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THE EFFECT OF AMOUNT OF LIGHT AND THE TEMPERATURE ON BIOMORPHOLOGICAL CHARACTERISTICS OF CHRYSANTHEMUMS DURING ALL-YEAR CULTURE

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Abstract. The ornamental value of chrysanthemums grown all year round is affected by climatic conditions. Publications describing quality of chrysanthemum usually refer only to selected climatic parameters and selected features of chrysanthemums. The aim of the present paper is a complete presentation of the problem. Two spray cultivars were cultivated in spring, summer, autumn and winter. To assess the strength and direction of a linear relationship between temperature (day, night, daily) or light (PAR) and biomorphological features, correlation coefficients (r) were calculated. Amount of light have a significant positive effect on the quantity of fresh mass of chrysanthemum and leaf area index (LAI). Light acted in a slightly smaller degree on increments of the main shoot, leaf area and relative chlorophyll content in leaves. Among examined temperatures the greatest influence has sum of day temperature. The temperature exerted a significantly positive effect on the quantity of fresh mass of chrysanthemum, the increments of the main shoot and the relative chlorophyll content in leaves. All biomorphological features are less positively correlated to sum of night and sum of daily temperatures. However, these characteristics are more depending on the amount of light rather than temperature.

Key words: *Chrysanthemum*, photoperiodic response, PAR, LAI

INTRODUCTION

The observed increasing market demand for chrysanthemums forces growers to apply more and more advanced growing methods, providing high quality plants. The ornamental value of chrysanthemums grown all year round is affected by climatic condi-

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tions – first of all light and temperature. These are the main elements thanks to which it is possible to control culture of these plants.

Light is a major ecological factor influencing physiological processes in green plants. Solar radiation is absorbed by plants in the process of photosynthesis and it is transformed into chemical energy accumulated in organic compounds. However, only a slight portion of solar radiation in the range of wavelengths from 400 to 700 nanometres is used in photosynthesis. It is the so-called Photosynthetically Active Radiation (PAR). The rate of photosynthesis depends on the wavelength in the PAR range, with the best results being obtained for the range of red (630–670 nm) and blue radiation (430–470 nm), and the poorest results recorded for green light (520–560 nm). Studies published so far indicate how light and temperature determine the ornamental value of grown chrysanthemums. According to Vogelmann [1963] light has the strongest effect on the development of inflorescence buds and then on the formation of inflorescences. That author also stressed that the effect of light intensity on plant development is quantitative in nature, with the decisive role being played by the duration of the action of light with a specific intensity. Hughes and Cockshull [1971] confirmed this statement. In their opinion flowering of chrysanthemums depends on the total diurnal light dose rather than light intensity.

Temperature is also significant parameter. During the long day period temperature has no influence on the flowering of chrysanthemums, but has an influence during short day (SD) period [de Jong and Smeets 1982]. Flower induction is relatively more temperature sensitive than flower development. Initiation of inflorescences is more rapid at temperature 16–22^{o}C [Cockshull 1979]. The optimum temperature for producing of receptacle is 18^{o}C [Van Ruiten and de Jong 1984]. However, cultivars differences were also noted. The effect of temperature on biomass production of chrysanthemum is not clear. At flowering, either a higher [Lepage et al. 1984], equal [Carvalho 2003] or a lower [Karlsson and Heins 1992] plant dry weight at sub-optimal temperature has been recorded. These different responses could result from different growth conditions but also cultivar differences might play a role.

Jerzy and Borkowska [2004] conducted investigations referring to the growth and flowering rhythm in chrysanthemums in 12 culture cycles throughout a year. Those authors observed a deterioration of plant quality in the period of insolation deficit. However, the ornamental value of chrysanthemums should be independent of the season of the year and in each culture period meet market requirements. Thus supplementary artificial lighting of grown plants is applied in the autumn and winter season [Langton et al. 1999; Heuvelink et al. 2002, Jerzy et al. 2004].

Publications describing the above mentioned dependences usually refer only to selected climate parameters (light, temperature) and selected features of chrysanthemums. The aim of the present paper is a complete presentation of the problem, with particular consideration of light (PAR) and day, night and daily temperature impact on biomorphological chrysanthemum features during all-year round culture.

MATERIAL AND METHODS

Two spray cultivars of chrysanthemums with similar photoperiodic reaction, i.e. 'Mona Lisa' and 'Sheena Select', were used in the experiment. Each year (2007 and 2008) plants were grown in four cycles differing in the natural day length: I – spring – from January to April, II – summer – from May to July, III – autumn – from August to October, IV – winter – from October to February. In one cycle 120 plants of each cultivar were grown. Each cycle consisted of two stages. In the first stage cuttings of chrysanthemums were grown in pots of 7 cm in diameter under the natural long day conditions (cycles II and III) or the day was artificially extended (cycles I and IV) by additional lighting using WSL 400W sodium lamps suspended 1.5 m above plants.

When the plants reached the height of 12–15.5 cm and produced 10–13 leaves, chrysanthemums were transplanted to containers of 5 dm^3. From that stage of experiment, the culture was started under short day conditions. The greenhouse was equipped with black out screens for darkening (Obscura A/B+B). Thanks to darkening in natural long day periods, light access was limited to 10 hours (from 7:00 to 17:00). In natural short day periods (November – February) no additional assimilation lighting was supplied. The greenhouse in which the experiment was conducted is located in Poznan (16°50' E and 52°25' N). In these conditions the real length of the light phase of day in January, November, December and partially in February was shorter than 10 hours (fig. 1.).

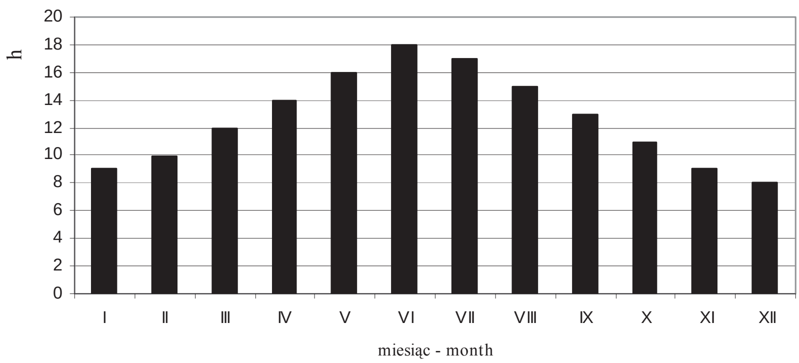

Fig. 1. Length of day measured in Poznan from January to December (16°50' E and 52°25' N)
Ryc. 1. Długości dnia obliczone dla Poznania od stycznia do grudnia (16°50' długości geograficznej wschodniej i 52°25' szerokości geograficznej północnej)

Moreover, the differences in the amount of light per one growing cycle were very significant (tab. 1). Plants were grown in highmoor peat limed to pH 6.5. Each time identical fertilization was applied using a fertigation system. The photoperiodic reaction of grown chrysanthemums was determined in each cycle and the following parameters were measured: increments of the main shoot of plants, fresh mass of the aboveground part of plants, the number and diameter of inflorescences, leaf area and relative chlorophyll content (SPAD measurements). Leaves growing immediately below twig branching were collected for measurements. Moreover, leaf area index (LAI), defining a total one-sided area of leaves per unit ground surface area taken by the plant, was also calculated. The data were subjected to statistical analysis of variance using Duncan's test. The Least Significant Difference Test (LSD) was performed at the P = 0.05.

Tabela 1. Ilość światła oraz suma średnich temperatur w roku 2007 i 2008
Table 1. Amount of light and mean temperatures in the years 2007 and 2008

Year Rok	Growing cycle Cykl uprawy	Amount of light Ilość światła, mol · m^{-2}	Sum of mean daily temperature Suma średnich temperatur dobowych °C	Sum of mean day temperature Suma średnich temperatur dnia °C	Sum of mean night temperature Suma średnich temperatur nocy °C
2007	I	346	1358	1335	1334
	II	973	1575	1650	1520
	III	439	1505	1571	1454
	IV	89	1156	1113	1171
2008	I	234	1220	1193	1240
	II	818	1661	1853	1527
	III	303	1459	1521	1413
	IV	104	1439	1382	1479

In the course of the experiments measurements were taken for temperature (day, night, diurnal) and the intensity of quantum radiation in terms of photosynthetically active radiation (PAR). Day temperature was defined as the temperature of the light phase, i.e. from 7:00 to 17:00, while night temperature – temperature of the dark phase from 17:00 to 7:00. For each culture cycles total amount of light (AL), sum of the mean day temperatures (SMDT), sum of the mean night temperatures (SMNT) and total mean daily temperatures (TMDT) were calculated. In order to assess the strength and direction of a linear relationship between temperature or radiation and biomorphological features, Pearson correlation coefficients (r) were calculated.

Climate parameter registration were done with the use of HOBO Micro Station Data Loger equipped with photosynthetic light (PAR) sensor (range of measurements: 0–2500 $\mu mol \cdot m^{-2} \cdot s^{-1}$) and temperature sensor (range: – 40°C do +75°C). The daily light amount during the whole period of plant cultivation was calculated according to the method proposed by Faust (2002). Measurements recorded every minute were summed up and then, they were multiplied by 60 (60 seconds per minute). In order to obtain the total amount of light in the given cycle of growing, the particular light amounts were added up. Temperature measurements were carried out at 1 minute intervals. The necessary calculation were carried out for day, night and day and night. The sum of mean temperatures was obtained by summarizing the mean values from particular growing cycles.

RESULTS AND DISCUSSION

The photoperiodic reaction of chrysanthemums was presented for all culture cycles in Fig. 2. The photoperiodic reaction of both grown chrysanthemum cultivars was calculated as the number of days from the beginning of obscuring to full blooming of

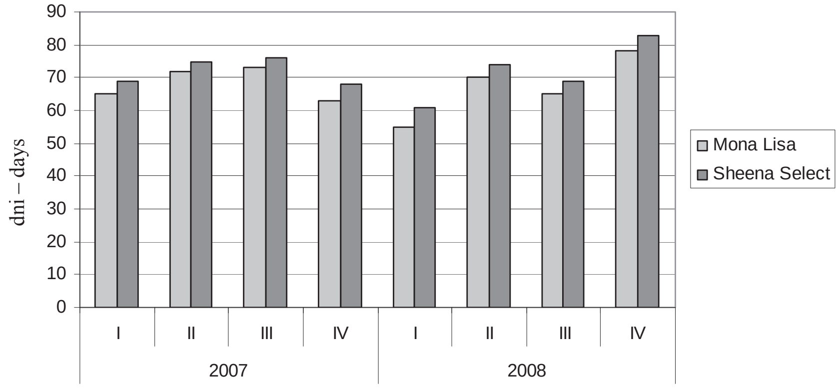

Fig. 2. Photoperiodic reasponse of chrysanthemum
Ryc. 2. Reakcja fotoperiodyczna chryzantem

plants. In 2007 the shortest photoperiodic reaction of both grown cultivars was recorded in the 1st and 4th, however in 2008 only in the 1st culture cycle. The longest culture time (starting from obscuring date) was recorded in 2007 in cycles II and III, while in 2008 in cycle IV. Explanations of these differentiation can be found in Table 1. In the year 2008 the mean night temperatures were too excessive and therefore, also the sum of mean day and night temperatures in IV cycle were also too high. Delayed flowering of chrysanthemum under high temperature conditions is a serious obstacle for all year round cut chrysanthemum flower production. Cathey [1954] reported that a night temperature had a greater effect on flowering time than a day temperature. Cockshull et al. [1981] reanalysed Cathey's data and concluded that flowering was in fact correlated with the average temperature and that the night temperature had no special influence. Pearson et al. [1993] concluded that the rate of progress to flowering (1/days to flowering) in chrysanthemum increases linearly with temperature up to an optimum and then decreases linearly with increasing supra-optimal temperatures. According to Whealy et al. [1987] a prolonged duration of 32–35°C temperature may stop chrysanthemum blooming altogether. Time to flowering shows an optimum response to temperature usually between 17^{o}C and 22^{o}C [de Jong 1978, de Lint and Heij 1987]. Jerzy and Borkowska [2004] investigated the photoperiodic reaction of 11 chrysanthemum cultivars from the Time group depending on the season of the year. They showed that the duration of culture depends to a considerable degree on the amount of light which reaches plants. Strong light has a decisive effect on the development of inflorescence buds, while weak light completely reduces or inhibits its development. However, the above mentioned authors did not refer to temperature. Effects of high temperature on floral development and flowering in spray chrysanthemum was examined by Nozaki and Fukai [2008]. To clarify the causes of flowering delay in spray chrysanthemum, two different genotypes of spray chrysanthemum were grown under high-temperature and short-day conditions: summer-to-autumn flowering type (SA type, high temperature tolerant) and autumn flowering type (A type, high temperature sensitive). Results clarify that two independent events caused by high temperatures occur in the shoot apex of spray chrysanthemum under short-day conditions. High temperatures slowed floral development in inflorescence, thereby increasing the number of florets in both SA and A chrysanthemum genotypes. Moreover, high temperatures slowed the developmental speed of inflorescence after the budding stage, and the time to reach the bud break stage was prolonged, thereby delaying flowering, especially in A chrysanthemum genotypes.

Results of the other measurements are shown on the example of the data of 2007 in Figure 3. It was shown a considerable effect of the date of culture on quality features and thus ornamental value of grown chrysanthemums. The highest increments of the main shoot were recorded in cycle III, while the lowest in cycle IV. The date of culture, i.e. culture conditions, influences significantly also fresh weight of aboveground parts for grown chrysanthemums. The highest fresh mass was produced by plants grown in the summer (cycle II), lower in the autumn (cycle III), while the lowest – in the winter and spring (cycles IV and I). The biggest leaf area was recorded for chrysanthemums cultured in cycle II ('Sheena Select') or in cycles II and III ('Mona Lisa'). The smallest area was formed by plants in both years in cycle IV.

The date of culture influenced also ornamental value of chrysanthemum inflorescences. The biggest diameters of inflorescences was recorded in most cases in the spring cycle (I), while the smallest both in the first and the second year of culture in the winter cycle (IV). The largest number of inflorescences was recorded in the period from May to October, i.e. in the 2nd and 3rd cycles of culture. Moreover, a significant effect of the date of culture was also observed in case of relative chlorophyll content in leaves and leaf area index. The highest values were recorded in the summer and autumn period (the 2nd and 3rd cycles of culture).

Pawlak and Jerzy [2006a, 2006b] compared the number of chrysanthemum inflorescences grown in spring (from 15 April – 1 May) and in autumn (from 25 July – 8 August). In their experiments in the spring cycle, the majority of cultivars produced ahigher number of inflorescences than in the autumn cycle.

Smaller inflorescence diameters of chrysanthemums from the Yoder Brothers group, grown in the summer months, were also observed in a study by Jerzy and Borkowska [2002].

The concept of the culture cycle is too general, since at the same time it includes different factors affecting the culture conditions, e.g. light and temperature conditions. Therefore, in order to assess the strength and direction of a linear relationship between temperature or light and the biomorphological features, correlation coefficients (r) were calculated (table 2–3). Statistical calculations, performed separately for each year of culture and jointly for both years of the study, indicate that the effect of investigated climatic conditions on individual biomorphological features of chrysanthemums was varied. The calculation were carried out jointly for two cultivars.

Both in the first and the second year of culture a positive correlation was found between the total amount of light (AL) in the period of plant growth and most analysed features. With an increase in the AL an increment of main stems, fresh weight of aboveground parts, leaf area and relative chlorophyll content in leaves, the number of inflorescences and leaf area index (LAI) was observed. No correlation was shown between AL in range of PAR and the diameter of inflorescences.

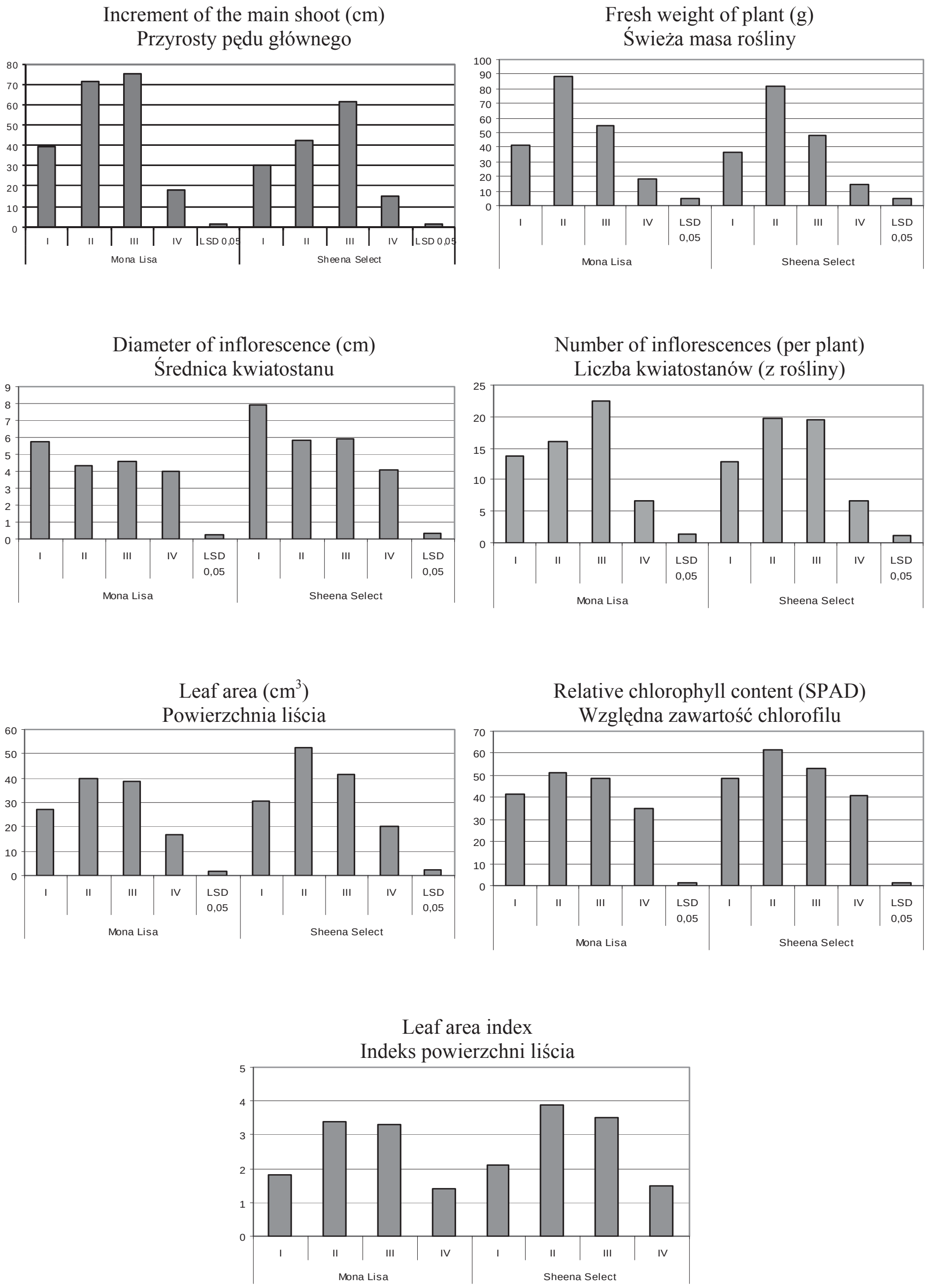

Fig. 3. Biomorphological characteristics of chrysanthemums depending on growing cycles of plants cultivation in 2007 year

Ryc. 3. Biomorfologiczne cechy chryzantem w zależności od cyklu w roku 2007

Table 2. The correlation coefficient between the amount of light (mol · m^{-2}) and biomorphological characteristics of chrysanthemums (mean value for grown cultivars)

Tabela 2. Współczynnik korelacji pomiędzy ilością światła (mol · m^{-2}), a wybranymi cechami biomorfologicznymi chryzantem (średnia dla uprawianych odmian)

Year Rok	Increments of the main shoot Przyrosty pędu głównego	Fresh mass of plant Świeża masa rośliny	Leaf area Powierzchnia liści	Number of inflorescences Liczba kwiatostanów	Diameter of inflorescence Średnica kwiatostanu	Relative chlorophyll content Względna zawartość chlorofilu	Leaf area index Indeks powierzchni liścia
2007	0.63	0.96	0.82	0.56	- 0.15	0.77	0.82
2008	0.73	0.64	0.54	0.66	- 0.03	0.50	0.71
2007 + 2008	0.66	0.76	0.66	0.54	- 0.05	0.60	0.75

Bolded correlations significant at P = 0.05 – Pogrubione korelacje istotne przy poziomie istotności α = 0,05

Table 3. The correlation coefficient between the temperature (^{o}C) and biomorphological characteristics of chrysanthemums (mean value for grown cultivars)

Tabela 3. Współczynnik korelacji pomiędzy temperaturą (^{o}C), a wybranymi cechami biomorfologicznymi chryzantem (średnia dla uprawianych odmian)

Parameter Parametr	Year Rok	Incerments of the main shoot Przyrosty pędu głównego	Fresh mass of plant Świeża masa rośliny	Leaf area Powierzchnia liścia	Number of inflorescences Liczba kwiatostanów	Diameter of inflorescence Średnica kwiatostanu	Relative chlorophyll content Względna zawartość chlorofilu	Leaf area index Indeks powierzchni liścia
Temperatura dobowa Daily temperature (TMDT)	2007	0.62	0.81	0.68	0.92	0.37	0.64	0.47
	2008	0.67	0.64	0.25	0.37	- 0.01	0.82	0.24
	2007 + 2008	0.60	0.70	0.43	0.41	0.17	0.59	0.31
Temperatura dnia Day temperature (SMDT)	2007	0.67	0.85	0.73	0.93	0.30	0.78	0.55
	2008	0.72	0.69	0.34	0.52	- 0.05	0.57	0.38
	2007 + 2008	0.64	0.73	0.46	0.45	0.10	0.62	0.40
Temperatura nocy Night temperature (SMNT)	2007	0.58	0.78	0.63	0.89	0.46	0.75	0.41
	2008	0.62	0.59	0.20	0.09	0.08	0.55	0.12
	2007 + 2008	0.57	0.66	0.38	0.34	0.26	0.60	0.23

Bolded correlations significant at P = 0.05 – Pogrubione korelacje istotne przy poziomie istotności α = 0,05

Correlation coefficients indicate that AL had the biggest effect on fresh mass of aboveground parts of plants (r = 0.76) and next LAI (r = 0.75), increments of the main shoots (r = 0.66) and leaf area (r = 0.66), relative chlorophyll content (r = 0.60). Among the measured temperatures the strongest positive effect on quality of chrysanthemums was found for sum of the mean day temperatures. This effect pertained particularly to fresh mass of the aboveground part (r = 0.73), increment of the main shoot (r = 0.64) and relative chlorophyll content (r = 0.62). The effect of the other temperatures (SMNT and TMDT), although statistically proven, was smaller.

The positive relation between day temperatures (SMDT) or daily temperatures (TMDT) and the number of inflorescences in both years of study was observed. However, the influence of night temperatures (SMNT) only in 2007 was noted. Perhaps this is related to too high temperatures during nights in 2008. Lepage et al. [1984] believe, that the increase in flower number is mainly due to the influence of night temperature, although cultivar specific deviations from this trend have been observed .

No significant relationship was shown between the total amount of light and the diameter of inflorescences. Positive effect of night temperatures (SMNT) was found only in 2007. Absence of any effect in the year 2008 probably was connected with too high night temperatures (tab. 1). Vince [1960] reducing the night temperatures from 15°C to 10°C increased flower size in eight cultivars between 3–34%. Machin [1997] reported that from June to September the main cause of a deteriorated quality of flowering plants include too high night temperatures in culture under screens. Carvahlo et al. [2005] divided period of chrysanthemums cultivation into 3 phases: long-day period (phase I), start of short-day period to visible terminal flower bud (phase II), and end of phase II to harvest stage (phase III). The mentioned authors noted that flower size increased with higher temperature during phase II, but decreased with temperature during end of phase II to harvest stage.

In experiment of Nothnagl and Larsen [2002] chrysanthemums grown at higher amounts of light formed inflorescences of 70 mm in diameter, while at smaller light amounts the average diameters decreased to 55 mm. Nothnagl et al. [2004] developed a model describing the influence of irradiance and temperature in the greenhouse on the size of chrysanthemum flowers. Data, collected from a light and a temperature experiment, showed that low light integrals and temperatures above 20 C had a retarding effect on flower growth.

Ploeg et al. [2005] confirmed the results obtained in the experiment referring to the height of chrysanthemums – taller plants grew during culture at a higher temperature. Under these conditions chrysanthemums produce longer shoots, which is related with a higher number of internodes.

This is also manifested in fresh weight of plants, i.e. the higher the temperature, the bigger the weight of grown plants. Results recorded in our experiment indicate that fresh weight of grown chrysanthemums was more dependent on the sum of the mean day temperatures (r = 0.73) than on the temperature during the night (r = 0.66).

According to Tutty et al. [1992], the elongation growth of internodes is influenced by the relationship between day and night temperatures, since the most intensive growth was recorded when day temperature was high (27.7°C) and night temperature was low (12°C). In the opposite system of temperatures or at similar day and night temperatures the elongation growth of internodes was weaker. Carvalho at al. [2002a] elaborated a model describing final internode length as a quadratic combination of day and night temperature.

Carvalho et al. [2002b] reported that the greater the amount of light and less dense of plants, the highest is the number of inflorescences on a shoot. Plants growing at less density per unit of area (32 plants/m^2) and at a bigger amount of light formed 33 inflorescences on a shoot, while those growing in a denser spacing and at a light which intensity was reduced by half – only 9 inflorescences. Also Carvalho and Heuvelink [2001] recorded that plants growing at a bigger amount of light produced more inflorescences per plant. Results recorded in our experiment confirm the above described dependences referring to the influence of light on the number of inflorescences. However, due to the value of r = 0.54 (years 2007 + 2008) we may only talk of a moderate degree of correlation. Our investigations also indicate the effect of light on LAI. This coefficient was strongly correlated with the total amount of light (r = 0.75). The effect of temperature on LAI was much smaller.

CONCLUSIONS

1. The amount of light exerted a significantly positive effect on the quantity of chrysanthemum fresh mass and on leaf area index (LAI). Light acted in a slightly smaller degree on the main shoot increments, leaf area and the relative chlorophyll content in leaves.

2. The temperature (particularly sum of mean day temperatures) exerted a significantly positive effect on the quantity of fresh mass of chrysanthemum, the increments of the main shoot and the relative chlorophyll content in leaves.

3. All biomorphological features were less positively correlated to the sum of mean night and the sum of mean daily temperatures. However these characteristics depended rather more on the amount of light than on temperature.

4. The influence of temperatures on inflorescence diameter was limited. The highest effect, however, was exerted mainly by night temperature. No dependence was found between the amount of light and the diameter of inflorescence.

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WPŁYW ILOŚCI ŚWIATŁA I TEMPERATURY NA BIOMORFOLOGICZNE CECHY CHRYZANTEM PODCZAS UPRAWY CAŁOROCZNEJ

Streszczenie. Wartość dekoracyjna chryzantem w uprawie całorocznej zależy od warunków klimatycznych. Publikacje opisujące jakość chryzantem dotyczą zwykle wybranych paramentów klimatycznych i niektórych cech roślin. Celem pracy były badania obejmujące całokształt problemu. Dwie odmiany chryzantem gałązkowych uprawiano wiosną, latem, jesienią i zimą. Aby ocenić siłę i kierunek zależności liniowej między temperaturą (dnia, nocy i dobową) lub radiacją (PAR) a cechami biomorfologicznymi, obliczono współczynniki korelacji. Ilość światła miała największy pozytywny wpływ na świeżą masę części nadziemnej i indeks powierzchni liści (LAI), w nieco mniejszym stopniu na przyrosty pędu głównego, powierzchnie liści i względną zawartość chlorofilu w liściach. Spośród badanych temperatur największy wpływ na rośliny miała suma temperatur dnia. Najsilniejsze odziaływanie odnotowano w przypadku świeżej masy części nadziemnej, przyrostów pędu głównego i względnej zwartości chlorofilu. Stwierdzono także istnienie nieco niższej, lecz także pozytywnej korelacji między wymienionymi cechami biomorfologicznymi chryzantem a sumą średnich temperatur nocy lub sumą średnich temperatur dobowych. Wielkość współczynników wskazuje jednak, iż wpływ światła na badane cechy był większy niż wpływ temperatur.

Słowa kluczowe: chryzantemy, reakcja fotoperiodyczna, PAR, LAI

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