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Yield and quality of spring Chinese cabbage as affected by different temperature conditions during seedling production

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ABSTRACT

The objective of the two-year studies was to estimate the effect of differentiated temperature conditions during seedling production on the yield and content of certain compounds in Chinese cabbage grown in the field for spring harvest. A part of the seedlings subjected to natural low non-freezing temperature for the last 16 days before planting, while the remaining plants grew in optimal conditions (control). The marketable yield increased by 6.37-9.33 t ha^{-1} as a consequence of low temperature stress during period of seedling raising. Despite of the fact that some plants formed external flower stalks (3.1%) in one year of the experiment, the share of Chinese cabbage heads suitable for trading in the total yield was also higher (by 1.2-5.2%) compared to control plants. However, all plants from seedlings raised at low temperatures formed internal bolts, while there were no flower stalks inside the heads of control cabbage. Seedling treatment had no distinct effect on the accumulation of dry matter, soluble sugar and L-ascorbic acid in Chinese cabbage heads. There was only a slight and not statistically confirmed tendency to the decrease in chlorophyll and carotenoids content in Chinese cabbage grown from seedlings of low temperature. The level of thiocyanates and crude fiber was the highest in control plants, differences amounted to 4.82-5.60 μg KSCN g^{-1} f.m. and 2.09-2.43% d.m., respectively. Results obtained in this study indicated that either temperature during raising seedlings or weather conditions influenced the Chinese cabbage yield and chemical composition of the heads.

INTRODUCTION

It is well known that the use of seedlings, well adapted for field environment, is essential for obtaining high yield and quality of the final products. Chinese cabbage seedlings should be acclimated before they are transplanted so the plants can more successfully withstand adverse weather conditions of spring season. Short-term exposure of plants to lower temperatures prior to transplanting is one of the used hardening techniques (Kalisz and Cebula 2001). The result of this stress is often long lasting and may affect the subsequent yields as well as nutrient content in heads at harvest (Daly and Tomkins 1995, Kalisz et al. 2006). Pattern of weather conditions during field cultivation also influences the yielding of vegetable crops and may further modify the consequences of low temperature exposure during seedling growth (Korkmaz and Dufault 2001).

The effect of low temperatures prevailing at early stages of plant growth is sometimes associated with the premature flowering (Moe and Guttormsen 1985, Felczyński 1995). Bolting is of economic importance to the Chinese cabbage industry because advanced flower stalk development results in an unmarketable head. On the other hand, seedling hardening with low temperature often makes plants yield higher as far as they do not bolt prematurely (Kalisz et al. 2006). It is hypothesized that use of cold-tolerant cultivars for early production and row covers in the field should be sufficient to reduce bolting in Chinese cabbage, even in case of applying such method of hardening. Therefore, the objectives of this study were to determine the long-term effects of low temperature during seedling raising period as well as weather conditions after transplanting on the yield of Chinese cabbage and nutritive value of mature heads.

MATERIAL AND METHODS

The effect of different temperature conditions during seedling production upon the yield and quality of Chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.) cv. 'Sapporo F_1' (Vikima Seeds) in 2004 – 2005 was investigated. The seeds were sown in the greenhouse 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. After 10 days (2004) or 12 days (2005) from sowing, a half of the seedlings were placed in unheated part of the greenhouse and exposed to uncontrolled low temperature conditions until planting, the remaining plants were kept in standard temperature and treated as a control group. The mean values of air temperature in different parts of greenhouse were presented in Table 1. Detailed characteristic of temperature conditions during Chinese cabbage seedling growth was described in separate research work (Kalisz and Cebula 2006).

Table 1. Means of air temperature in heated and unheated greenhouse for the last 16 days before seedling planting in 2004 and 2005 (°C)

Greenhouse	Maximum		Mean daily		Minimum	
	2004	2005	2004	2005	2004	2005
Heated	29.6	27.0	19.8	18.6	13.7	12.4
Unheated	22.1	21.9	11.6	12.9	4.7	6.0

The field experiment was conducted at the Research Station of the Agricultural University in Kraków. Chinese cabbage seedlings were set-out at a density of 7.1 plants per m^2 on April 21 (2004) and April 20 (2005). Directly after planting the plants were covered with non-woven propylene (Agrowłóknina 17 g m^{-2}) by period of 26 days. Cultivation practices (fertilization, irrigation, plant protection) were carried out in accordance with the currently accepted recommendations.

All data concerning the weather conditions during the experiment were obtained from the meteorological station in Kraków-Balice, located in the close vicinity of the field.

The course of weather conditions was rather uniform in 2004 (Fig. 1). Mean daily air temperature fluctuated in range from 7.4°C in the last ten days of April to 19.0°C at the end of vegetation period. In this year temperatures were moderated, especially during development of Chinese cabbage heads and in time of harvests. Minimum temperature was not lowest by whole period of field cultivation from 1.9°C (in the middle of May), the maximum temperature of 25.6°C was recorded in the first ten days of June. Temperature of air was changed in considerably wider range in 2005. There occurred a considerably drop in temperature directly after planting the seedlings, minimum temperature down to -2.0°C, also mean daily temperature reached its lowest value at this time (3.6°C). After transitory warming on early May, it had come again cool weather lasting to the middle of this month. End of May and early June of this year was a very warm with highest value of mean daily and maximum temperature (25.5°C and 32.6°C, respectively). Total precipitation during plant growth in the field amounted to 83.8 mm (2004) and 95.4 mm (2005). Distribution of atmospheric rainfalls was more uniform in the first year of the experiment. Total precipitation was 34.3 mm higher in the first three weeks after planting in 2005 than in similar period of 2004.

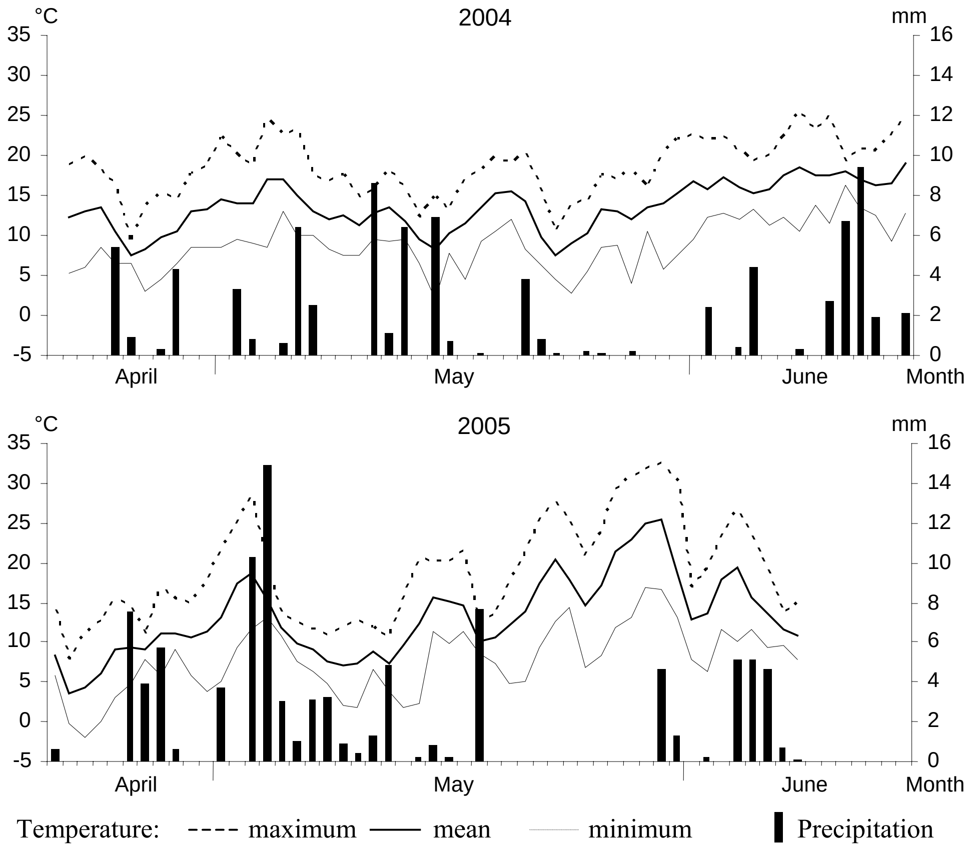

Fig. 1. Pattern of weather conditions during Chinese cabbage growth in the field

The Chinese cabbage was collected as it reached harvest maturity and divided into marketable and unmarketable yield. The weight of the crop and the number of heads from each plot were recorded. Marketable yield involved heads of the highest quality (class I) and slightly deformed or damaged (class II). The plants with visible bolting shoots were treated as a separate part of unmarketable yield. Harvest period took place from June 9 to June 15 in 2004 and from June 6 to June 8 in 2005.

Plant samples were collected during harvests in order to determine the content of dry matter (drying at 105°C to constant weight); soluble sugar (anthrone method); L-ascorbic acid (Tillmans method), chlorophyll a, chlorophyll b and carotenoids (Lichtenthaler method); thiocyanates (Johnston and Jones 1966) and crude fiber (Jermakov 1972).

The results were statistically evaluated using analysis of variance, significant differences between means were calculated at $\alpha = 0.05$ (yield parameters) or $\alpha = 0.01$ (laboratory data).

RESULTS

The yield and mean head weight of Chinese cabbage was affected by thermal conditions during seedling production, however, the results did not always differ statistically (Table 2). Chinese cabbage produced from seedlings, which had been exposed to low temperature, gave yields at a distinctly higher level (99.32 t ha^{-1} in 2004 and 72.87 t ha^{-1} in 2005), while marketable yield obtained from control plants was lower by 6.37 and 9.33 t ha^{-1}, respectively. The results pointed out relatively slight effect of temperature conditions before planting on number of heads suitable for trading. However, plants of low temperature treated seedlings gave slightly more marketable heads (by 3 720 and 1 488 numbers ha^{-1}, respectively to the year of the experiment). It was proved statistically only on the basis of 2-year means. The mean weight of head calculated in the marketable yield was 1.05-1.52 kg. In the first year, Chinese cabbage was characterized by a similar head weight, while in the second one the lowest head weight was obtained from control plants (1.05 kg). It should be mentioned that plants gave higher yields and produced distinctly greater heads in 2004 than in 2005.

Table 2. Marketable yield and mean weight of head of Chinese cabbage depending on temperature conditions during seedling production

Seedling treatment	Marketable yield ($t\ ha^{-1}$)			Number of marketable heads per ha			Mean head weight (kg)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Control	92.95	63.54	78.25	61 756	60 268	61 012	1.51	1.05	1.28
Low temperature	99.32	72.87	86.10	65 476	61 756	63 616	1.52	1.18	1.35
$LSD_{0.05}$	4.67	6.99	4.06	n.s.	n.s.	1184	n.s.	0.05	0.05

In both years of the experiment, the share of marketable heads in the total yield of Chinese cabbage produced from control seedlings was lowest, amounting to 87.4-86.2%, respectively in the 2004 and 2005 (Fig. 2). The results showed that use of low temperature treated seedlings improved the quality of the yield, especially in the first year (92.6%), despite of the fact, that part of plants formed external flower stalks before harvests (3.1%). In the next year, the share of heads suitable for trading was rather similar in both treatments, however, control plants gave slightly more unmarketable heads (by 1.2%). There was no evidence of Chinese cabbage bolting in the second year of the experiment.

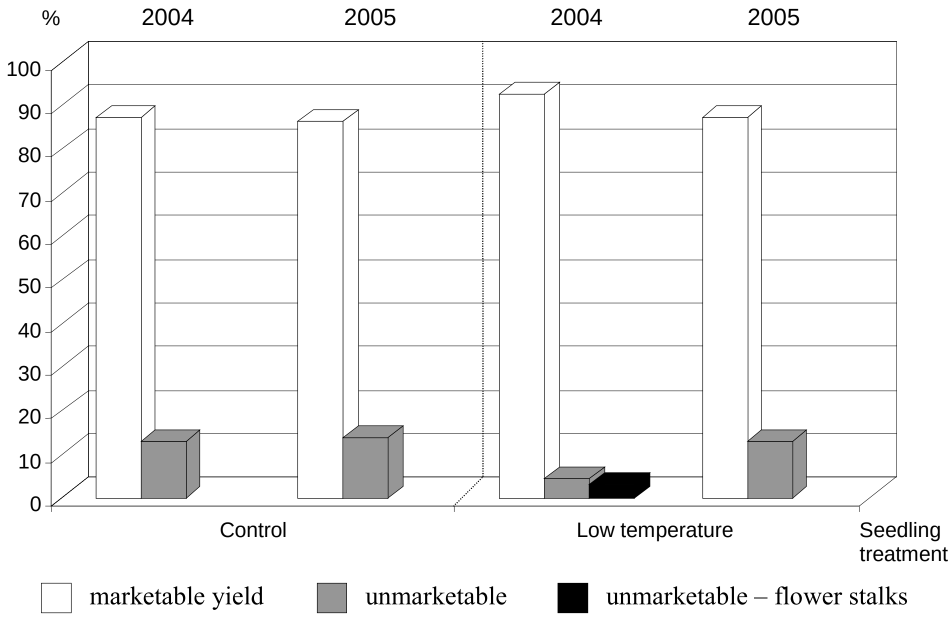

Fig. 2. Structure of total yield of Chinese cabbage depending on temperature conditions during seedling production

Analysis of the marketable yield structure of Chinese cabbage showed that only in 2004 more heads of class I were developed by plants from seedlings of low temperature (Fig. 3). The share of class I heads was higher by 4.7%, as compared to control plants. The second group of heads was those in class II which share was 2.5% (plants grown from seedlings subjected to lower temperatures) or 7.2% (control). In the next year, plants of both treatments gave similar numbers of heads in the highest class (on average 97.7%).

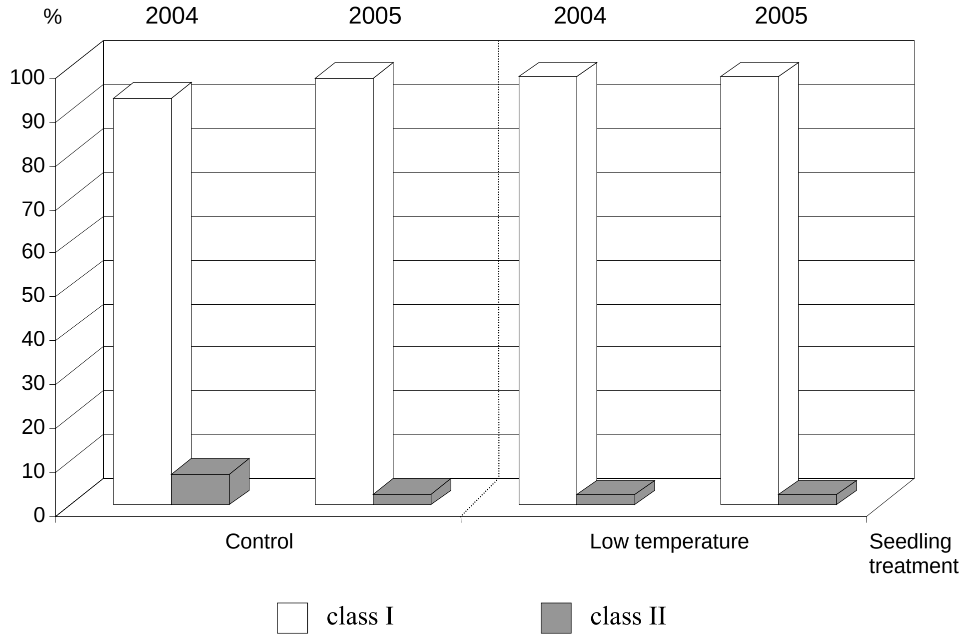

Fig. 3. Quality classes of heads in marketable yield of Chinese cabbage depending on temperature conditions during seedling production

Growth temperature during seedling production had no distinct effect on the dry matter, soluble sugar and L-ascorbic acid content in Chinese cabbage heads (Table 3). The content of dry matter was within the range of 3.50-4.92%, soluble sugar 0.48-1.81% f.m., and L-ascorbic acid 17.40-24.48 mg% f.m. Great changes in these compounds were noted in relation to the year of the study, also differences turned out to be statistically insignificant in a few cases. Nevertheless, it was noticeable that Chinese cabbage grown from low temperature subjected seedlings contained markedly more dry matter and L-ascorbic acid in the first year of the experiment, as well as soluble sugar in the following year. A reverse effect was observed in the last year, when control plants accumulated the highest amounts of vitamin C.

Table 3. Dry matter, soluble sugar and L-ascorbic acid content in Chinese cabbage at harvest depending on temperature conditions during seedling production

Seedling treatment	Dry matter (%)			Soluble sugar (% f.m.)			L-ascorbic acid (mg% f.m.)		
	2004	2005	Mean	2004	2005	Mean	2004	2005	Mean
Control	4.48	3.71	4.10	1.81	0.48	1.15	21.95	20.10	21.03
Low temperature	4.92	3.50	4.21	1.69	1.03	1.36	24.48	17.40	20.94
$LSD_{0.01}$	0.22	n.s.	n.s.	n.s.	0.18	0.09	1.96	0.12	n.s.

The content of pigments in matured Chinese cabbage heads was unaffected by temperature conditions during seedling production (Table 4). Distinctly higher amounts of chlorophyll b was found in plants from control seedlings (on average 0.0133 mg g^{-1} f.m.) as compared with those of other experimental treatment (0.0074 mg g^{-1} f.m.), but it was noted only in the case of 2-year means. Nevertheless, there was a slight and not statistically confirmed tendency to the decrease in chlorophyll and carotenoids content in Chinese cabbage grown from seedlings subjected to low temperature before planting.

In all years of the experiment markedly more thiocyanates contained Chinese cabbage produced from control seedlings – 20.65 µg KSCN g^{-1} f.m. in 2004 and 18.35 µg KSCN g^{-1} f.m. in 2005 (Table 5). Plants of the low temperature seedling treatment had smaller content of thiocyanates by 5.60 i 4.82 µg KSCN g^{-1} f.m., respectively. A similar pattern of changes in crude fiber accumulation was noted. The highest content of crude fiber was observed for Chinese cabbage grown from seedlings raised in heated greenhouse prior to transplanting (12.59% d.m. in 2004 and 15.41% d.m. in 2005), differences amounted to 2.09 and 2.43% d.m., respectively.

Table 4. Chlorophyll a, chlorophyll b and carotenoids content in Chinese cabbage at harvest depending on temperature conditions during seedling production

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	0.0228	0.0253	0.0241	0.0133	0.0133	0.0133	0.0103	0.0125	0.0114
Low temperature	0.0225	0.0085	0.0155	0.0088	0.0060	0.0074	0.0098	0.0050	0.0074
$LSD_{0.01}$	n.s.	n.s.	n.s.	n.s.	n.s.	0.0041	n.s.	n.s.	n.s.

Table 5. Content of thiocyanates and crude fiber in Chinese cabbage at harvest depending on temperature conditions during seedling production

Seedling treatment	Thiocyanates (μg KSCN g^{-1} f.m.)			Crude fiber (% d.m.)		
	2004	2005	Mean	2004	2005	Mean
Control	20.65	18.35	19.50	12.59	15.41	14.00
Low temperature	15.05	13.53	14.29	10.50	12.98	11.74
$LSD_{0.01}$	0.61	1.80	1.20	0.88	0.87	0.78

DISCUSSION

Results obtained in the study indicated that either temperature during raising seedlings or pattern of weather conditions during field cultivation influenced the Chinese cabbage yield and content of certain compounds in the heads. It was proved on the basis of additionally made statistical analysis, taking into consideration the year as a factor (data not presented).

In the first year of the experiment, when the climatic conditions were more beneficial, plants in both experimental treatments gave the highest yield (amounted to 92.95-99.32 t ha^{-1}) and produced heads of higher mean weight (1.51-1.52 kg). Many research studies have shown that Chinese cabbage yields varied from year to year due to weather conditions (Fritz and Honma 1984, Staugaitis and Starkuté 1999, Kalisz and Cebula 2001), which confirm the significance of this factor. It is interesting that in both years higher marketable yield of better quality was obtained from low temperature treated seedlings. The reasons for this finding should be seen in greater acclimation ability to field conditions of plants exposed to lower temperatures prior to transplanting.

The effect of low temperature conditions during seedling production on bolting in Chinese cabbage has been confirmed by many authors (Benoit et al. 1981, Guttormsen and Moe 1985, Moe and Guttormsen 1985, Wiebe 1990, Kalisz and Cebula 2001). In the present study, there was an effect of such temperatures on premature flowering of field-grown Chinese cabbage. Plants formed external flower stalks only in 2004 and the percentage of bolting heads was very small at that time (amounted to 3.1%). It is generally accepted that mean daily temperatures higher than 15-18°C during seedling growth significantly reduce bolting compared with lower temperatures (Daly and Tomkins 1995). Analysis of data, presented in the earlier research work, showed that mean daily air temperature in unheated greenhouse was below 15.5°C (2004) and 16.2°C (2005), moreover, the minimum temperature did not increase above 11°C in both years (Kalisz and Cebula 2006). Hence, it was expected that such thermal conditions during seedling growth should promote flower initiation and bolting in a much higher degree than observed. On the other hand, bolting was also determined by dissecting the heads at harvests. As noted, all plants from seedlings raised at low temperatures formed internal bolts, while control cabbage had no flower stalks inside the heads at all (data not shown). However, internal flower stalks do not cause yield losses as long as they remain small. Stronger plant response (external bolts), which has been observed in 2004, may be related to less favorable thermal conditions during seedling growth in that year (Kalisz and Cebula 2006). It should be pointed out that there is a possibility of Chinese cabbage yield reduction due to bolting as a result of using seedlings raised under conditions which induce reproductive development in plants.

Both seedling treatments had no distinct effect on the accumulation of dry matter, soluble sugar and L-ascorbic acid in matured Chinese cabbage heads. The content of dry matter was within the range of 3.50-4.92%, soluble sugar 0.48-1.81% f.m., and L-ascorbic acid 17.40-24.48 mg% f.m., depending on the year and experimental treatment. It covers average values reported by Xuguang et al. (1991), Felczyński (1995), Kalisz and Cebula (1996), Staugaitis and Starkuté (1999). Chinese cabbage contained less these components in 2005 when higher temperatures at the end of vegetation period were observed in relation to former year. Hara and Sonoda (1982) found that field-grown cabbage had lower dry matter content at higher temperatures in comparison to plants cultivated in lower temperatures. The obtained results may also find explanation in the studies reported by Lee and Kader (2000) and Tamura (2004) who claimed that lower temperatures usually induce the accumulation of sugars and L-ascorbic acid in field crops. Statistical analysis showed that pigment content in matured Chinese cabbage heads was not affected by different temperature conditions during seedling production. Insignificant effect of this factor on the accumulation of chlorophyll and carotenoids in Chinese cabbage seedlings was also presented in other publication (Kalisz and Cebula 2006). Nevertheless, it should be pointed out that in the present experiment plants from low temperature treated seedlings had slightly less chlorophyll a, chlorophyll b and carotenoids in relation to control ones (on average by 0.0086, 0.0059 and 0.0040 mg g^{-1} f.m.). The level of thiocyanate accumulation in Chinese cabbage was lower than that reported by Kunicki and Capecka (2000) for broccoli. Studies concerning the effect of temperature on thiocyanate content in plants present contradictory opinions (Bible and Chong 1975, Capecka 1996). However, the obtained data suggest that accumulation of thiocyanates may be reduced by low temperature treatment of seedlings. Chinese cabbage produced from these seedlings contained on average by 5.21 μg KSCN g^{-1} f.m. less than control plants. The content of crude fiber in Chinese cabbage was similar to the results from study by Xuguang et al. (1991) and lower to that presented by Elkner and Horbowicz (1996). Hara and Sonoda (1982) showed that the crude fiber content in cabbage increased slightly with increase in temperature before harvests. It would explain greatest contents of crude fiber in Chinese cabbage harvested in 2005 when higher temperatures before harvests were noted as well as in plants from control seedlings (grown in more beneficial temperatures prior transplanting).

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PLONOWANIE ORAZ JAKOŚĆ WIOSENNEJ KAPUSTY PEKIŃSKIEJ W ZALEŻNOŚCI OD RÓŻNYCH WARUNKÓW TERMICZNYCH W CZASIE PRODUKCJI ROZSADY

Streszczenie: Celem 2-letnich badań było oszacowanie wpływu zróżnicowanych warunków termicznych powietrza w otoczeniu rozsady na plonowanie oraz zawartość niektórych składników chemicznych w kapuście pekińskiej uprawianej w polu na zbiór wiosenny. Rozsadę przygotowywano zarówno w optymalnych warunkach termicznych (kontrola), jak i stresu temperaturowego oddziałującego na rośliny przez okres ostatnich 16 dni cyklu produkcyjnego (temperatura niższa od optymalnej w warunkach niekontrolowanych - zimna szklarnia). Zastosowanie rozsady poddanej działaniu niższych temperatur przyniosło wzrost plonu handlowego średnio o 6,37-9,33 t ha^{-1}. W roku 2004 część roślin wytworzyło zewnętrzne pędy kwiatostanowe (3,1%), lecz pomimo to udział plonu handlowego w ogólnym również był większy (o 1,2-5,2%) niż u kontrolnych. Wszystkie rośliny uprawiane z rozsady rosnącej w warunkach stresu temperaturowego formowały pędy wewnętrzne w główkach, których nie zaobserwowano w roślinach kontrolnych. Nie stwierdzono jednoznacznego wpływu temperatury w czasie produkcji rozsady na zawartość suchej masy, cukrów rozpuszczalnych i kwasu L-askorbinowego w główkach kapusty pekińskiej. Ilość chlorofilu a, chlorofilu b i karotenoidów była podobna, chociaż nieznacznie mniej tych barwników posiadały rośliny, których rozsadę produkowano w niższych temperaturach. W główkach kapusty pekińskiej uzyskanej z rozsady kontrolnej stwierdzono większą zawartość tiocyjanianów (średnio o 5,21 µg KSCN g^{-1} św.m.) i włókna surowego (średnio o 2,26% s.m.) Wielkość plonu oraz skład chemiczny kapusty pekińskiej były uzależnione zarówno od warunków produkcji rozsady jak i czynników pogodowych podczas uprawy polowej.

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