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Effect of ozone treatment and light colour on photosynthesis and yield of lettuce

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ABSTRACT

Between factors which may influence on plant growth are light conditions and chemical composition of atmosphere. The objective of this study was to investigate the effect of ozone treatment (at the stage of seeds and seeds + seedlings, described as O_3-I and O_3-II) and light colour (white, blue, and white + blue 50:50) on photosynthesis and yield of lettuce (*Lactuca sativa* L. 'Subyana F_1') grown in a hydroponic system. During the experiments the following conditions were maintained: photoperiod 12 h; temperature 22 °C; relative humidity (RH) 65–70%. LED lamps emitted the following light colours: white, blue and white + blue (50:50) (described as W, B and W + B). For all colours, quantum irradiance was 70 μmol m^{-2} s^{-1}. Plants were fertigated with a standard nutrient solution with the following chemical composition (mg dm^{-3}): N-NH_4 < 10, N-NO_3 150, P-PO_4 50, K 150, Ca 150, Mg 50, Fe 3.00, Mn 0.5, Zn 0.44, Cu 0.03, B 0.01; pH 5.50, EC 1.8 mS cm^{-1}. The analysed factors significantly modified photosynthetic activity, growth, yield, chlorophyll content (SPAD measurements) and chemical composition of plants. The highest net photosynthesis rate (P_N) was recorded in plants cultivated with O_3-I under W + B light, while the lowest was observed for O_3-II under B light. In the case of O_3-II a highly significant increase of mean N content in leaves was observed, together with decreases of P, Ca, Mg, Na, Fe and Mn contents in comparison to control plants. An improvement of yield (although not statistically significant) was found in O_3-I plants, while O_3-II application caused a decrease of the yield, for B light by about −27.87%, for W −53.74% and for W + B −46.51%. Similar observations were noted for the number of leaves. Moreover, a significant effect of O_3-I on chlorophyll content was noted, excluding plants cultivated under W light. It seems that ozonization of seeds improves their germination and some other growth and physiological processes, while a second ozonization impairs the condition of plants and has a similar effect as tropospheric ozone in outside conditions. From the practical point of view, it would be interesting to investigate the effect of ozonization and other light colours on different crop species.

1. Introduction

One of the crops successfully grown in a closed plant factory system is lettuce (Kang et al., 2013). Climatic conditions, plant nutrition, temperature and light intensity have a strong effect on the growth and yield and nutritional quality of vegetables. Light condition is one of the most important variables affecting photosynthesis and primary metabolites in plants (Perez-Balibrea et al., 2008). 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). Changes in the spectrum of light strongly influenced the parameters of the anatomy, morphology of leaves and physiology (Głowacka, 2002a,b, 2004; Hogewoning et al., 2010). It is known that blue light is important in chlorophyll biosynthesis, stomatal opening, maturation of chloroplasts, enzyme synthesis and photosynthesis. Blue light is also indispens-

Abbreviations: W, white light; B, blue light; W + B, white + blue light; LED, Light Emitting Diode; P_N, net photosynthetic rate; g_s, stomatal conductance; E, transpiration rate; C_i, concentration intercellular CO_2.

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able for morphologically healthy plant growth (Tibbits et al., 1983; Okamoto et al., 1996). It is possible that combinational light regimes may help to optimize growth. The most commonly used radiation sources for space-based plant research chamber rooms are fluorescent lamps. However, these broad-spectrum lights have various limitations and consequently are not an optimum radiation source for plants. Recently, LEDs have been developed as alternative light sources for plants because of their wavelength specificity and narrow bandwidth, small mass volume, solid state construction, long life and minimum heating (Brown et al., 1995).

Ozone is generally treated as highly phytotoxic air pollution in the troposphere. However, the positive role of ozonization also has been proved as a seed protection factor against fungal development. It is especially used during storage to control the elimination of microorganisms (Rodrigues et al., 2015). The positive role of ozonization was also demonstrated for grain storage, as well as postharvest fruits (Pereira et al., 2008), in food ripening rooms (Pinto et al., 2007; Serra et al., 2003), and in the degradation of mycotoxins (Akbas and Ozdemir, 2006). Klaptchuk (2004) patented an application of ozone used to sterilize seeds and degrade residual herbicides, while Yvin and Coste (1995) patented ozonization for seed germination. It has been found that ozonization accelerates tomato seed germination by breaking dormancy (Sudhakar et al., 2011). Studies by Violleau et al. (2008) have suggested that long periods of ozonization may be harmful for the quality of seeds. There has been limited research on further ozonization effects on plant physiological status and element contents. In literature there is no research on the effect of two factors on plants, considering both light and ozonization.

The objective of this study was to investigate the effect of ozone treatment (at the stage of seeds and seedlings) and light colour (blue, white and the combination of blue and white) on photosynthesis and yield of lettuce grown hydroponically.

2. Materials and methods

2.1. Plant cultivation

Studies were conducted in 2013 in a controlled environment growth room located at the Experimental Station of the Departments of the Faculty of Horticulture and Landscape Architecture, Poznań University of Life Sciences (Poland). The aim of the study was to assess the effect of various ozone treatments (at the stage of seeds and seeds + seedlings) and light colour (white, blue, and white + blue 50:50) on plant response manifested in the nutrient status and yield of hydroponically grown butterhead lettuce (*Lactuca sativa* L. cv. 'Subyana F_1') (from Rijk Zwaan company). The experiments were conducted in a two-factorial design in 5 replications (1 single plant was a replication) with the following factors: A – ozone treatment (3), B – light colour (3). During the experiments the following conditions were maintained: photoperiod 12 h; temperature 22 °C; RH 65% to 70%. LED lamps emitted the following light colours: white, blue, and white + blue (50:50) (described as W, B, W + B). For all colours, quantum irradiance was 70 μmol m^{-2} s^{-1}. Spectrum characteristics of lamps determined using a spectroradiometer (USB 4000; Ocean Optics) are presented in Fig. 1.

180 dry seeds were sown individually into rockwool cubes. Seedlings (3–4-leaf stage) were transplanted into rockwool blocks (10 × 10 × 10 cm). Seeds and seedlings (in the respective combinations) were exposed to 30 min of exposure to ozone (at stage of seeds and seeds + seedlings, described as O_3-I and O_3-II) produced by the ozonator Biosphera 14 (Biosphera sp z o.o., Poland), which generates 14 g O_3 h^{-1}. Seeds were ozonated for 0.5 h in close chamber with ca 24m^3 volume. Plants were placed in polyethylen (PE) containers (V 3.45 dm^3), forming hydroponic stagnation.

2.2. Plant nutrition

The chemical composition of tap water, on the basis of which the nutrient solution for plant fertigation was prepared, was as follows (in mg dm^{-3}): N-NH_4 trace amounts, N-NO_3–3.7, P-PO_4–0.3, K – 1.8, Ca – 57.3, Mg – 13.4, S-SO_4–58.3, Na – 22.7, Cl – 42, Fe – 0.08, Mn – 0.06, Zn – 0.50, Cu – trace amounts, B – 0.011, Mo – trace amounts, HCO_3–277.5, pH – 7.00, EC – 0.735 mS cm^{-1}. Plants were fertigated with a standard nutrient solution with the following chemical composition (mg dm^{-3}): N-NH_4 < 10, N-NO_3 150, P-PO_4 50, K 150, Ca 150, Mg 50, Fe 3.00, Mn 0.5, Zn 0.44, Cu 0.03, B 0.01; pH 5.50, EC 1.8 mS cm^{-1}. Plants were watered according to the needs with the nutrient solution at a rate of about 0.15–0.30 dm^3 $plant^{-1}$. To prepare nutrient solutions the following fertilizers were used: potassium nitrate (13% N-NO_3, 38.2% K), calcium nitrate (14.7% N-NO_3, 18.5% Ca), magnesium nitrate (11% N-NO_3, 9.5% Mg), monopotassium phosphate (22.3% P, 28.2% K), potassium sulphur (44.8% K, 17% S), magnesium sulphur (9.9% Mg, 13% S), Librel FeDP7 (7% Fe), manganese sulphate ($MnSO_4 \cdot H_2O$, 32.3% Mn), copper sulphate (25.6% Cu), borax (11.3% B) and sodium molybdate (39.6% Mo). To regulate pH values, nitric acid was used (38%).

2.3. Gas exchange measurements

The handheld photosynthesis system Ci 340aa (CID BIOSCIENCE Inc., Camas, USA) was used to evaluate the net photosynthetic rate (P_N), stomatal conductance (g_s), transpiration rate (E) and intercellular CO_2 (C_i) concentration. For these purposes, constant conditions of measurements in the leaf chamber were maintained: CO_2 inflow concentration (390 μmol (CO_2)mol^{-1}), photosynthetic photon flux density (PPFD) 1000 μmol (photon) m^{-2} s^{-1}, chamber temperature 25 °C, relative humidity 40 ± 3%.

2.4. Biometric and SPAD measurements

On the last day of every experiment (30 days after plants exposure to different light conditions) the following biometric parameters of plants were measured: the number of leaves, and the weight of lettuce head (g). The index of leaf greenness (SPAD) was also measured on the outside and the most developed leaves using a Minolta Chlorophyll Meter SPAD-502 (Konica Minolta, Japan). Every single plant was measured 25 times. This measurement is used to determine the intensity of green colour in leaves and consists in determination of the light absorption coefficient connected with the presence of chlorophyll at a wavelength of 650 nm and absorption by the leaf tissue at a wavelength of 940 nm. In experiments on lettuce a significant correlation (R^2 = 0.85–0.92) was found between SPAD values and chlorophyll content in tissues (León et al., 2007).

2.5. Chemical analysis

The aboveground parts of the all plants from respective combinations were collected on the last day of every cycle to be dried 48 h at 45–50 °C to stable mass and then ground. Before mineralization the plant material was dried 1 hour in temperature 105 °C. In order to assay the total contents of N, P, K, Ca, Mg and Na, the plant material was mineralized in concentrated sulfuric acid, and for analyses of total Fe, Mn, Zn and Cu a mixture of nitric and perchloric acids (3:1, v/v) was applied (IUNG, 1972). After mineralization the following determinations were performed: N-total using the distillation method according to Kjeldahl in a Parnas Wagner apparatus; P – colorimetrically with ammonia molybdate; K, Ca, Mg, Na, Fe,