Effects of Row Covers Using Non-woven Fleece on the Yields, Rate of Bolting, and Quality of Heading Chinese Cabbage in Early Spring Cultivation

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The aim of the research was to determine the impact of row covers on the growth, yield, and selected nutritional compounds contents in Chinese cabbage (*Brassica rapa* L. Pekinensis Group), cultivated in a field with or without non-woven fleece ($17 \text{ g} \cdot \text{m}^{-2}$). Application of row covers accelerated the growth and development of the plants due to more favorable microclimatic conditions than in an open field. All tested biometrical parameters of the rosettes, determined after removing covers, were considerably higher than in the uncovered control. Therefore, direct covers could be successfully used for promote the growth of Chinese cabbage rosettes after transplanting. Total and marketable yields of covered plants were higher by 36% and 91%, respectively, than in the control. No external flower stalks were observed in either treatment, but about 50% of control heads had internal bolters. Row covering could be an effective prevention method against Chinese cabbage bolting in spring production in Central Europe. Laboratory analysis performed directly after removing covers showed higher contents of L-ascorbic acid, chlorophylls, and carotenoids in the plants in an open field. However, in the subsequent few weeks, such differences between treatments decreased and at harvest time, the level of these compounds was similar. Mature heads of control Chinese cabbage contained significantly more soluble sugars, crude fiber and thiocyanates than covered plants. The models were proposed to predict changes in fresh and dry weight as a function of time.

Key Words: *Brassica rapa* L. Pekinensis Group, modelling, non-woven fleece, nutrients, yield.

Introduction

Row covers are often used for the early production of vegetable crops in different regions of the world. Chinese cabbage (*Brassica rapa* L. Pekinensis Group) is an example of a plant that requires warmer climate conditions than prevail in many areas of Europe (Villora et al., 2004); therefore, this species needs microclimate modification techniques, for example direct covering. Low above-zero temperatures and ground frosts in the field may slow down growth or damage the plants. Such weather conditions occur in spring until the middle of May in Poland. Row covers, mainly nonwoven, are usually used in early field production to protect plants (Olle and Bender, 2010). The primary purposes of covering are as follows: improve microclimate conditions

in the immediate surroundings of the crops in a complex way (Gimenez et al., 2002; Moreno et al., 2002; Otto et al., 2000b), accelerate plant growth and development (Gimenez et al., 2002; Otto et al., 2000b), and increase the earliness and yields of vegetable crops (Biesiada, 2008; Olle and Bender, 2010; Rekika et al., 2008; Rekowska, 2011). Undoubtedly, morphological, physiological, and biochemical consequences of direct covering are considerable (Moreno et al., 2001; Olle and Bender, 2010). Several papers have described the effects of direct covers on *Brassica* vegetable development or on the quantity and quality of their yields (Biesiada, 2008; Buta and Apahidean, 2009; Kunicki et al., 1996). There are various scientific reports about the response of Chinese cabbage to covering. Otto et al. (2000a) compared non-woven fleece-covered and open field-grown plants in relation to leaf area index development, specific leaf area changes, and the course of aboveground biomass changes in Chinese cabbage. Cara et al. (2002) reported physiological responses of Chinese cabbage to different methods of covering from the aspects of foliar

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urease activity, amino acid content, and mineral composition. Moreno et al. (2001) conducted an experiment that aimed to assess the content of fresh weight (FW), dry weight (DW), carotenoid and chlorophyll pigments, peroxidase activity, and content of some heavy metals (Pb, Cd). Another paper by these authors (Moreno et al., 2002) took into account FW and DW, yield level, leaf pH, citric and ascorbic acid content, and sugar and uronic acid concentrations in cell-wall fractions. Hernandez et al. (2004) described nutrient uptake and their concentrations in the leaves of Chinese cabbage, DW content, yield characteristics (total and commercial yield, bolted plants, tipburn affected plants, deformed heads). All above-cited experiments with Chinese cabbage were conducted in Córdoba and Granada, south Spain. We decided to expand knowledge on the response of Chinese cabbage to covering in a moderately cold climatic zone (south Poland). The novel aim of the present experiment was to compare the growth, development, yield, and nutritional value of Chinese cabbage plants in two important phases of production: directly after removing covers and at harvest. An attempt to develop regression equations, describing FW and DW changes during plant growth, was also made. Prediction models of time course of FW and DW in covered and uncovered plants were proposed.

Materials and Methods

Experimental design

The Chinese cabbage (*Brassica rapa* L. Pekinensis Group), cultivar Optiko F₁ (Bejo Zaden, NL), was produced from transplants prepared in a greenhouse, in 96-cell trays (single cell volume 53 cm³) filled with peat substrate. Experiments were conducted in 2004–2005. Seeds were sown in the last 10 days of March, transplant production took approximately 3–4 weeks. Plants were watered regularly, maintaining substratum moisture at an optimum level. Seedlings were fertilized at the 4–5 leaf stage using a soluble calcium nitrate CalciNit Hydro (1 g per 1000 cm³ water). Transplants at the 6–7 leaf stage were planted out in a field (21 April 2004 and 20 April 2005) of the Vegetable Experimental Station of the University of Agriculture in Kraków, Poland (50°04'N, 19°51'E). The experimental station, located in southern Poland, has a humid continental climate (Dfb) according to Köppen's classification. A field experiment, designed with 4 replications, involved plants cultivated under non-woven fleece and in an open field (control). The experiment was performed in soil classified as brown type, with loess as the basement complex.

Yield trials

Plants were cultivated with 40 × 35 cm spacing. Standard plot sizes were: 1.20 m × 7.00 m = 8.40 m² (total plot size with protective belts, 60 plants), of which the harvest plot had an area 3.36 m², and included 24 plants. Half of the plants were covered with non-woven

fleece (17 g·m⁻²), immediately after transplanting, and the rest were grown in an open field. The covering period lasted 26 days in both experimental years. Standard cultivation procedures were performed during plant production (fertilization, irrigation, plant protection against pests and diseases). Amount of fertilizers was calculated on the base of soil analyzes to achieve nutrient levels of 100 mg N, 80 mg P, 150 mg K, and 1500 mg Ca per 1000 cm³ of soil. Harvests were carried out for maturing plants, specifying the mass of the plants and their number. Quality of yields was assessed according to the United Nations Economic Commission for Europe (UNECE) Standard FFV-44 concerning the marketing and commercial quality control of Chinese cabbage (UNECE, 1991–2010). Marketable yield involved heads of the highest quality, not deformed or damaged. Structure of the total yield was calculated on the basis of the number of marketable and non-marketable plants. Occurrence of external and internal bolting shoots was assessed. The presence of internal bolters was noted on the base of 20 randomly selected and longitudinally cut heads, from each experimental object, then the length of inner bolters, defined as the length of inflorescence buds above the youngest leaves, was measured (Fig. 1). Obtained data were extrapolated to the number of heads with inner bolting and their ratio of the total yield. Harvests took place from the end of May to the end of June.

Plant measurement

A comprehensive evaluation of plant morphological parameters was performed directly after removing covers for both experimental objects. The assessment took into account the height and diameter of plant rosettes, leaf number per plant, and leaf characteristics (area, length, width, shape coefficient). Height was measured from the soil surface to the top of rosettes, and their diameter at its widest part. All leaves of more than 1 cm in length were counted. The images of the biggest leaf of each rosette were analyzed using the image software KSRUN 3.0 (Carl Zeiss Vision GmbH, München-Hallbergmoos, Germany) to estimate their area. Length (from base of petiole to leaf apex) and width (the widest part of the leaf blade) were also measured, using ImageJ (NIH, Bethesda, MD, USA). Based on these two parameters, shape coefficients of the leaves were calculated.

Laboratory analyses

During field cultivation, FW and DW of Chinese cabbage plants were determined at 7-day intervals, and included 5 samplings. Covering with non-woven fleece was ended after the third sampling; however, the impact of the cover was estimated also during the last two samplings. Twenty randomly selected plants from each object were assessed at each sampling.

The dynamic of the increase in plant mass was specified on the basis of absolute and relative growth rates using the following formulas:

Fig. 1. Longitudinal cross-section of Chinese cabbage head with inner bolting (A) and without bolters (B). Arrow shows the method of measuring of inner bolters' length.

$$GR = (W_2 - W_1) / (T_2 - T_1) \text{ (g} \cdot \text{day}^{-1}\text{)}$$

$$RGR = (\ln W_2 - \ln W_1) / (T_2 - T_1) \text{ [g} \cdot \text{(g} \cdot \text{day}^{-1})^{-1}\text{]}$$

where:

W_1 —DW at the beginning of the sampling period,

W_2 —DW at the end of the sampling period,

T_1 —beginning of the sampling period (day after transplanting of W_1 estimation),

T_2 —end of the sampling period (day after transplanting of W_2 estimation).

The rosettes of Chinese cabbage directly after removing covers and the heads at the stage of harvest maturity were collected for laboratory analyses. After covering, L-ascorbic acid, chlorophyll a (Chl a), chlorophyll b (Chl b), and carotenoids were determined, and at the stage of harvest maturity, additionally soluble sugars, crude fibre, and thiocyanate contents were assessed.

DW was determined by drying the sample at 92–95°C until a constant weight was obtained, measured using Sartorius A120S (Goettingen, Germany). The total soluble sugars were determined by the anthrone method (Yemm and Willis, 1954). For this analysis, plant material was mixed with 80% ethanol. After the addition of anthrone reagent, samples were placed for 30 min in a water bath (100°C), cooled down to 20–22°C and the absorbance was measured at 625 nm using a Helios Beta spectrophotometer (Thermo Fisher Scientific Inc., Waltham, MA, USA). L-ascorbic acid was measured by Tillman's method (Krelowska-Kulaś, 1993). Plant material (50 g) was mixed with 200 cm³ CH₃COOH and, after 30 min, the extract was titrated with the reagent 2,6-dichlorophenolindophenol (Tillman's reagent). The content of Chl a, Chl b, and carotenoids was determined in fresh plant samples by the Lichtenthaler and Wellburn (1983) method after acetone extraction, at 646, 663,

and 470 nm, respectively, with a Helios Beta spectrophotometer (Thermo Fisher Scientific Inc.). The crude fiber content was identified according to Yermakov et al. (1987), calculating the difference in weight of samples before and after etching with a mixture of HNO₃ and CH₃COOH. Amount of thiocyanates was determined colorimetrically by the procedure of Johnston and Jones (1966). Each sample was hydrolyzed and deproteinized by lead acetate. The absorption was determined at a wavelength of 460 nm. Thiocyanate content was expressed per mg KSCN (potassium rhodanate) in 1 g FW.

Microclimatic conditions

Temperature and relative humidity of the air were measured by HOBO Pro RH/Temp. data loggers (Onset Comp. Corp., Bourne, MA, USA) at 1-hour intervals. Temperature of soil (at 10 cm depth) was recorded similarly by HOBO Temp. loggers. Sensors were placed under non-woven covers and in the open field until the end of the covering period. Loggers were left in the field until the end of harvest. Data were averaged separately for covering and non-covering periods.

Data analysis

Statistical analyses were conducted using STATISTICA 9.0 (StatSoft Inc., Tulsa, OK, USA). Means were compared by *t*-test at $P < 0.05$. The results are presented as the mean of four replicates. Similar trends were observed in subsequent years; therefore, the data from all trials were pooled over the years. Polynomial regression analysis was performed to model changes in fresh and dry weight during plant vegetation in the field. Regression equations were developed separately for plants under cover and in the open field. Coefficients of determination (R^2) and adjusted coeffi-

cients of determination ($R^2_{adj.}$) were calculated, assessing obtained models with a significance level of $P < 0.05$.

Results and Discussion

Microclimate and frost protection

The first year of the experiment was characterized by higher air and soil temperatures and lower air relative humidity during the covering period than in the second year (Table 1). The mean, maximum, and minimum air temperatures were higher under row cover than in the open field by 2.0, 3.1, and 2.3°C, respectively. Similar observations were obtained for soil temperature, and differences reached 2.2, 2.5, and 2.1°C, respectively. Daily changes of air and soil temperatures under cover and in the open field are presented in Figure 2. When air temperature in the open field dropped to -4.8°C between 4:00 to 6:00 AM, under cover 0.3°C was noted at the same time. The daily course of air and soil temperatures pointed out the positive effect of row cover on thermal conditions in the surroundings of covered plants. Non-woven fleece of medium weight is often used to protect plants against ground frost (up to -6°C) (Olle and Bender, 2010). Reghin et al. (2002a) found that non-woven fleece protected non-heading Chinese cabbage (pak choi) against cold, while open-field plants had leaves entirely nipped by frost. In another experiment, Reghin et al. (2002b) observed that row cover had a positive effect on lettuce yield, even with frost, while frost damage in plots without covers reduced plant weight by 34%. Plants of Chinese cabbage can withstand mild frost without damage. Their tolerance in this respect could be increased through exposure to non-freezing low temperatures, which is called cold acclimation. This technique is often used in the case of transplants. Nam et al. (2001) found that 4-week-old Chinese cabbage plants increased their freezing tolerance from -3°C to -4°C after 5 days acclimation at $5\text{--}10^\circ\text{C}$. Sasaki et al. (1996) showed that cabbage seedlings exposed to non-freezing temperature (5°C) acquired freezing tolerance down to -6°C . The degree of freezing tolerance increased with the duration of exposure to low temperature (up to 10 days). However, prolonged exposure to ground frosts (day by day) leads to frost damage. Unfortunately, field experiments on critical damage temperatures for Chinese cabbage are scarce. Yields of this species in adverse temperatures of an open field in early spring are usually

lower due to the greater number of non-commercial cabbages (without heads, malformed, bolted, frost damaged) (Hernandez et al., 2004). In the present experiment, ground frosts occurred only in 2005, directly after planting out (from -0.6 to -4.8°C , for 5 days). There was no visible frost damage of covered plants and finally higher yields were noted. Plants from uncovered plots, exposed previously to lower temperatures or even ground frosts, had lower commercial quality. Air and soil temperatures and air relative humidity were still recorded in the field after removing row covers until the end of the experiment (non-covering period). Data presented in Table 1 show small differences in microclimatic parameters in this period between experimental years.

Growth parameters of Chinese cabbage and its modelling

Changes in FW and DW content during development of Chinese cabbage are presented in Figure 3. The fresh weight of plants proved to be significantly greater in row cover treatment over the entire cycle of production. A similar situation was observed in respect to dry weight. The final values of FW for covered plants was 108.3% higher than for plants grown in an open field. On day 36 after transplanting (last sampling), the content of DW in Chinese cabbage with covers was 103.1% higher than that in control plants. More favorable conditions under

Fig. 2. Time course change of air and soil temperatures under row covers and in the open field on a chosen day when ground frost occurred (22 April 2005).

Table 1. Microclimatic conditions during covering period and after removing covers.

Period	Treatment	Year	Air temperature ($^\circ\text{C}$)			Air relative humidity (%)	Soil temperature ($^\circ\text{C}$)		
			mean	max	min		mean	max	min
Covering	open field	2004	12.5	19.9	6.0	76.9	13.1	15.8	10.7
		2005	10.5	17.7	3.6	78.5	11.1	13.0	9.3
	row cover	2004	14.4	23.2	8.1	80.7	15.4	17.9	13.1
		2005	12.6	20.6	6.1	82.7	13.3	15.8	11.1
Non-covering	—	2004	15.6	23.3	8.3	73.6	16.3	19.1	13.7
		2005	16.4	25.2	8.2	81.9	16.3	18.4	14.3

Fig. 3. Changes in observed (points) and predict (lines) FW and DW content in Chinese cabbage plants during growth under row covers and in the open field; vertical bars represent standard error.

covers promoted plant growth, which was manifested in a rapid increase in FW and DW. A much slower increase in these parameters was noted for plants grown in less favorable microclimatic conditions (temperature, humidity) in the open field. Hernandez et al. (2004) observed a similar response of Chinese cabbage to covering; however, differences between treatments were much smaller. Final biomass (DW) values were 28.6% higher for covered plants than for the control (open field), 3.5 times lower than in the present experiment. Also, Moreno et al. (2002) argued that better thermal conditions under covers resulted in higher FW and DW content than in the control (plants in an open field).

The nature of the changes in FW and DW seemed to have non-linear characteristics. For that reason, these data were used for analysis of regression models to create polynomial equations, based on DAT (days after transplanting), which are given in Table 2. Very high coefficients of determination (R^2 , $R^2_{adj.}$) were obtained, which showed that the regression line approximated the real data points very well (Fig. 3). Such equations could be useful for predicting Chinese cabbage biomass development. Other studies also pointed out that time is a useful independent variable in simulation models for Chinese cabbage (Wurr et al., 1996; Zhang et al., 2007).

Chinese cabbage cultivated under covers showed significantly higher values of GRs in the first three samplings, by about 5, 4, and 3 times, respectively, than the uncovered control (Table 3). The same dependency was observed for RGR, but only in the first sampling, when covered plants showed 2-fold higher values of this parameter. However, RGR measured in the last sampling was 2-fold higher for uncovered plants than covered plants. Thus, the use of covers accelerated growth, which could improve earliness, but this effect gradually disap-

Table 2. Polynomial regression models for FW and DW (g per plant) changes in Chinese cabbage over time (DAT—days after transplanting).

Treatment	Parameter (y)	Equation	R^2	$R^2_{adj.}$	P
Open field	FW	$y = 65.515 - 10.940 \cdot \text{DAT} + 0.485 \cdot \text{DAT}^2$	0.851	0.725	0.004
	DW	$y = 9.252 - 1.386 \cdot \text{DAT} + 0.052 \cdot \text{DAT}^2$	0.840	0.706	0.011
Row cover	FW	$y = -55.687 + 2.291 \cdot \text{DAT} + 0.548 \cdot \text{DAT}^2$	0.891	0.793	0.009
	DW	$y = 4.369 - 0.970 \cdot \text{DAT} + 0.067 \cdot \text{DAT}^2$	0.860	0.740	0.014

R^2 : coefficient of determination, $R^2_{adj.}$: adjusted coefficient of determination, P : significance level.

Table 3. Absolute (GR) and relative (RGR) growth rate of Chinese cabbage plants (means of 2004–2005).

Treatment	GR ($\text{g} \cdot \text{day}^{-1}$)				RGR [$\text{g} \cdot (\text{g} \cdot \text{day}^{-1})^{-1}$]			
	S1–S2	S2–S3	S3–S4	S4–S5	S1–S2	S2–S3	S3–S4	S4–S5
Open field	0.125 ± 0.016	0.375 ± 0.031	0.964 ± 0.080	2.378 ± 0.145	0.112 ± 0.009	0.139 ± 0.011	0.137 ± 0.012	0.132 ± 0.004
Row cover	0.615 ± 0.022	1.375 ± 0.045	2.629 ± 0.213	3.270 ± 0.374	0.255 ± 0.011	0.150 ± 0.003	0.115 ± 0.008	0.075 ± 0.009
<i>t</i> -test	***	***	***	NS	***	NS	NS	**

Symbols S1, S2, S3, S4, S5 correspond to samples taken 8, 15, 22, 29, 36 days after transplanting; covers were removed after S3 sampling. Mean values within each column are significantly different at $P = 0.001$ (***), 0.01 (**), 0.05 (*); NS: non-significant differences; $\pm$ SE: standard error.

peared after removing covers.

Morphological parameters of Chinese cabbage plants of both experimental objects, after removing covers, are presented in Table 4. In all cases, plants covered with non-woven fleece had significantly greater height, rosette diameter, and bigger leaves. Higher temperature and humidity under covers, especially after transplanting, when temperature is the most limiting factor for Chinese cabbage development, promoted subsequent growth of the plants. In a review, Olle and Bender (2010) concluded that covered vegetable crops were characterized by more accelerated growth and development than uncovered plants. This phenomenon is widely known, but rather insufficiently described for Brassicas in the scientific literature.

Yield characteristics and rate of bolting

Covering the plants with non-woven fleece increased the yield of Chinese cabbage (Table 5). Total and marketable yields of covered Chinese cabbage, expressed in $t \cdot ha^{-1}$, were 36% and 91% higher than in control objects, respectively. A significantly higher number of marketable heads was harvested in cover treatment (by 56%), and all heads were heavier. The structure of total yield was better for covered Chinese cabbage. Earliness was improved by around 13 days, on average. Increased yield of better quality was connected to greater biomass

of the plants under cover, which was caused by more favorable thermal conditions. Moreno et al. (2002) also underlined the higher yields of covered Chinese cabbage than in the open field. Marketable yield was 480% higher under non-woven fleece than in the open-field control. Hernandez et al. (2004) obtained 5-fold higher commercial yield under row cover than for the uncovered control. Covering plants can also improve earliness, which has been proved for several vegetables (Olle and Bender, 2010).

Another consequence of production in an open field, and ipso facto exposure of the plants to lower air and soil temperatures, is premature bolting of Chinese cabbage. This species is a seed-vernalization-type plant. Low temperatures acting on the germinating seeds and juvenile plants in early spring usually cause flower bud differentiation and early bolting (Li et al., 2010). Preventive methods involve mainly the cultivation of plants in plastic tunnels or under row covers and growing cultivars with low bolting properties (Moreno et al., 2002; Zhang et al., 2008). In the present experiment, no visible symptoms of external bolting were noted. However, 41 and 62% of open field plants, respectively, in 2004 and 2005, had bolters inside the heads (Table 6). The greater number of internal bolters of open-field Chinese cabbage in 2005 was caused by lower temperatures in the initial period of cultivation. Covered plants did

Table 4. Growth parameters of Chinese cabbage plants after removing of covers (means of 2004–2005).

Treatment	Height (cm)	Rosette diameter (cm)	Leaf number	Leaf area (cm ²)	Leaf length (cm)	Leaf width (cm)	Leaf shape coefficient
Open field	9.8	30.1	14.2	109.0	17.5	10.6	1.7
Row cover	24.1	49.3	17.3	392.3	31.3	21.1	1.5
<i>t</i> -test	***	***	***	***	***	***	**

Mean values within each column are significantly different at $P = 0.001$ (***), 0.01 (**), 0.05 (*); NS: non-significant differences.

Table 5. Yield parameters of Chinese cabbage (means of 2004–2005).

Treatment	Total yield		Marketable yield		Share of marketable yield (%)	Mean weight of head (kg)	First harvest (DAT)
	$t \cdot ha^{-1}$	number of heads per ha	$t \cdot ha^{-1}$	number of heads per ha			
Open field	66.41	69 941	46.19	43 899	62.8	1.06	59
Row cover	90.20	71 429	88.05	68 452	95.8	1.29	46
<i>t</i> -test	***	***	***	***	—	**	—

Mean values within each column are significantly different at $P = 0.001$ (***), 0.01 (**), 0.05 (*); NS: non-significant differences; DAT—days after transplanting.

Table 6. Characteristics of Chinese cabbage bolting.

Treatment	Length of inner bolters (cm)		Marketable heads with inner bolting (number of heads per ha)		Percentage of heads with inner bolting in total yield	
	2004	2005	2004	2005	2004	2005
Open field	0.77	1.92	29 051	43 179	41.1	62.4
Row cover	0.00	0.00	0.00	0.00	0.0	0.0
<i>t</i> -test	**	***	***	***	—	—

Mean values within each column are significantly different at $P = 0.001$ (***), 0.01 (**), 0.05 (*); NS: non-significant differences.

not form visually observed internal inflorescence buds in either experimental year, so row covering could be treated as an effective method against Chinese cabbage bolting in spring production under Central Europe climatic conditions. This effect is related to the improvement of microclimatic conditions under covers. Such a response of previously vernalized plants to higher temperatures is called de-vernalization (Shin et al., 1989). In an experiment located in south Spain using Chinese cabbage, Moreno et al. (2002) observed a higher rate of bolting in plants from an open field (33.5%) than in covered plants (6.9%), which was a consequence of the temperature difference (row cover: 19.1°C; open field: 14.1°C). According to Hernandez et al. (2004), 18.4% of Chinese cabbage plants cultivated in an open field had bolters while only 1.2% of those covered with polypropylene fleece. The better thermal regime under row cover noticed in this experiment, especially at the beginning of the production cycle, led the de-vernalization effect. The effects of low temperatures on Chinese cabbage bolting was described also by Guttormsen (1992) on the basis of experiments conducted in Norway. In his experiment, air temperature was higher on average by 2.4°C under polypropylene covers than in the open field. Such a difference in temperature reduced bolting of Chinese cabbage from 21 to 7%. Cultivars of this species differ with respect to their susceptibility to premature bolting. Growing bolting-tolerant cultivars in early spring can also increase the yield (Li et al., 2010). Many European cultivars form bolting shoots very early, even under row covers (Kalisz and Cebula, 2001). Currently, Chinese cabbage cultivars have higher resistance, enabling them to overcome the premature bolting that occurs with cultivation in spring, especially in combination with other production techniques.

Chemical composition of the plants

Chemical composition of Chinese cabbage directly after covering and at harvest maturity is presented in Table 7. After removing covers, plants grown in the open field contained much more L-ascorbic acid, Chl a, Chl b, and carotenoid pigments than those covered with non-woven fleece. Moreno et al. (2001) observed that plants without covers had a higher content of pigments (chlorophylls and carotenoids). They explained the lower content in covered plants as a result of diminished solar radiation, higher temperatures, and relative humidity. Acikgoz and Altintas (2011) indicated that the amount and intensity of light during plant vegetation have a positive influence on the level of ascorbic acid. Thus, reduction of light transmission across non-woven fleece was the reason for the reduction of L-ascorbic acid content in Chinese cabbage plants in the present experiment in relation to the uncovered control. Differences in the content of the pigments and ascorbic acid in younger plants (sampled after removing covers) and mature heads resulted from their different morphology. After unveiling, the plants had intensively green leaf rosettes, while at harvest maturity, the heads with green outer leaves and etiolated inner leaves were the objects of analysis. A considerable rate of etiolated leaves in a sample resulted in lower levels of the chosen analyzed parameters. It is interesting that after a few weeks of growth in the field (when covers were already removed), the level of L-ascorbic acid and pigments became similar in experimental objects, but the Chl a: Chl b ratio became different, and higher values for open-field plants were observed. There were also significant differences in soluble sugars, crude fiber, and thiocyanates contents at harvest. Plants from the open field contained higher amounts of these compounds than covered plants. Moreno et al. (2002) observed that plants grown in the open field had more sugars than covered plants. This

Table 7. Content of chosen chemical compounds in Chinese cabbage after removing covers (rosettes) and at harvest maturity (heads); means of 2004–2005.

Developmental stage	Treatment	L-ascorbic acid (mg/100 g FW)	Carotenoids (mg/100 g FW)	Chl a (mg/100 g FW)	Chl b (mg/100 g FW)
Rosettes	open field	76.11	18.81	56.89	26.95
	row cover	42.61	12.28	38.31	18.96
	<i>t</i> -test	***	***	***	***
Heads		L-ascorbic acid (mg/100 g FW)	Carotenoids (mg/100 g FW)	Chl a (mg/100 g FW)	Chl b (mg/100 g FW)
	open field	20.28	1.20	2.63	1.16
	row cover	21.43	1.04	2.32	1.28
	<i>t</i> -test	NS	NS	NS	NS
		Chl a: Chl b ratio	Soluble sugars (% FW)	Crude fiber (% DW)	Thiocyanates (μg KSCN·g ⁻¹ FW)
	open field	2.27	1.34	14.32	23.28
	row cover	1.81	1.25	13.60	15.46
	<i>t</i> -test	**	*	*	***

Mean values within each column are significantly different at $P = 0.001$ (***), 0.01 (**), 0.05 (*); NS: non-significant differences.

was explained by the greater photosynthesis and slower growth rate of control Chinese cabbage. Lower sugar content in kohlrabi tubers covered with non-woven fleece than in the control was also observed by Biesiada (2008). Under the conditions of the present experiment, higher thiocyanates were found in Chinese cabbage grown in the open field. This suggests that higher temperatures negatively affected the content of these compounds.

In conclusion, it should be emphasized that covering Chinese cabbage with non-woven fleece resulted in faster growth and development of the plants due to more favorable thermal conditions under cover. Row cover protected the plants against ground frosts and provided significantly higher yields of better market quality in comparison to the control (open field). Directly after covering, rosettes of Chinese cabbage grown in the open field had more L-ascorbic acid, chlorophylls, and carotenoids. At harvest maturity, heads of earlier covered plants contained a similar amount of L-ascorbic acid and pigments to control plants, but smaller amounts of sugars, crude fiber, and thiocyanates. Under the conditions of the experiment, it was possible to predict changes in FW and DW content on the basis of the developed models.

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