EFFECT OF LIGHT CONDITIONS AND TEMPERATURE ON FRESH YIELD OF SOME SPICE PLANTS GROWN IN CONTAINERS

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Summary
The aim of this work was to study the effect of quantity of light, length of day and temperature on yield of five species of spice plants. Another purpose of the study was to determine the correlation between the climatic factors mentioned above and to find the optimum coefficient of growth for the individual species. Three levels of temperature during the day were determined: 15, 20 and 25ºC (at night the temperature was by 5ºC lower). Two daily light integrals (2.9 and 3.8 mol·m⁻²·d⁻¹) and three levels of photoperiod (12, 14 and 16-h) were chosen.

Photon flux and temperature had the greatest influence on yield. A higher yield of fresh mass was obtained for all species in the condition of 3.8 mol·m⁻²·d⁻¹. Yield depended linearly on amount of photon absorbed by plants in the growth time. Dry weight was directly connected with RRT (the ratio of radiant energy to thermal energy) and increased linearly as RRT increased.

key words: light, photoperiod, spice plants, temperature

INTRODUCTION

The volume of biomass production changes during plant ontogenesis and it is the result of the accumulation of organic and mineral compounds as well as water. Plant productivity assessment involves investigations of the levels of the produced dry weight during: one day, the vegetation period or the entire year. The productivity of a single plant or the entire crop resulting from the photosynthesis and respiration depends on all factors modifying the intensity of these two processes (Good & Bell 1985). Little can be done to modify the environment outdoors, so plant growth and development of field crops is largely controlled by the weather. In greenhouses and in closed systems these environmental factors are commonly manipulated to control flowering and plant morphology to produce crops with specific characteristics in a desired period of time (Kozai & Ohyama 2006, Runkle & Heins 2006). Of the five environmental
factors of plant growth, light, temperature, water, nutrients and gases, the first two are different forms of energy: i.e., radiant and thermal. The daily light integral (DLI), also occasionally termed the "light sum", is defined as the number of photons received during one day, per unit area of plant growing area, where the photons are characterized by wavelengths within the region of the light spectrum effective for photosynthesis (400 to 700 nm). Daily light integral has been shown to be a key factor in producing consistent and predictable foliar biomass in plant production systems (Both et al. 1997; Albright et al. 2000). For many floriculture crops, plant quality and mass increase as DLI increases. For example, in Achillea millefolium, Gaura lindheimeri, and Lavandula angustifolia, quality ratings (e.g., stem thickness, inflorescence count, flower color, and branching) increased as the DLI increased from 5 to 20 mol·m^{-2}·d^{-1} (Fausey et al. 2005). Temperature controls plant development including morphogenesis and plant quality. These processes make temperature a major growth factor. It is well known that the relationship between temperature and light exerts a significant impact on plant quality (Liu & Heins 1997). The concept of the ratio of radiant energy to thermal energy (RRT) has been developed in recent years and its main aim is to facilitate the determination of the effect of light and temperature interaction on plant growth, development and quality. Growers frequently try to maintain appropriate levels of light and temperature in order to obtain satisfactory plant quality in a possibly short period of time (Liu & Heins 1998).

So far no universal system of determination of the combined effect of light and temperature on plant yield and quality has been developed. The RRT, i.e. the ratio of radiant energy to thermal energy, can be one of the parameters that control plant yield and quality (Liu & Heins 1997). In this paper, we study how temperature as well as light duration and quantity influence plant morphology of spice plants grown in containers in controlled environments.

MATERIALS AND METHODS

Studies were carried out in the experimental station "Marcelin" of the Poznan University of Life Sciences in the years 1999-2004. The five following species of spice plants were comprised of the experiment: dill cv. Ambrozja (Anethum graveolens L.), garden chervil (Anthriscus cerefolium L. Hoffm.), garden rocket (Eruca sativa Lam.), parsley cv. Titan (Petroselinum crispum Mill. subsp. crispum) and salad onion cv. Sprint (Allium cepa L.). Plants were grown in the growth chambers. The three-factor experiment was performed in eight replications, where four pots were treated as one replication. The first factor was the temperature, the second - daily light integral and the third - day length. Three levels of temperature during the day were used: 15, 20 and 25°C (at night the temperature was by 5°C lower). Two daily light integral of PAR (2.9 and 3.8 mol·m^{-2}) and three levels of day length (12, 14 and 16-h) were applied. Photosynthetic photon flux density (PPFD) was dependent on photoperiod so that daily light integral of PAR amounted to 2.9 or 3.8 mol·m^{-2}. The irradiance received by the plants was measured by PAR photometer (model
PAR-10). The entire experiment consisted of 18 combinations for each species of spice plants. Each combination of experiment for each species was performed in two series. Means for individual factor was calculated by data from the combinations of the others factors.

Artificial light was provided using fluorescent lamps 36W/84 of Philips Company. The experimental plants were grown in pots of 280 cm$^3$ volume. The number of plants grown in pots was identical for individual species and amounted to 25-40 depending on species. The plants were measured every 7 days, first time 7 days after emergence for all species with the exception of parsley (14 days after emergence). In every pot 10 plants were measured. Dill, parsley, garden rocket and garden chervil were harvested when the plants developed three pairs of proper leaves. In the case of salad onions, it was harvested when the plants reached the height of 15-17 cm. The harvesting involved hand cutting of plants close to the surface of the substrate. After the harvest, the volume of the fresh mass of plants from the pot and the yield of dry weight with the application of drier-balance WPS 210S were determined.

The index of the absolute growth rate (GR) was calculated on the basis of the following formula:

$$ \text{GR} = \frac{dW}{dt} $$

where: $dW$ – mass of fresh plant material at the moment of harvesting (g), $dt$ – time of cultivation (day).

This coefficient allows determining the most optimal growth conditions for individual plant species.

The RRT coefficient was calculated on the basis of the following formula:

$$ \text{RRT} = \frac{DLI}{DTT} $$

where: DLI (daily light integral) is the total daily PPFD (mol·m$^{-2}$·d$^{-1}$), DTT (daily thermal time) is the mean daily temperature (ºC).

The significance of the impact of light, day length and temperature on yields of five investigated spice plants was determined with the F test. Differences between means were performed with the Newman-Keuls test at the level of significance P=0.05. In order to determine correlations between the applied experimental factors and fresh and dry weight yields of the experimental plants, the correlation coefficient was calculated and regression analysis was performed. All statistical analyses were carried out with the Stat program.

RESULTS AND DISCUSSION

The fresh mass yield volume of the examined plants depended, mainly, on the daily light integral. In the presented investigations, significantly higher fresh mass yields were determined in the case of plants which were cultivated at the daily light integral dose of 3.8 mol·m$^{-2}$·d$^{-1}$ than those which obtained the photon flux dose of only 2.9 mol·m$^{-2}$·d$^{-1}$ (Table 1).
daily quantity of PAR reduced the net assimilation rate in tomato, cucumber and paprika plants.

Table 1. The effect of daily light integral, day length and temperature on the plants fresh mass, dry weight and Growth Rate Coefficient (means from two series of experiment)

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Daily light integral (mol·m⁻²)</th>
<th>Day length (h)</th>
<th>Temperature (°C)</th>
<th>Fresh mass (g·pot⁻¹)</th>
<th>Dry weight (g·pot⁻¹)</th>
<th>Growth Rate (GR, g·days⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.9</td>
<td>3.8</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>dill</td>
<td>5.2 b*</td>
<td>6.6 a</td>
<td>6.5 a</td>
<td>5.8 b</td>
<td>5.3 c</td>
<td>5.0 c</td>
</tr>
<tr>
<td>garden chervil</td>
<td>5.5 b</td>
<td>7.2 a</td>
<td>6.4 a</td>
<td>6.1 a</td>
<td>6.6 a</td>
<td>5.6 b</td>
</tr>
<tr>
<td>garden rocket</td>
<td>6.9 b</td>
<td>8.7 a</td>
<td>8.4 a</td>
<td>8.0 a</td>
<td>7.0 b</td>
<td>8.6 a</td>
</tr>
<tr>
<td>parsley</td>
<td>4.7 b</td>
<td>8.1 a</td>
<td>6.6 a</td>
<td>5.6 b</td>
<td>7.1 a</td>
<td>5.9 b</td>
</tr>
<tr>
<td>salad onion</td>
<td>4.1 b</td>
<td>4.6 a</td>
<td>4.3 b</td>
<td>4.9 a</td>
<td>3.8 c</td>
<td>4.5 b</td>
</tr>
</tbody>
</table>

*Values followed by the same letters for individual species and factors do not differ significantly at P=0.05

Monteith (1977) was the first who demonstrated that biomass production, in cultivations with appropriate levels of irrigation and fertilization, depends linearly on the quantity of the absorbed light. This dependence is known and has been described in many papers (Warren-Wilson 1981; Jameison et al. 1995; Tei et al. 1996). Also in the described investigations, a linear correlation was found between the sum of photons absorbed during the period of growth of plants and the fresh mass yield (Fig. 1). However, further investigations revealed that this correlation differs for dissimilar plant species (Prince 1991, Brechner et al. 2007) as was also confirmed by the authors’ own experiments. In their investigations, plant species characterized by the lowest light requirements (garden rocket and garden chervil) were found to exhibit the highest fresh mass increments in relation to the absorbed photons.
Fresh mass (g·pot⁻¹)

* correlation significant at P=0.05, **correlation significant at P=0.01

Fig. 1. Relationship between the quantum of light and fresh yield

The level of photosynthesis was identical at the temperature of 15 and
25°C, at low light intensity. However, at higher light intensity, the level of
photosynthesis is considerably higher at the temperature of 25°C than at 15°C
(Hall & Rao 1999). This correlation was also demonstrated in the described
experiments. In the case of parsley garden chervil and salad onion significantly
higher yields were obtained at the temperature of 20°C, and for dill at 25°C.
Only garden rocket was characterized by the highest fresh mass yields at the
temperature of 15°C (Table 1). Jones (1992) maintains that the response of
plants to temperature is specific for different plants. High temperature acceler-
ates the development and decreases the leaf area of garden rocket and, conse-
quently, leads to the reduction of fresh mass yield. A similar response to high
temperature was also reported by Hälvä et al (1993). In their experiments on dill,
they obtained the highest yields at the lowest cultivation temperature (15/11°C)
and the lowest yields at the highest cultivation temperatures (25/21°C). The low-
est temperature increased the length of the growing period (greater amount of the
absorbed photons) resulting in greater fresh mass yields. On the other hand, in
experiments on sweet basil, a plant species of high temperature requirements,
carried out by Putievsky (1983) the highest fresh mass yields were obtained at
the highest temperatures (30/12°C). In the case of oregano, the highest yield of
fresh mass was obtained at moderate temperatures (24/12°C).

The effect of the day length on the fresh mass yields of the experimental
plant species depended on the value of the photon flux. The day length diversified
the yields of cultivated plants more at the daily light integral of 3.8 mol·m⁻²·d⁻¹.
than at the photon flux of 2.9 mol·m\(^{-2}\)·d\(^{-1}\) (unpublished data). The highest yields at 12-hour day length were recorded in the case of dill and garden rocket and for garden rocket also at 14-hour day. For parsley the highest yield was obtained at 16-hour day but it was not significantly different from yield at 12-hour day. A significantly higher yield of salad onion fresh mass was recorded at 14-hour day length. The day length failed to influence fresh mass yields of garden chervil. Farooqi et al. (1999) and Miguel et al. (2002) reported higher fresh mass yields of several medicinal plants at a longer day length. However, in contrast with the authors’ own studies, the above mentioned results were obtained at a higher daily dose of active photosynthetic radiation. The results obtained by the authors indicate that at a low daily dose of quantum radiation, the length of the lighting period and PPFD exerted small influence on the photosynthetic intensity and fresh mass yields. At higher doses of the daily light integral, a shorter lighting period with a greater PPFD value turned out to be more favourable for the majority of plant species. However, for the plant species characterized by low light requirements such as garden chervil, it was not essential.

The level of fresh mass yield was closely associated with the length of the vegetation period, but only in the case of dill and salad onion this correlation was positive. Cultivation at lower daily values of photon influxes was frequently connected with a longer vegetative period and lower effective biomass increments. This correlation is clearly illustrated by the absolute growth rate (GR) index which turned out to be considerably higher for the 3.8 mol·m\(^{-2}\)·d\(^{-1}\) daily light integral than for the 2.9 mol·m\(^{-2}\)·d\(^{-1}\) photon flux (Table 1).

The dry weight content in the examined spice plant species was higher in the case of the higher daily light integral and lower temperature and lower for the smaller daily light integral and higher temperature. According to Krug (1997), higher temperature leads to lower content of dry weight in plants. The recorded dry weight yield depended on the value of the RRT coefficient (Fig. 2). Higher RRT coefficient values were associated with higher dry weight yields of the examined plants and this correlation is proved by investigations carried out by other researchers (Harris & Scoot 1968; Liu & Heins 1998). Dry weight production is correlated with the total radiation absorbed by plants and depends on the effective PAR transformation during the process of photosynthesis (Charles-Edwards 1978; Masson et al. 1991; Aufhammer 1998). The authors’ own research and well as experiments carried out by other researchers indicate that, in order to obtain an effective plant biomass increment in the shortest time, it is important to select an appropriate proportion of light to temperature (Heins et al. 2000). In the case of plants used in the described experiments, the most optimal RRT value ranged from 0.22 to 0.25.
CONCLUSIONS

1. Temperature and day length exerted a smaller influence on the experimental spice plant fresh mass yields than the photon flux, with the exception of the salad onion.

2. All plant species were characterized by higher fresh mass yields as well as a higher value of the absolute GR coefficient at the 3.8 daily light integral than at the 2.9 daily light integral.

3. A linear correlation was found between the total amount of absorbed photons during the growth period and fresh mass yields.

4. The dry weight of experimental plants was correlated with the value of the ratio of radiant energy to thermal energy (RRT). The higher value of the RRT coefficient was connected with the higher dry weight content determined in experimental plants.

REFERENCES


Wpływ warunków świetlnych i temperatury na plon świeżej masy kilku gatunków roślin przyprawowych uprawianych w pojemnikach

Streszczenie

Celem pracy było zbadanie wpływu ilości światła, długości dnia i temperatury na plon zieleni pięciu gatunków roślin przyprawowych. Podjęto także próbę określenia współdziałania wymienionych czynników klimatycznych i ustalenie optymalnych warunków wzrostu dla poszczególnych gatunków. Wyznaczono trzy poziomy temperatury dziennych: 15, 20 i 25°C (temperatura w okresie nocy była o 5°C niższa) oraz dwa poziomy dobowej ilości światła (2,9 i 3,8 mol·m⁻²·dzień⁻¹) i trzy długości oświetlenia dla każdej dawki światła (12, 14 i 16 h). Strumień fotonów i temperatura miały największy wpływ na plon roślin w momencie zbioru. Wszystkie gatunki charakteryzowały się większym plonem świeżego ziela przy strumieniu fotonów 3,8 mol·m⁻²·dzień⁻¹. Stwierdzono także liniową zależność pomiędzy sumą zaabsorbowanych fotonów w ciągu okresu wzrostu a plonem świeżej masy. Zawartość suchej masy w zielu była skorelowana z wielkością współczynnika korelacji światła i temperatury (RRT). Większa wartość współczynnika RRT wiązała się z wyższą zawartością suchej masy w zielu.