will be transferred to fruit. However, the effect of UV-B radiation on yield is not obvious.

In conclusion, under the doubled CO_2 concentration the effects of lost doses of UV-B radiation could not only improve the growth of tomato seedling and the quality of fruit, but also further promote the effects of doubled CO_2 concentration. The best dose of UV-B radiation is about $1.163\ kJ \cdot m^{-2}$. When the dose of UV-B radiation is more than it, the effects of UV-B will be reduced.

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References

Ambasht N K, Agrawal M (1995). Physiological responses of field grozon Zea mays L plant to enhanced UV-B radiation. Biotronics, 24(2): 15–23

Cen Y P, Bomman J F (1993). The effects of exposure to enhanced UV-B radiation on the penetration of monochromatic and polychromatic UV-B in leaves of Brassia napus. Physiological Plant, 87: 247–251

Chen T, Wang X L (1999). The effect of enhanced UV-B radiation on the activities of SOD, CAT and POX in wheat leaves. Journal of Wuhan Botanical Research, 17(2): 101–104 (in Chinese)

Fang S X, Gu J T, Wei Q, Song X F (1996). The effect of CO_2 enrichment on the growth of four species of fruits and vegetable. Chinese Agricultural Science Bulletin, 12(6): 14–16 (in Chinese)

Guo W H, Li T L (2003). Effects of different mixed organic matter application on the CO_2 concentration in greenhouse and the physiological effects of tomato plants. Acta Horticulturae Sinica, 30(5): 592–594 (in Chinese)

Hou Y D, Xing Y X (1997). Progress in study of CO_2 enrichment in vegetables. Journal of Shandong Agricultural University, 28(1): 73–77 (in Chinese)

Jiang G M, Han X G (1997). Response of plant growth to elevated CO_2: A review on the chief methods and basic conclusions based on experiments in the external countries in past decade. Acta Phytoecologica Sinica, 21(6): 489–502 (in Chinese)

Klironomos J N, Allen M F (1995). UV-B medicated changes on below-ground communitis with the roots of Acer saccharum. Functional Ecology, 9: 323–330

Li Y, Wang X L (1998). The effect of enhanced UV-B radiation on the physiological indicator, yield and quality of wheat. Acta Scientiae Circumstantiae, 18(5): 504–509 (in Chinese)

Li Y, Zu Y Q, Wang X L (2000). Plant responses to atmosphere ozone depletion, ultraviolet-B radiation increase reaching the earth’s surface. Journal of Wuhan Botanical Research, 18(5): 426–430 (in Chinese)

Mirecki R M, Teramura A H (1984). Effects of ultraviolet-B irradiance on soybean. V. The dependence of plant sensitivity on the photosynthetic photon flux density during and after leaf expansion. Plant physiology, 74: 475–480

Tevini M, Braun J, Fieser G (1991). The protective function of the epidermal layer of rye seedling against ultraviolet-B radiation. Photochemistry Photobiology, 53: 329–333

Wang C Y, Pan Y R, Bai Y M, Wen M (1997). The experiment study of effects doubled CO_2 concentration on several main crops in China. Acta Meteorologica Sinica, 55(1): 86–94 (in Chinese)

Wang J, Li F M, Zou ZH R, Wang X L (2004). Study on double CO2 concentration reduce the inhibition of enhanced UV-B radiation on tomato in plastic greenhouse. Acta Botany Boreal-Occident Sinica, 24(5): 817–821 (in Chinese)

Wang X L, Xu S H, Li Y X (1994). Studies on the physi-ecological responses of Chinese Cabbage to CO_2 doubling. Acta Horticulturae Sinica, 21(3): 245–250 (in Chinese)

Wang Y L, Wang X L, Yue M (2000). Effects of supplementary radiation of UV-B and red light on fruit quality of tomato in winter plastic greenhouse. Acta Botany Boreal-Occident Sinica, 20(4): 590–595 (in Chinese)

Waton R T, Rodhe H, Oescheger H (1990). Greenhouse gases and aerosols. In: Houghton J T, Jenkins G J, Ephranums J J, eds. Climate: The IPCC Scientific Assessment. New York: Cambridge University Press, 1–40

Xu M, Chen S, Liu G X, Hu Z Y (2004). Pilot study of physiological and morphological acclimation of Scenedesmus armatus under extreme-high-CO_2-stress. Journal of Wuhan Botanical Research, 22(5): 439–444 (in Chinese)

Xu M J, Ma W X, Hua S C (1993). Determination of vitamin C in food by molybdenum blue spectrophotometry. Food and Fermentation Industries, (5): 38–41 (in Chinese)

Yue M, Wang X L (1998). A preliminary study of the responses of wheat and oat reproductive characteristics to enhanced UV-B radiation. China Environmental Science, 18(1): 68–71 (in Chinese)

Zhang X P (1995). Effect of light intensity and CO_2 supplement on growth and flowering of Gladiolus. Acta Horticulturae Sinica, 22(1): 73–76 (in Chinese)

Zhang Z Q (1985). The Experimental Handbook of Plant Physiology. Shanghai: Scientific and Technical Publishers, 134

Zhao G Q, Wang X L, Yue M, Li F M (2003). The combined effects of enhanced UV-B radiation and CO_2 on the growth and photosynthesis of broad bean seedling. Acta Botany Boreal-Occident Sinica, 23(1): 6–10 (in Chinese)