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The effect of temperature on growth and chemical composition of Chinese cabbage seedlings in spring period

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ABSTRACT

A two-year experiment, conducted in spring period, was carried out to analyse the growth and content of certain compounds of Chinese cabbage seedlings produced in different thermal conditions. A part of the plants was kept in a heated greenhouse (the control group), while the remaining ones were exposed to natural low non-freezing temperature for the last 16 days before the end of the raising period (in an unheated greenhouse).

The growth of the plants in low temperature conditions was slower than that of the control. It was clearly observed on the basis of measurements held at different stages of seedling development. The height of the control plants increased in time from 1.2-1.7 cm to 7.4-13.4 cm, while those of other temperature treatments from 1.0-1.6 cm to 4.4-10.1 cm, in consecutive years. Similarly, at higher temperatures

the seedlings showed faster leaf development (from 0.7-0.8 to 5.6-6.8 leaves) in comparison to plants subjected to low temperatures (from 0.8-0.8 to 4.0-4.6 leaves). Such a response of plants to differentiated growth temperature was also confirmed at the end of the raising period when some morphological parameters were compared. At low temperature, the final size of Chinese cabbage plants was significantly smaller than that of the plants grown in more beneficial conditions. As noted, differences between treatments reached on average 2.6 cm in the height, 1.7 in the number of leaves and 6.8 cm^2 in the area of single leaf. Seedlings subjected to low temperature also showed decrease in fresh and dry matter content (by 3.35 g $plant^{-1}$ and 0.98%, respectively) and they usually accumulated lower amounts of soluble sugar (by 0.44% f.m.). However, there was no significant effect of the temperature conditions on the chlorophyll a, chlorophyll b and carotenoids content in Chinese cabbage seedlings.

INTRODUCTION

The Chinese cabbage can be grown successfully either in spring or fall. All of the commercial production of the Chinese cabbage for spring harvests is grown from seedlings. Early planting is crucial to achieve an early yield and consequently a high price. However, there is a risk of environmental stress associated with exposing young plants to cool weather after field setting, the sooner the planting date the stronger the stress (Palada et al. 1987). For this reason, it is particularly important to prepare plants to outdoor conditions. One of the used techniques for plant acclimation is exposing them to lower temperatures before planting (Kalisz and Cebula 2001a). Proper manipulation of this factor during the period of Chinese cabbage seedling propagation in a greenhouse finally leads to an increase in their tolerance to adverse field conditons of a spring season.

It is well known that temperature is one of the conclusory factors controlling the growth of plants (Berghage 1998, Heins et al. 2000). Each plant species has an optimum temperature when the growth is rapid, while lower non-freezing temperatures allow the plant to grow, but at a considerably reduced rate. Moreover, the response of plants to unfavourable temperatures results in a modification of many physiological and biochemical processes leading to changes in the chemical composition (Nam et al. 1995). The degree of these changes is mainly dependent on the temperature level, the temperature exposure duration and the stage of plant development. Seedlings are generally more sensitive to unfavourable thermal conditions than more developed plants (Daly and Tomkins 1995). Low temperatures have been reported to reduce the growth of Chinese cabbage seedlings (Wiebe 1990) and to influence their chemical composition (Moe and Guttormsen 1985, Sasaki et al. 1996). However, still limited research is available describing complex effects of natural low but non-freezing and no constant temperatures on Chinese cabbage at the seedling stage. Therefore, the objective of this study was to evaluate the growth and content of certain compounds of young plants exposed to different thermal conditions prior to field transplanting.

MATERIAL AND METHODS

The experiment was conducted in 2004 and 2005 in the greenhouse of the Agricultural University in Kraków. Seeds of Chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.) cv. 'Sapporo F_1' (Vikima Seed) were sown on March 26 (2004) and March 23 (2005) into VEFI trays (96 cells per tray, cell volume of 53.0 cm^3), containing peat-based substrate. Seedling emergence was observed after 3-4 days from sowing. They were uniformly overhead irrigated as needed, and 3 weeks after sowing were fertigated with soluble fertilizer (Yara CalciNit: N – 15.5%, Ca – 19.0%; 1 dag per dm^3 of water). When the seedlings had formed one leaf of about 2 cm length, a half of trays were transferred to the unheated part of the greenhouse. Natural low temperature period took place from April 5 to April 20 in 2004 and from April 4 to April 19 in 2005. The remaining plants were kept in heated greenhouse (control). In both places seedlings grew under natural light conditions.

Air temperature was automatically recorded by using HOBO Pro RH/Temp. data loggers (Onset Computer Corp., USA) in 1-hour intervals. The maximum, mean and minimum temperatures as well as differences between heated and unheated greenhouse compartments were calculated on the basis of these data. The temperature frequency expressed as the total number of hours with temperature values that occurred within specific range (from 0°C to 37°C, in steps of 1°C) during the last 16 days of seedling growth.

The air temperatures during the first 10-12 days from sowing remained the same for both experimental treatments (Fig. 1). The average values of mean daily temperature for this period amounted to 19.2°C and 18.2°C, while the maximum to 27.9°C and 26.9°C, and the minimum to 13.6°C and 12.1°C, respectively in 2004 and 2005. In the next period of production, the course of mean daily air temperature in the heated greenhouse (control seedlings) was within the range of 15.7-22.0°C in 2004 and 14.6-21.3°C in 2005, while in the unheated one 7.5-15.5°C and 7.5-16.2°C, respectively. It was noted that the minimum temperature recorded in the control did not drop below 9°C in both years (11.4-16.4°C and 9.8-16.0°C, respectively in the years 2004 and 2005). Plants in low temperature treatment were subjected to definitely the lowest minimum temperature (0.7-9.0°C and 0.3-10.2°C, respectively).

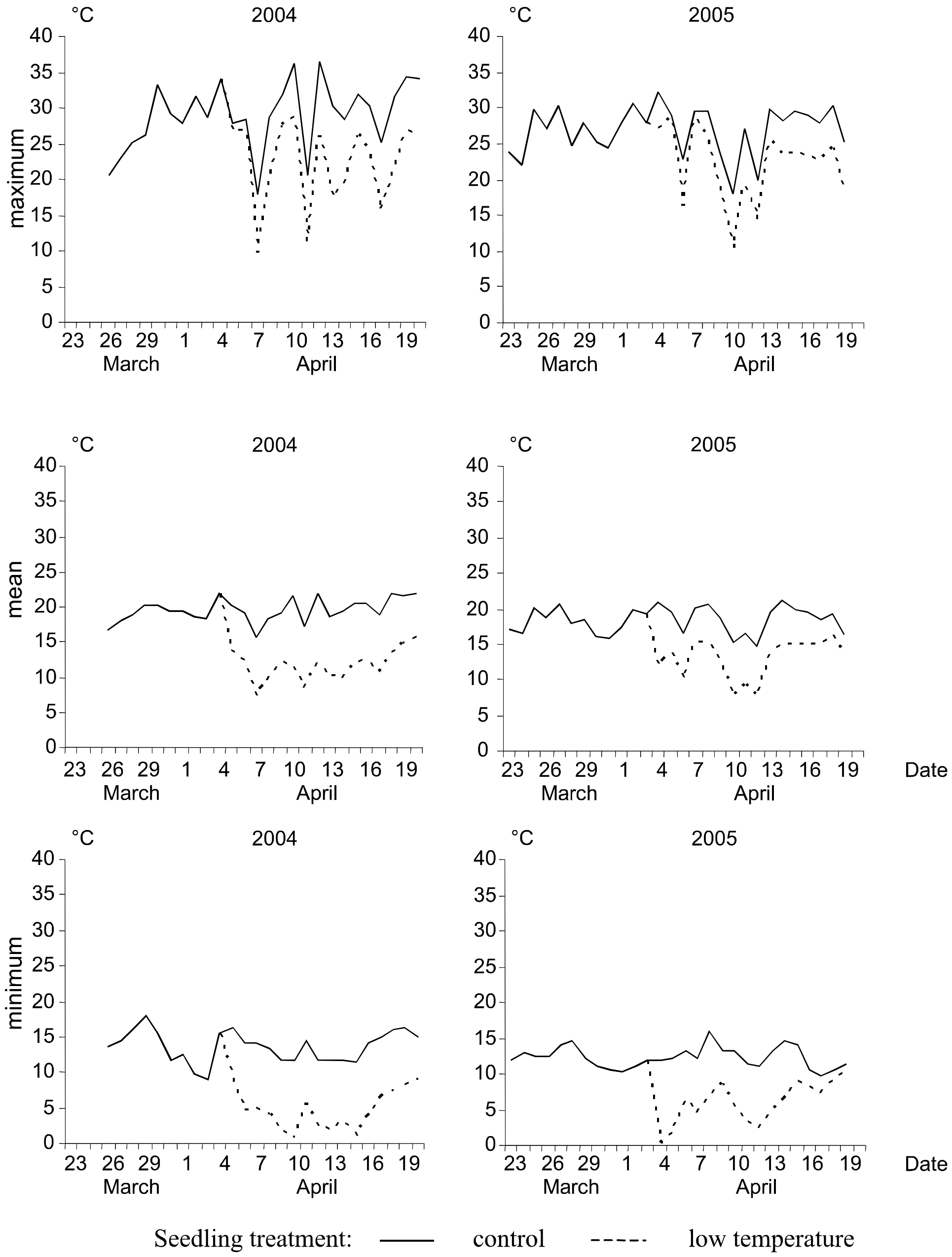

Figure 1. Pattern of maximum, mean and minimum air temperature during Chinese cabbage seedling production

The recorded data showed that the maximum air temperature was changed in the considerably widest range in both treatments. In the neighbourhood of the control seedlings this temperature was within the range of 17.9-36.6°C in 2004 and 17.9-32.2°C in 2005, while for those grown in the unheated greenhouse, it fluctuated from 9.8°C to 28.7°C and from 10.6°C to 28.7°C, respectively.

The height of the same 10 seedlings in trays and their number of leaves were recorded in 4-day intervals, from April 2 to April 18 in 2004 and from April 1 to April 17 in 2005, always in the morning hours. The first measurement was held before the temperature treatment. The height of plants was measured from the base of the stem to the top of the tallest leaf, the counted leaves had at least 1 cm length. At the end of the raising period (April 21 in 2004 and April 20 in 2005) twenty plants were randomly selected from each tray of different temperature conditions to evaluate seedling quality. Measurements of the height, number of leaves and leaf area were made for these plants. The height and number of leaves were measured on seedlings removed from the trays and placed on a flat surface. The largest leaf from each plant was cut out and its area was calculated using image analysis software KSRUN 3.0 (Carl Zeiss Vision GmbH). At that time the fresh matter of seedlings without roots was also determined using a Sartorius A120S analytical balance as well as the content of dry matter (drying at 105°C to constant weight), soluble sugar (anthrone method), chlorophyll a, chlorophyll b and carotenoids (Lichtenthaler method).

The results were statistically evaluated at significance level $p = 0.05$ (morphological measurements) or $p = 0.01$ (laboratory analysis). Linear correlation coefficients (r) were also calculated between the differences in temperatures and plant growth parameters (height, number of leaves) at $p = 0.05$, $N = 10$.

RESULTS

The data concerning the course of temperatures in heated and unheated greenhouse in general were illustrated and described in the previous chapter.

The daily mean air temperature differences between the experimental treatments ranged from 6.4°C to 10.0°C in 2004 and from 2.9°C to 9.0°C in 2005 (Fig. 2). The estimated differences were greater for the maximum temperature (1.2-12.8°C and 0.4-7.7°C, respectively) and for minimum temperature (5.8-11.0°C and 1.2-11.5°C). It should be stressed that differences in the maximum temperature showed a slight tendency to increase in time, while in the case of mean and minimum temperatures this tendency was reverse, especially in the last week of seedling production. In the first year of the experiment the differentiation in thermal conditions between the heated and unheated greenhouse was much higher than in the following year.

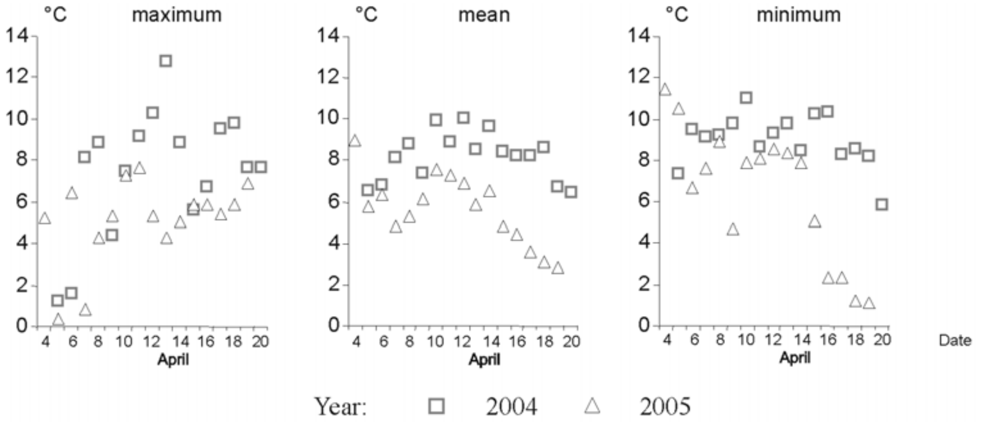

Figure 2. Air temperature differences between heated and unheated greenhouse during growth of Chinese cabbage seedlings

In both years, it was noticeable that temperature frequency values were shifted higher under control conditions, while in the unheated greenhouse fell to a considerably lowest range (Fig. 3). The air temperature between 0°C and 10°C, expressed on the basis of hourly data, was recorded by 0 and 1 hour (0.0% and 0.3% of total hours, i.e. 384 hours) in the neighbourhood of control plants, and by 153 and 139 hours (39.8% and 36.2%) in case of seedlings placed in the unheated greenhouse, respectively in the years 2004 and 2005. The temperature above 10°C and up to 20°C appeared by 237-252 hours (61.7-65.6%) and by 180-179 hours (46.9-46.6%), respectively. The values upper 20°C were observed by 147-131 hours (38.3-34.1%) in the vicinity of control plants or by 51-66 hours (13.3-17.2%) in the unheated greenhouse, in consecutive years.

The inhibition of plant growth as a consequence of lower air temperatures was already observed in the time of second measurements when Chinese cabbage exposed to such conditions was smallest (expressed as plant height) by on average 0.4 cm (Fig. 4). In the first year, the height of seedlings transferred to an unheated greenhouse reached on the next terms of measurements on average 2.3, 4.0 and 4.4 cm, and was lower by 0.8, 2.2 and 3.0 cm, respectively, in comparison with the control plants. The growth of the seedlings was much faster in both treatments in 2005 in comparison with the previous year, especially in case of the control group plants. At the third and subsequent measurements, the average height of these seedlings amounted to 8.0, 10.0 and 13.4 cm and they were taller by 2.8, 3.7 and 3.3 cm, respectively, as compared to those of the other temperature variant. The height of plants grown in control conditions increased between the first and the last measurement by 516.7% and 688.2% in consecutive years, while in case of those subjected to low temperature by 340.0% and 531.3%, respectively. The average growth rate of Chinese cabbage seedlings (changes in height per day) was 0.39-0.73 (control) and 0.21-0.53 (low temperature) in consecutive years.

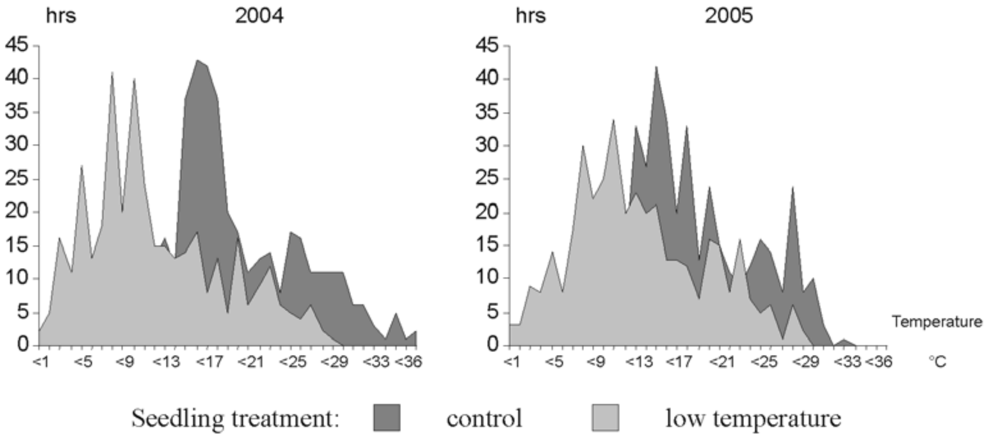

Figure 3. Temperature frequency distribution during growth of Chinese cabbage seedlings under different temperature conditions

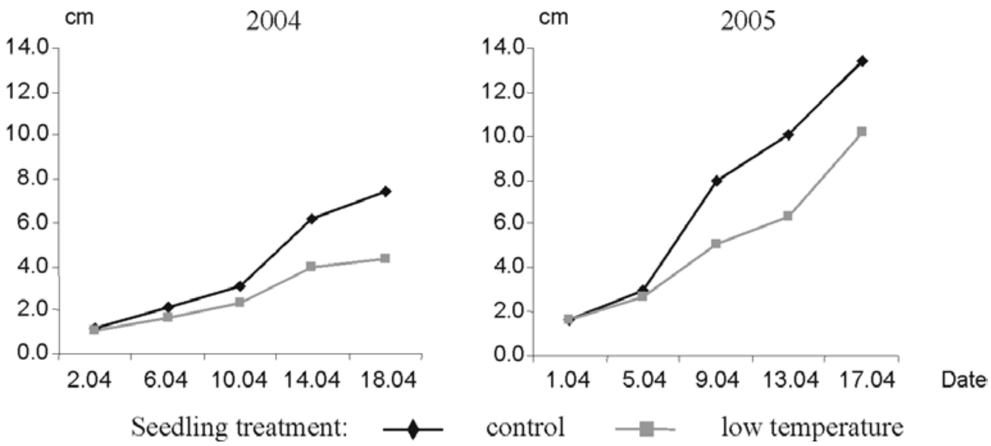

Figure 4. Changes in height during growth of Chinese cabbage seedlings under different temperature conditions

Similar changes were observed in the number of Chinese cabbage leaves (Fig. 5). The seedlings grown at higher temperatures had a higher number of leaves as compared with those of the other temperature variant. The response of the seedlings to various thermal conditions was already observed at the time of second measurement (differences reached 0.4-0.6 leaves per plant, depending on the year). On the next dates of measurements leaf numbers of plants, which had been exposed to low temperature, were lower by 1.0; 1.5 and 1.6 leaves in 2004 and by 1.4, 1.6 and 2.2 leaves in 2005, respectively. In case of the control plants, the number of leaves increased between the first and the last measurement by 700% and 750% in consecutive years, while in those exposed to lower temperature by 400% and 475%, respectively. The leaf unfolding rate (leaves per day) was 0.31-0.38 and 0.20-0.24, respectively for the control and low temperature treated seedlings. The comparison of the years showed smaller differences in this parametr in particular temperature treatments than observed in the plant height.

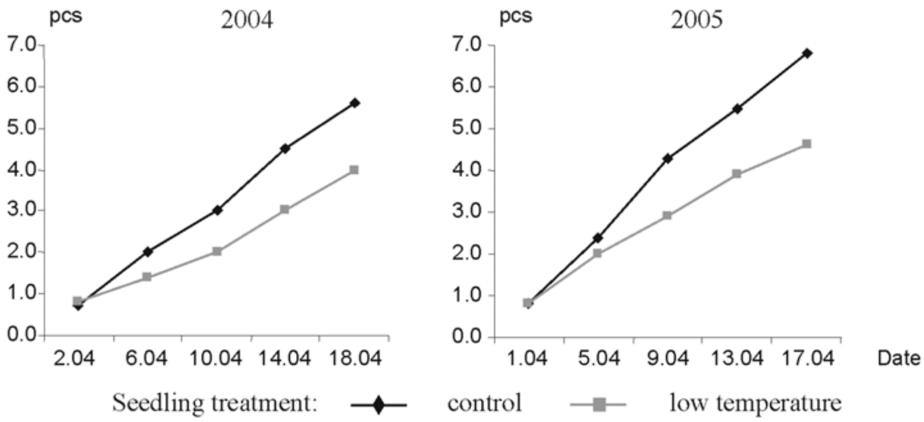

Figure 5. Changes in number of leaves during growth of Chinese cabbage seedlings under different temperature conditions

Significant relationships were found between temperature conditions and growth parameters of Chinese cabbage seedlings. The estimated correlation coefficients (r) between seedling height and temperatures (maximum, minimum and mean daily temperature, respectively) were: 0.729, 0.810 and 0.760, while in case of the number of leaves the calculated r was equal to 0.792, 0.881 and 0.840.

The measurements concerning the height, number of leaves and leaf area, carried out at the end of the raising period, confirmed significant effect of temperature treatments on the growth of Chinese cabbage seedlings (Table 1). The plants grown in the unheated greenhouse had the lowest height (9.5 cm in 2004 and 12.6 cm in 2005) and were lower by 1.6 cm and 3.7 cm, respectively, in comparison with those grown in more beneficial conditions. A similar situation was observed for the number of leaves. More leaves were created by plants grown in higher temperatures (on average 7.5 leaves), and differences amounted to 1.7-1.8 pieces. The seedlings held in the heated greenhouse also had the largest leaf area (38.0 cm^2 in 2004 and 49.9 cm^2 in 2005), while in low temperature the expansion of leaf was more restricted (by 1.8 and 11.8 cm^2, respectively). In the first year of the experiment the difference in leaf area was rather small but also statistically proved.

Table 1. The effect of different temperature conditions on morphological characteristics of Chinese cabbage seedlings at the end of the raising period

Seedling treatment	Height (cm)			Number of leaves (per plant)			Leaf area (cm^2)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Control	11.1	16.3	13.7	7.5	7.5	7.5	38.0	49.9	44.0
Low temperature	9.5	12.6	11.1	5.7	5.8	5.8	36.2	38.1	37.2
$LSD_{0.05}$	0.2	0.8	0.3	0.4	0.7	0.5	0.4	5.0	2.5

Low temperature treatment was found to have a significant effect on the fresh matter, dry matter and soluble sugar in Chinese cabbage seedlings (Table 2). The plants held in such conditions produced the lowest fresh matter (5.18 g plant^{-1} in 2004 and 5.40 g plant^{-1} in 2005), while for the control seedlings the fresh matter was higher by 1.12 g plant^{-1} and 5.58 g plant^{-1}, respectively. A similar dependence was observed in the amount of dry matter. In plants exposed to low temperature, the content of dry matter was lower (7.36% and 8.00%, depending on the year) compared with those of the control plants (differences reached 1.56% and 0.40%). The seedlings subjected to low temperatures also accumulated smaller amounts of soluble sugar (0.70% f.m. in 2004 and 1.75% f.m. in 2005), while the plants grown in the heated greenhouse contained more sugars (by 0.67% f.m. and 0.22% f.m., respectively). In 2005 such changes were not proved statistically, but significance differentiation was noted in the case of 2-year means.

Table 2. The effect of different temperature conditions on fresh matter, dry matter and soluble sugar content of Chinese cabbage seedlings at the end of the raising period

Seedling treatment	Fresh matter (g plant^{-1})			Dry matter (%)			Soluble sugar (% f.m.)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Control	6.30	10.98	8.64	8.92	8.40	8.66	1.37	1.97	1.67
Low temperature	5.18	5.40	5.29	7.36	8.00	7.68	0.70	1.75	1.23
$LSD_{0.01}$	0.89	4.93	2.07	0.45	0.09	0.24	0.46	n.s.	0.32

Statistical analysis showed no significant effect of temperature conditions on the chlorophyll and carotenoids accumulation of Chinese cabbage seedlings (Table 3). The content of chlorophyll a in Chinese cabbage seedlings ranged from 0.613 to 0.681 mg g^{-1} f.m., while in case of chlorophyll b – from 0.264 to 0.324 mg g^{-1} f.m., and carotenoids – from 0.206 to 0.235 mg g^{-1} f.m. Great differentiation in the content of these compounds was noted with relation to the year of the studies – the control plants accumulated slightly more pigments in 2004, while in the following year the situation was reverse. Analysis of variance based on 2-year means also did not show distinct and significant dependencies.

Table 3. The effect of different temperature conditions on chlorophyll a, chlorophyll b and carotenoids content of Chinese cabbage seedlings at the end of the raising period

Seedling treatment	Chlorophyll a (mg g $^{-1}$ f.m.)			Chlorophyll b (mg g $^{-1}$ f.m.)			Carotenoids (mg g $^{-1}$ f.m.)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Control	0.681	0.613	0.647	0.324	0.264	0.294	0.235	0.206	0.221
Low temperature	0.622	0.679	0.651	0.272	0.304	0.288	0.228	0.235	0.232
$LSD_{0.01}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

DISCUSSION

The growth of Chinese cabbage seedlings in low temperature conditions was greatly reduced as compared to the control plants. Unfavourable thermal conditions made Chinese cabbage grow slower, which could be expressed as a decrease in the plant height, number of leaves and leaf area development (Noto and Leonardi 1995, Kalisz and Cebula 2001b). The reduction in growth of cabbage seedlings held in low temperature was also observed by Sasaki et al. (1996). Such a response of plants to unfavourable thermal conditions is well known and described in the literature (Olesen and Grevsen 1997, Heins et al. 2000). On the other hand, plant growth can be accelerated with increasing temperature. According to Wiebe (1990), the number of leaves in Chinese cabbage seedlings raised clearly with higher temperature compared with those subjected to low temperature. In the present study, the temperature was proved to be the important factor for Chinese cabbage seedling growth. It was clearly observed during sequential measurements as well as at the end of the raising period when morphological parameters of the seedlings were compared.

The results obtained in this study indicated that temperature conditions during seedlings raising were more beneficial for plant growth in 2005. The air temperature in the vicinity of Chinese cabbage was on higher level in comparison to the former year as well as the differences in thermal conditions between the heated and unheated greenhouse were lower. As a consequence, seedlings of both treatments had higher fresh matter, the height and larger leaves than in the first year. Moreover, leaf area development of the control seedlings was faster in this year, a single leaf was greater by 31% as compared to those subjected to low temperatures. It is also interesting that the number of leaves formed by plants was rather similar in both years, respectively to the particular experimental treatments.

Temperature affected fresh and dry matter content in the seedlings. The control Chinese cabbage formed more leaves of larger area than the seedlings exposed to low temperatures and thereby increased irradiance absorbed by the plants as well as enlarged their size, finally resulting in higher dry matter accumulation. According to Moe and Guttormsen (1985), the increase of temperature in the propagation stage resulted in higher dry matter of Chinese cabbage seedlings. A marked increase of fresh matter in Chinese cabbage grown at higher temperatures observed also Noto i Leonardi (1995). Similar effect was described by Gaye and Maurer (1991) for Brussels sprouts seedlings grown on a seedbed. Those authors noted an increase in plant fresh and dry matter which resulted from microclimatic changes effected by row covers in comparison to uncovered plants. In the present study, lower content of soluble sugar was determined in the seedlings grown in less beneficial thermal conditions. On the contrary, Nam et al. (2001) noted that the amount of soluble sugar increased in Chinese cabbage seedlings as a result of cold acclimation, however, it should be stressed that plants were exposed to very low temperature. Also Sasaki et al. (1996) observed the increase in glucose, fructose and sucrose content in cabbage seedlings during first days of cold acclimation at constant temperature, but later the level of sucrose began to decrease. However, the response of plants at constant temperature may be quite different than in the fluctuating one, recorded in the present study. Therefore, based on the data obtained, it did not induce accumulation of sugars in seedlings. In the first year of the experiment when the differentiation in thermal conditions between the heated and unheated greenhouse was higher, a slight increase in pigment content was noted for plants grown at more favourable temperatures. However, Chinese cabbage seedlings subjected to low temperatures contained a little more chlorophyll and carotenoids in the following year. Nevertheless, no direct relationships found between the temperature conditions during seedling production and the content of pigments in Chinese cabbage suggest that this factor did not play a significant role in the accumulation of chlorophyll a, chlorophyll b and carotenoids.

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WPŁYW TEMPERATURY NA WZROST I SKŁAD CHEMICZNY ROZSADY KAPUSTY PEKIŃSKIEJ W PRODUKCJI WIOSENNEJ

Streszczenie: Celem 2-letniego doświadczenia, prowadzonego w okresie wiosennym, było oszacowanie wpływu temperatury powietrza na wzrost roślin oraz zawartość niektórych składników chemicznych w rozsadzie kapusty pekińskiej. Rozsadę przygotowywano w warunkach zbliżonych do optymalnych (kontrola) oraz w niższych temperaturach, uzyskanych w naturalny sposób w szklarni nieogrzewanej, które utrzymywały się w otoczeniu roślin przez okres ostatnich 16 dni cyklu produkcji.

Wzrost rozsady kapusty pekińskiej było znacznie spowolniony w niższych temperaturach. Wysokość roślin kontrolnych zmieniała się wraz z upływem czasu w zakresie od 1,2-1,7 cm do 7,4-13,4 cm, odpowiednio dla kolejnych lat badań, podczas gdy u poddanych wpływowi niższych temperatur zmiany w ich wysokości były mniejsze (od 1,0-1,6 cm do 4,4-10,1 cm). Kapusta pekińska w bardziej korzystnych warunkach termicznych szybciej również tworzyła nowe liście (w liczbie od 0,7-0,8 do 5,6-6,8 szt.) w porównaniu z rozsadą w nieogrzewanej szklarni (od 0,8-0,8 do 4,0-4,6 szt.). Pomiary morfologiczne wykonane po zakończeniu produkcji potwierdziły hamujący wpływ niższych temperatur na wzrost młodych roślin. W chłodniejszym środowisku rozsada była istotnie mniejsza w stosunku do kontrolnej, w ujęciu średnim rośliny były niższe o 2,6 cm, posiadały mniej liści (o 1,7 szt.), a powierzchnia pojedynczego liścia była mniejsza o 6,8 cm^2. Zaobserwowano ponadto redukcję świeżej masy (średnio o 3,35 g na roślinę) oraz zmniejszenie zawartości suchej masy (o 0,98%) u roślin z tego obiektu doświadczenia. Ilość cukrów rozpuszczalnych również kształtowała się na niższym poziomie, różnica wynosiła średnio 0,44% św.m. w porównaniu z rozsadą produkowaną w wyższych temperaturach. Nie zaobserwowano natomiast istotnego wpływu warunków termicznych na gromadzenie chlorofilu a, chlorofilu b oraz karotenoidów przez kapustę pekińską w tej fazie wzrostu.

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