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PERFORMANCE OF BIODEGRADABLE FLOATING DIRECT COVERS IN THE FIELD PRODUCTION OF BUTTERHEAD LETTUCE DURING SPRING AND AUTUMN TRIALS

Andrzej Kalisz[1] ✉, Agnieszka Sękara[1], Aneta Grabowska[1], Konrad Sulak[2], Ewa Capecka[1], Andrzej Libik[1], Rita Jurkow[1], Bogdan Kulig[3]

[1] Department of Horticulture, University of Agriculture in Krakow, 29 Listopada 54, 31-425 Kraków, Poland
[2] Department of Synthetic Fibers, Institute of Biopolymers and Chemical Fibers, Sklodowskiej-Curie 19/27, 90-570 Łódź, Poland
[3] Department of Agroecology and Plant Production, University of Agriculture in Krakow, Mickiewicza 21, 31-120 Kraków, Poland

ABSTRACT

Non-degradable polypropylene nonwovens are difficult to dispose and their utilization represents high economic costs. This study was conducted on lettuce cultivated during the spring and autumn seasons in the southern part of Poland to test biodegradable nonwovens as plant covers. Several nonwovens were developed from aliphatic-aromatic copolyesters (AAC), one without modifiers (SB48/11) and three with the addition of fatty acid dimers: two commercial variants (SB20/13, SB21/13) and one made from plant biomass (SB28/13). Nonwoven polypropylene (PP) fleece was included as a control cover. One week after covering with SB48/11, stomatal conductance (g_s) increased in lettuce plants in parallel with higher transpiration rate (E) and sub-stomatal CO_2 concentration (C_i) relative to the control, but differences in these parameters evened out in mature plants. In the spring, degradable covers with their higher mass per unit area, caused a decrease in marketable yield of lettuce compared to the control PP, resulting mainly from the deterioration of plant quality and lower mean weight per head. In the autumn season, yield was statistically not different between treatments. Yield of spring lettuces was 78% higher compared to the autumn cultivation period. Plants grown under SB20/13 had the lowest dry weight and L-ascorbic acid, while plants under SB21/13 had the highest dry weight and L-ascorbic acid content. Plants under SB28/13 had higher chlorophyll *a* content. Generally, no effect of covers was noted for carotenoid concentrations. The content of dry weight, L-ascorbic acid, and carotenoids were higher in plants harvested in spring, while no effects of crop season on chlorophyll level were observed. All tested biodegradable nonwovens are a potential substitute for standard polypropylene in autumn trials, but for spring covering unit weight of these materials should be reduced.

Key words: biodegradation, nonwoven covers, *Lactuca sativa* L., yield, photosynthesis

INTRODUCTION

Floating row covers are widely used in vegetable crop production in Central Europe climatic conditions. Removal and disposal of these plastics after the growing season is economically expensive and environmentally problematic. Several alternatives to non-degradable oil-based polymers to solve this problem have been evaluated by researchers across the world [Kasirajan et al. 2012]. Early work in this area indicated that fragments of some degradable polymers were left in the soil for extended periods of time [Ngouajio

✉ andrzej.kalisz@urk.edu.pl

et al. 2008]. The best polymers should decompose in the soil completely after use. They should also meet a set of minimum requirements to include adequate strength and elongation at break for installation in the field and adequate mechanical properties with regard to ageing during the useful lifetime of the film [Briassoulis 2006]. More knowledge is also needed on the effect of particular biodegradable polymers on crop growth, microclimate modifications, soil biota, soil fertility, and crop yields [Kasirajan et al. 2012]. Limitations on the use of biodegradable polymers as floating row covers are due to large mass per unit area, which can pose a threat of crushing plants, and their high cost of production. Field testing of the biodegradable polymers is necessary to assess their performance in a crop production system.

Detailed characteristics of biodegradable polymers, derived either from petroleum resources or from biological resources, were presented by Vroman and Tighzert [2009]. Among the biopolymers, aliphatic-aromatic copolyesters (AAC) combine good material properties and biodegradability with widely available and low-cost monomers as well as existing polyester facilities that provide the potential for a lower price [Bohlman 2005]. Most research into biodegradable films in field conditions has focused on plant mulches or low tunnel covers [Waterer 2010, Kasirajan et al. 2012]. Therefore, we decided to investigate innovative AAC nonwovens, including material supplemented with a fatty acid dimer or plant biomass, for floating row covering of the field grown plants. Several vegetable crops show a positive increase in growth and yield with the application of non-degradable row covers, which was reviewed by Olle and Bender [2010]. However, there are few publications on the use of AAC nonwovens as floating row covers. Siwek et al. [2012] tested IBWCH cover made from AAC in comparison to polylactide (PLA) and polypropylene (PP) nonwovens in the production of early lettuce. They showed that applied covers affected lettuce yield similarly and the IBWCH cover ensured comparable thermal properties to PP nonwoven. AAC nonwovens were also used as floating covers in the production of field cucumber [Zawiska and Siwek 2014] and overwintering onion [Siwek et al. 2013] with some positive effects on the yield of these plants.

In the past, the problems of using biodegradable polymers in crop production were either premature breakdown (the films disintegrate before harvest) or post-mature breakdown (the films degrade at a slower rate than the expected) [Kijchavengkul et al. 2008]. Many factors affect the biodegradability of polymers, such as environmental conditions and polymer properties (polymer structure and chain flexibility, crystallinity, molecular weight, copolymer composition, thickness, size, and shape of the film) [Kale et al. 2007, Kyrikou and Briassoulis 2007]. The mechanisms through which aromatic-aliphatic copolyesters degrade were described by Chen et al. [2008] in their review. They concluded that biodegradability of AAC varied with chain length of the aliphatic polyester segment and atacticity of copolyesters. Thus, significant degradation of aliphatic-aromatic copolyesters can be observed only at relative low fractions of aromatic component. Nevertheless, biodegradability tests of new generation polymers, performed in laboratory and in the field, are necessary to estimate the impact of such materials and their degradation products on the environment.

Research studies in diverse locations on different lettuce types have evaluated planting dates and growing season effects on the yield and chemical composition of plants [Kobryń 2001, Dufault et al. 2006, Pavlou et al. 2007, Koudela and Petříková 2008]. Similar studies have been conducted for several other leafy vegetable crops [Francke and Majkowska-Gadomska 2008, Kołota et al. 2010, Kunicki et al. 2010, Caruso et al. 2011, Rekowska and Jurga-Szlempo 2011, Golubkina et al. 2018]. The conclusions reached in these studies indicate that cultivation period and, consequently, different weather conditions affect crops. Introducing a specific polymers for plant protecting in the spring and in the autumn season can cause alteration in crop performance, which is due to the interaction effects between external weather conditions and microclimate modifications related to the physicochemical properties of the specific cover.

The aim of the present study was to evaluate the effects of different floating direct covers on butterhead lettuce produced in the field. The paper focuses on the following specific objectives: 1) that biopolymer materials had similar functional properties as polypropylene nonwoven, 2) to compare yield and chemical composition of lettuce plants covered with biopolymers using PP nonwoven as a control, 3) the evaluation of size and quality of spring and autumn lettuce yields, 4) to study changes in the structure of sample biopolymers due to degradation.

MATERIALS AND METHODS

Experimental site

The field trials took place in a region of Kraków in southern Poland (50°04'N, 19°51'E) and were performed at the Vegetable Experimental Station of University of Agriculture in Krakow. Three cultivation cycles were carried out: spring 2012, spring 2014 and autumn 2014. According to the Köppen classification, the climate of the region is humid continental (Dfb). The soil type is described as a Fluvic Cambisol, with respect to the classification of the World Reference Base for Soil Resources.

Plant material and field work

Butterhead lettuce (*Lactuca sativa* L.) cv. Melodion (Enza Zaden) seedlings were planted in the field on 4th April 2012 (1st spring season), 8th April 2014 (2nd spring season), and on 1st September 2014 (autumn season). Four-week-old seedlings with 3–4 mature leaves were used. In the spring season, floating row covers were stretched over the plants immediately after transplanting and kept until 4th May 2012 and 13th May 2014. In autumn season, nonwovens were spread on plants on 25th September and kept on until harvest. In 2014 in both cycles of cultivation the same type of covers were used. Tillage, sprinkler irrigation, fertilisation, weed management, and plant protection were conducted according to the cultivation recommendations for this. Plants were harvested 48 and 49 days after transplanting in the spring 2012 and 2014, respectively, and after 50 days in the autumn 2014. Climatic conditions during the growing seasons are presented in Table 1.

Experimental design and nonwovens characteristics

Field experiments were designed as split-block, with two treatments in spring 2012 (biodegradable SB48/11 and non-degradable polypropylene (PP) nonwoven served as control – Experiment I) and four treatments in spring and autumn of 2014 (biodegradable SB20/13, SB21/13, SB28/13, and non-degradable PP nonwoven as a control – Experiment II), replicated three times in plots which were 3 m long and 0.9 m wide. In 2014, crop cycle (spring, autumn) was considered as a separate experimental factor. Plant spacing was 30 × 30 cm, each plot consisted of 10 plants with neighbour plants on all sides. Polymeric materials (aliphatic-aromatic copolyester – AAC) and degradable nonwovens were made by Institute of Biopolymers and Chemical Fibers (IBWCh, Łódź, Poland) using a laboratory line designed by the Polmatex-Cenaro Central Research and Development Centre of Textile Machines in Łódź. Nonwoven SB48/11 (mass per unit area 71.3 g m^{-2}, thickness 0.26 mm, fibre diameter 15.3 µm) was made of aliphatic-aromatic copolyester (AAC) without any modifiers. SB20/13 and SB21/13 (mass per unit area 74.2 and 75.2 g m^{-2},

Table 1. Cultivation data and microclimatic conditions in the field during the three crop seasons: spring 2012, spring and autumn 2014

	Spring 2012	Spring 2014	Autumn 2014
Transplanting	4 April	8 April	1 September
Harvest	22 May	27 May	21 October
Growing season duration (days)	48	49	50
Average air min temperature (°C)	6.3	6.4	9.1
Average air mean temperature (°C)	12.7	12.3	13.9
Average air max temperature (°C)	18.9	18.1	19.5
Total rainfall (mm)	65.2	135.0	66.4
Average daily PAR (µmol m^{-2} s^{-1})	620.7	554.5	397.9
Average daylength (h·min)	14.31	14.44	11.58

thickness 0.40 and 0.38 mm, fibre diameter 24.2 and 23.9 µm, respectively) contained the modifier Pripol 1009 (a fatty acid dimer from Croda, Netherlands). The last SB28/13 nonwoven with mass per unit area of 81.8 g m^{-2}, thickness 0.41 mm, and fibre diameter 24.5 µm was based on a polymer designated as 26 + 33 + 34 + 35/30/13 which was AAC with modifier obtained from corn starch, derived from plant biomass. Subsequent types of covers were obtained while improving the production technology and introducing different ingredients into their composition (besides AAC): SB48/12 − no modifier; SB20/13 and SB21/13 − modifier Pripol 1009; and the most innovative material SB28/13 − modifier from plant biomass. Agryl PP nonwoven (control) from Fiberweb France in both experiments had mass per unit area of 19 g m^{-2}.

Biodegradability tests

Biodegradation of nonwoven fabric SB28/13 and polymer 26 + 33 + 34 + 35/30/13 (used for SB28/13 fleece production) were tested within Experiment III at the accredited Laboratory of Microbiology at IBWCh according to the procedure "Determination of the degree of disintegration of plastic materials and textiles under simulated composting conditions in a laboratory scale test" [ISO 20200:2004]. Compost originating from an industrial compost prism (Municipal Services Company of the city of Łódź, Poland) was used as inoculum. Biodegradation process parameters were set to: temperature 58°C ±2°C, pH 7, and inoculum humidity 54.2%. Each of the samples was tested in three replications. The biodegradation process was evaluated at defined time intervals (1, 4, 8, 12, 16, 20 and 24 weeks). Then, the samples were dried to constant weight and the mass loss was estimated.

Photosynthetic performance of lettuce plants

Photosynthetic rate (A), transpiration rate (E), stomatal conductance (g_s), and sub-stomatal CO_2 concentration (C_i) of three recently fully-expanded leaves of the plants (five plants per treatment) in Experiment I were determined with a LCi portable photosynthesis system (ADC BioScientific, UK) between 10:00 and 14:00. Gas-exchange measurements were performed 37 and 48 days after transplanting (11^{th} and 22^{nd} May 2012, respectively). Water-use efficiency (WUE) was calculated as A/E.

Yield parameters

Lettuce from experiment II was harvested from the centre of the plots and all heads were weighed. For the yield quality evaluation, the heads were divided into grade I and grade II (according to European Union marketing standard for lettuces). These qualitative grades constituted marketable yield. Plants that did not meet the above-mentioned criteria were also counted. The structure of total yield was calculated on the basis of the number of harvested plants belonging to individual quality classes.

Plant analyses

Lettuce samples (8–10 heads per treatment, Experiments I and II) were collected for laboratory analyses. Samples were dried at 65°C and then weighed using a Sartorius A120S balance (Sartorius AG, Germany) to determine percentage content of dry weight (DW) in fresh weight (FW). In order to assay L-ascorbic acid, plant material (50 g) was mixed with 200 cm^3 acetic acid (acidity regulator) for 30 min, and then titrated with Tillman's reagent (2,6-dichlorophenolindophenol). Plant samples were also examined for the concentration of chlorophyll *a* and *b* and carotenoids according to the method of Lichtenthaler and Wellburn [1983]. Leaf samples (0.1 g) were grounded with 3 mg of magnesium carbonate ($MgCO_3$) as a pigment stabilizer. The pigments were extracted in 80% (*v*/*v*) aqueous acetone (25 cm^3). The absorbance of the extracts was determined at wavelengths of 665, 648 and 470 nm using a spectrophotometer (Helios Beta, Thermo Fisher Scientific Inc., USA). The ratio of chlorophyll *a* to chlorophyll *b* (Chl *a* : Chl *b*) and ratio of carotenoids to chlorophylls (Car : Chls) were also calculated.

STATISTICAL ANALYSIS

The results were statistically verified using the ANOVA module of Statistica 13.1 (Dell Inc., USA). In the case of significant differences, homogenous groups were determined on the basis of Tukey's HSD test (2014) or t test (2012) at $P < 0.05$. Significance level was indicated as $P < 0.05$ (*), $P < 0.01$ (**), or $P < 0.001$ (***). Each value is presented as a mean of 3 replicates ±SD (standard deviation).

RESULTS AND DISCUSSION

Photosynthetic gas exchange characteristics of lettuce grown under SB48/11 and polypropylene nonwoven (Exp. I) are presented in Table 2. Lettuce plants covered with control PP nonwoven showed reductions in stomatal conductance (g_s), transpiration rate (E), and sub-stomatal CO_2 concentration (C_i) in comparison to SB48/11 during the measurements performed 11 of May. However, no effects of nonwoven type on photosynthetic rate (A) or water-use efficiency (WUE) were observed at that time. At 48 days after transplanting (22 May), there were no differences in photosynthetic performance of plants covered with biodegradable SB48/11 and those covered with commercial PP nonwoven.

Different nonwoven materials have different transmission, absorption, and reflection properties with respect to radiation within the photosynthetically active radiation (PAR) and infrared ranges, and these properties affect spectral conditions under the covers [Siwek et al. 2012]. Reductions of PAR under covers may lead to lower photosynthesis in comparison to an open field; however, this can be, at least partially, compensated by higher soil and air temperatures near the plants. Jursík et al. [2016] found that changes in photosynthetic rate in lettuce are highly influenced by nonwoven cover. There are little other data describing differences in leaf gas exchange of plants grown under various materials [Ibarra-Jiménez et al. 2005]. Generally, photosynthesis is altered when plants are covered with polymers.

The effects of various nonwoven materials (biodegradable and non-degradable) on the yield of lettuce (Exp. II) are given in Table 3. The highest grade I yield and marketable yield in the spring was obtained from control plants covered with commercial polypropylene nonwoven. Degradable covers caused a decrease in these yields as compared to control cover. However, in the autumn season, grade I yield and marketable yield of the plants covered with biodegradable materials were the same as in the control. No significant effects

Table 2. Effects of nonwoven type on the photosynthetic performance of lettuce in Experiment I (spring 2012)

Date	Parameter	SB48/11	Control	Significance level
11 May	photosynthetic rate A (µmol m^{-2} s^{-1})	13.207 ±1.205	13.097 ±2.526	ns
	sub-stomatal CO_2 C_i (vpm)	287.33 ±3.599 b	276.47 ±14.192 a	**
	transpiration rate E (mmol m^{-2} s^{-1})	7.533 ±0.286 b	6.797 ±0.681 a	***
	stomatal conductance g_s (mol m^{-2} s^{-1})	0.717 ±0.179 b	0.538 ±0.146 a	**
	water use efficiency WUE (µmol CO_2/mmol H_2O)	1.755 ±0.171	1.918 ±0.259	ns
22 May	photosynthetic rate A (µmol m^{-2} s^{-1})	9.048 ±2.060	9.344 ±3.273	ns
	sub-stomatal CO_2 C_i (vpm)	237.27 ±32.301	231.40 ±38.611	ns
	transpiration rate E (mmol m^{-2} s^{-1})	3.729 ±0.719	3.344 ±0.554	ns
	stomatal conductance g_s (mol m^{-2} s^{-1})	0.177 ±0.060	0.150 ±0.015	ns
	water use efficiency WUE (µmol CO_2/mmol H_2O)	2.475 ±0.529	2.717 ±0.627	ns

Means within a row followed by different letters are significantly different at P < 0.05, with comparisons performed using t test. Levels of significance: * = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant. Each value represents the mean ±SD

Table 3. Effects of nonwoven type, crop season and their interaction on the yield and mean head weight of lettuce in Experiment II (spring and autumn 2014)

Nonwoven type	Grade I yield ($kg\ m^{-2}$)	Grade II yield ($kg\ m^{-2}$)	Marketable yield ($kg\ m^{-2}$)	Total yield ($kg\ m^{-2}$)	Mean head weight (g)
			Means for nonwoven type		
SB20/13	2.87 ±0.899 A	0.61 ±0.331	3.48 ±0.829 A	3.76 ±0.918 AB	405 ±0.103 AB
SB21/13	2.64 ±0.547 A	0.53 ±0.442	3.17 ±0.730 A	3.69 ±0.815 A	390 ±0.090 AB
SB28/13	2.71 ±1.185 A	0.72 ±0.280	3.42 ±1.306 A	3.58 ±1.217 A	380 ±0.109 A
Control	3.93 ±2.146 B	0.35 ±0.291	4.28 ±1.875 B	4.34 ±1.810 B	439 ±0.176 B
			Means for crop season		
Spring	4.02 ±1.245 B	0.58 ±0.442	4.60 ±0.979 B	4.88 ±0.756 B	509 ±0.066 B
Autumn	2.05 ±0.413 A	0.53 ±0.230	2.58 ±0.366 A	2.77 ±0.300 A	298 ±0.028 A
			Spring		
SB20/13	3.49 ±0.856 bc	0.66 ±0.427	4.15 ±0.514 c	4.55 ±0.421 b	497 ±0.028 bc
SB21/13	3.07 ±0.354 abc	0.65 ±0.590	3.72 ±0.547 bc	4.38 ±0.357 b	466 ±0.042 b
SB28/13	3.69 ±0.545 c	0.86 ±0.245	4.55 ±0.464 c	4.64 ±0.442 b	474 ±0.046 b
Control	5.83 ±0.712 d	0.13 ±0.231	5.96 ±0.493 d	5.96 ±0.493 c	597 ±0.049 c
			Autumn		
SB20/13	2.25 ±0.349 abc	0.56 ±0.291	2.81 ±0.303 ab	2.96 ±0.156 a	312 ±0.001 a
SB21/13	2.20 ±0.235 abc	0.41 ±0.308	2.61 ±0.314 ab	2.99 ±0.305 a	313 ±0.034 a
SB28/13	1.72 ±0.565 a	0.57 ±0.268	2.29 ±0.478 a	2.51 ±0.347 a	285 ±0.041 a
Control	2.03 ±0.434 ab	0.57 ±0.104	2.60 ±0.330 ab	2.72 ±0.164 a	280 ±0.009 a
			Significance level		
Nonwoven (N)	**	ns	**	**	*
Crop season (CS)	***	ns	***	***	***
N × CS	**	ns	**	**	**

Means within a column followed by different letters (capital letters for main effects and lower case letters for interaction effects) are significantly different at $P < 0.05$, with comparisons performed using Tukey's HSD test. Levels of significance: * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, ns = not significant. Each value represents the mean ±SD

of covering on the grade II yield were observed. In the spring, total yield of lettuces covered with biodegradable materials was lower in comparison to control PP nonwoven. Regardless of the type of cover used in the lettuce grown in the autumn cycle, total yield did not differ significantly. No differences between treatments in mean head weight were found in the autumn. In the spring the heaviest heads were formed by lettuce under nonwoven PP, though plants grown under SB20/13 had no statistically different head weights. Yield of spring lettuce was higher (78% and 76.5% for marketable and total yield, respectively) in comparison to the autumn cultivation period, regardless of the type of cover. Mean head weight was also higher in spring: lettuce heads harvested in the autumn were 1.7-fold lighter.

The highest quality of yield was noted for control lettuce in the spring (Fig. 1). More than 96% of heads belonged to grade I quality, and was lowered by 33.4%, 27.7% and 20.8% in the case of biodegradable nonwovens (SB21/13, SB20/13 and SB28/13, respectively). Neither in spring nor autumn a significant influence of the type of cover on the yield of II grade was observed. Only the effect of cultivation date was observed: yield

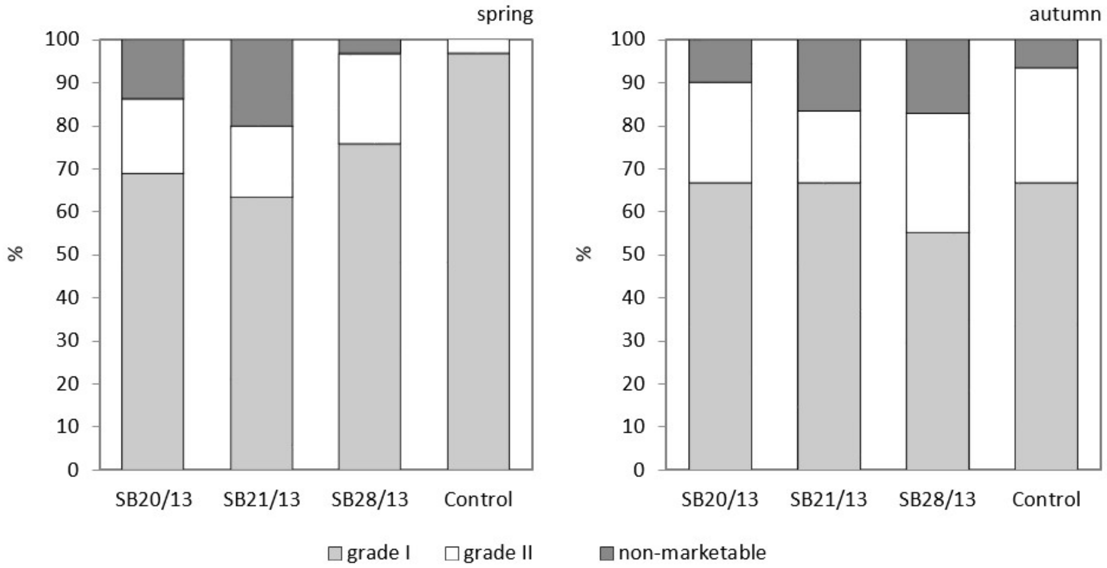


Fig. 1. Effects of nonwoven type on the yield structure of lettuce in Experiment II (spring and autumn 2014)

of lettuce harvested in the autumn had lower quality. In autumn, control plants and lettuce covered with SB20/13 and SB21/13 produced only 66.7% grade I heads. Only 55.2% of plants grown under SB28/13 gave heads of this quality. The lowest number of plants in the grade II was noted for SB21/13. The number of heads from the control treatment that did not fulfill marketable criteria was 6.7%, while around 16% of heads were non-marketable when lettuce was covered with SB21/13 and SB28/13.

Degradable covers adversely affected the yields of spring lettuce when compared to PP nonwoven. The primary reason for yield loss under biodegradable covers was the deterioration of the lettuce head quality. In the autumn season, no significant effect of nonwoven type on marketable yield level was noted and the quality of lettuce heads from the plots covered with PP nonwoven was more comparable to other covers. Higher yield quality in the spring season was particularly evident for the control PP nonwoven treatment where all plants formed heads suitable for trade and there was a low share of grade II heads in marketable yield. In the spring season, lettuce covered with degradable fleeces had a much higher proportion of poor quality heads relative to the control (PP nonwoven). Among the treatments under biodegradable covers, only plants under the SB28/13 had a negligible share of non-marketable heads in total yield. The reason for lower marketable yield of lettuce under SB28/13 relative to the control PP nonwoven was primarily due to the reduction of mean head weight. In our opinion, this negative effect of the biodegradable covers on the yield of lettuce resulted from the covers' much higher mass per unit area (around 4 fold higher) as compared to the PP nonwoven. Higher mass per unit area may disturb the growth and development of plants due to the force exerted on the lettuce rosettes/heads formed from leaves with a delicate structure. Polymer materials have different air permeability and may alter microclimatic conditions in the plant surroundings in different ways [Epps and Leonas 2000, Siwek et al. 2012, Ozturk et al. 2016], which could also affect the yield of lettuce. Interestingly, Siwek et al. [2013] did not observe any significant changes in the yield of overwintering onion between AAC floating covers with different mass per unit areas (50 and 75 g m^{-2}) or between different Bionolle (polybutylene succinate) floating covers (59 and 100 g m^{-2}).

Differences in the crop yields between particular cultivation seasons can be attributed to different patterns of microclimatic conditions. Lower yield during the autumn season was most due to higher initial temperatures, shorter daylength, and lower values of PAR in later phases of plant ontogeny (Tab. 1). This is in agreement with data published by Pavlou et al. [2007] who showed significant effect of crop season on the yield of romaine-type lettuce where yield was greater in the late-spring season compared to the late-autumn period. Koudela and Petříková [2008] found that leaf rosette weight was significantly influenced by growing season (spring, summer, autumn) and indicated that for different leaf lettuce types summer cultivation was the most weight-increasing period. Al-harbi [2001] and Kaleri et al. [2016] determined several yield parameters of lettuce and observed significant differences among various sowing and planting dates. The data reported here confirms that lettuce yields are unique to specific environment factors of particular growing seasons.

There was a significant effect of covering with SB48/11 (Exp. I) on the dry weight and L-ascorbic acid content (Table 4). This cover lowered plant dry weight content, but increased concentrations of L-ascorbic acid. Covering with biodegradable SB48/11 had no effect on the content of chlorophyll *a*, chlorophyll *b*, or carotenoids. SB48/11 did not affect the chlorophyll *a* to *b* ratio or the carotenoids to chlorophylls ratio.

In Exp. II, the content of dry weight was dependent on the nonwoven type and crop season (Tab. 5). Lettuce grown in spring under the SB28/13 cover had the highest content of dry weight and was not different from SB21/13. The lowest dry weight contents were observed under the control and SB28/13 nonwoven in the autumn, and under SB20/13 in the spring. Lettuce cultivated in the spring under SB21/13 and SB28/13 had the highest concentration of L-ascorbic acid, while SB28/13 plants grown in autumn showed the lowest content of this compound. A significant difference in chlorophyll *a* content was found only between autumn plants covered with SB20/13 and spring lettuce grown under SB28/13. Carotenoids content was not significantly different between SB28/13 and SB20/13 in the spring. Means for nonwoven type showed that plants grown under SB20/13 had the lowest content of dry weight and L-ascorbic acid, while plants grown under SB21/13 had the highest. The means pointed to SB28/13 as a cover causing the highest increase in chlorophyll *a* content, but generally no effect of covers was noted for carotenoids level in the lettuce plants. No significant differences in the level of chlorophyll *b* were observed. The contents of dry weight, L-ascorbic acid, and carotenoids were the highest in plants harvested in the spring, while no effect of crop season on chlorophyll levels was observed.

There were no effects of experimental treatments (Exp. II) on the chlorophyll *a* to chlorophyll *b* ratio (Fig. 2). The lowest ratio of carotenoids to chlorophylls was noted for plants covered with SB28/13 in the autumn season – differences in the carotenoids to chlorophylls ratio were only significant in comparison to spring plants covered with SB20/13. Generally, the type of nonwoven did not influence this ratio, however, it was higher for spring lettuce plants than those harvested in the autumn.

The significant influence of environmental factors, including microclimatic conditions, on several

Table 4. Effects of nonwoven type on the content of dry weight, L-ascorbic acid and plant pigments (chlorophylls and carotenoids) of lettuce in Experiment I (spring 2012)

Parameter	SB48/11	Control	Significance level
Dry weight (% FW)	5.57 ±0.025 a	5.84 ±0.017 b	***
L-ascorbic acid (mg 100 g^{-1} FW)	14.33 ±0.404 b	11.40 ±0.001 a	***
Chlorophyll *a* (mg 100 g^{-1} FW)	58.53 ±0.018	59.17 ±0.021	ns
Chlorophyll *b* (mg 100 g^{-1} FW)	28.53 ±0.010	33.17 ±0.046	ns
Carotenoids (mg 100 g^{-1} FW)	11.77 ±0.010	9.53 ±0.025	ns
Chl *a* : Chl *b*	2.05 ±0.096	1.78 ±0.195	ns
Car : Chls	0.14 ±0.011	0.10 ±0.027	ns

Means within a row followed by different letters are significantly different at P < 0.05, with comparisons performed using t test. Levels of significance: * = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant. Each value represents the mean ±SD

Table 5. Effects of nonwoven type, crop season and their intertaction on the content of dry weight, L-ascorbic acid and plant pigments (chlorophylls and carotenoids) in lettuce in Experiment II (spring and autumn 2014)

Nonwoven type	Dry weight (% FW)	L-ascorbic acid (mg 100 g^{-1} FW)	Chlorophyll *a* (mg 100 g^{-1} FW)	Chlorophyll *b* (mg 100 g^{-1} FW)	Carotenoids (mg 100 g^{-1} FW)
			Means for nonwoven type		
SB20/13	3.99 ±0.257 A	14.98 ±7.535 A	34.56 ±10.363 A	12.49 ±5.798	9.94 ±4.528
SB21/13	4.59 ±0.334 C	18.69 ±11.588 D	38.55 ±7.411 AB	13.45 ±1.190	10.23 ±1.925
SB28/13	4.41 ±0.570 B	17.37 ±11.416 C	47.55 ±6.045 B	14.57 ±1.784	13.11 ±2.078
Control	4.29 ±0.386 B	16.10 ±8.347 B	36.61 ±7.725 AB	11.88 ±3.279	10.35 ±2.294
			Means for crop season		
Spring	4.57 ±0.488 B	25.65 ±3.177 B	40.72 ±8.800	13.70 ±2.780	12.11 ±2.931 B
Autumn	4.07 ±0.171 A	7.92 ±0.678 A	37.91 ±9.457	12.49 ±3.998	9.70 ±2.677 A
			Spring		
SB20/13	3.80 ±0.243 a	21.85 ±0.642 c	41.57 ±5.004 ab	12.76 ±2.035	13.77 ±2.398 b
SB21/13	4.89 ±0.010 de	29.26 ±0.640 e	34.19 ±2.086 ab	14.06 ±0.819	9.50 ±0.538 ab
SB28/13	4.93 ±0.031 e	27.78 ±0.780 e	50.19 ±5.358 b	15.53 ±1.746	14.50 ±1.567 b
Control	4.64 ±0.050 d	23.70 ±0.642 d	36.91 ±12.100 ab	12.46 ±5.081	10.66 ±3.561 ab
			Autumn		
SB20/13	4.17 ±0.021 bc	8.11 ±0.116 ab	27.54 ±9.799 a	12.21 ±8.926	6.11 ±1.199 a
SB21/13	4.28 ±0.011 c	8.12 ±0.100 ab	42.90 ±8.726 ab	12.84 ±1.327	10.95 ±2.721 ab
SB28/13	3.89 ±0.071 a	6.96 ±0.202 a	44.90 ±6.452 ab	13.60 ±1.452	11.71 ±1.572 ab
Control	3.94 ±0.021 ab	8.50 ±0.669 b	36.30 ±1.577 ab	11.29 ±0.192	10.04 ±0.424 ab
			Significance level		
Nonwoven (N)	***	***	*	ns	ns
Crop season (CS)	***	***	ns	ns	*
N × CS	***	***	*	ns	**

Means within a column followed by different letters (capital letters for main effects and lower case letters for interaction effects) are significantly different at P < 0.05, with comparisons performed using Tukey's HSD test. Levels of significance: * = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant. Each value represents the mean ±SD

chemical components of the plants is widely known, though the response of specific plants and chemical components may be unique. Plants cultivated in different seasons experience various patterns of weather causing alterations in the level of chemical constituents, which was observed by many researchers [Liu et al. 2007, Francke and Majkowska-Gadomska 2008, Koudela and Petříková 2008, Kołota et al. 2010]. In the present experiment, spring plants had a higher content of dry weight than plants harvested in the autumn. Although Francke and Majkowska-Gadomska [2008] found higher dry weight content in the leaves of plants grown in the spring compared to those harvested in the fall, this was not confirmed statistically, while Koudela and Petříková [2008] and Kunicki et al. [2010] noted higher dry weight content in the plants harvested in autumn than in earlier growing seasons. According to Reinink [1993] light quantity is a main factor influencing dry weight content in lettuce, thus in periods with higher light intensity, higher content of dry weight should be expected. This type of relationship has been confirmed by Kalisz et al. [2012] on pak choy. The higher content of L-ascorbic acid in spring lettuce observed in the present experiment may be related to the

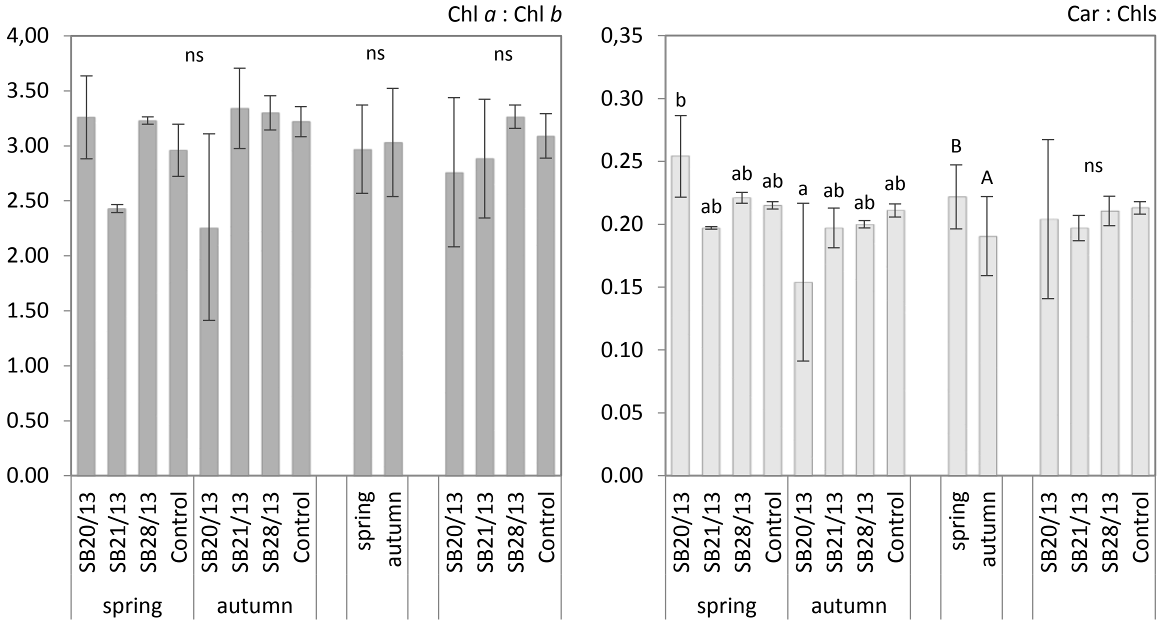


Fig. 2. Effects of nonwoven type, crop season (spring, autumn) and their interaction on the ratios of chlorophyll *a* : chlorophyll *b* (Chl *a* : Chl *b*) and carotenoids : total chlorophylls (Car : Chls) in Experiment II (2014). Means followed by different letters (capital letters for main effects and lower case letters for interaction effects) are significantly different at $P \leq 0.05$, with comparisons performed using Tukey's HSD test. Error bars represent ±SD

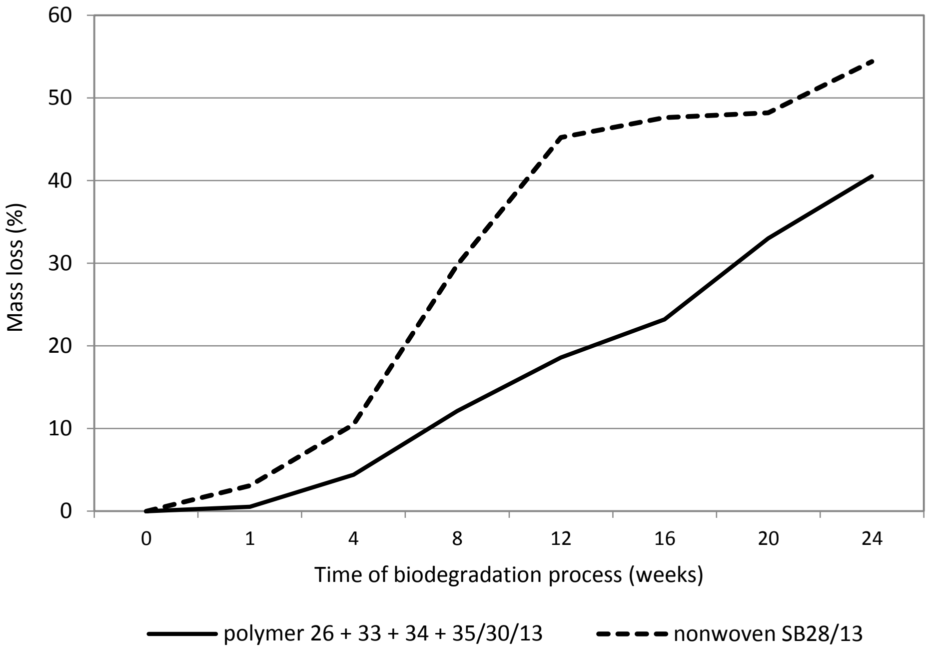
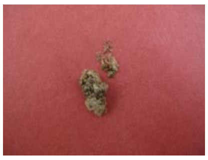


Fig. 3. Mass loss in the polymer 26 + 33 + 34 + 35/30/13 granules and nonwoven SB28/13 (AAC made from 26 + 33 + 34 + 35/30/13 with addition of plant biomass) during the biodegradation process (Exp. III)

Table 6. Photos of the polymer 26 + 33 + 34 + 35/30/13 granules and nonwoven SB28/13 (AAC made from polymer 26 + 33 + 34 + 35/30/13 with addition of plant biomass) during biodegradation (from 0 to 24 weeks) (Exp. III)

Weeks of biodegradation	Polymer 26 + 33 + 34 + 35/30/13	Nonwoven SB28/13
0		
1		
4		
8		
12		
16		
20		
24		

results of Koudela and Petříková [2008] who in one of two experimental years found more vitamin C in lettuce in spring than in autumn. Similarly, Francke and Majkowska-Gadomska [2008] observed that L-ascorbic acid content was almost two fold higher in radicchio plants grown in the spring than in autumn period. Uklańska-Pusz and Adamczewska-Sowińska [2011] reported that the average chlorophyll content for endive cultivars was about 21% higher in the spring as compared to the autumn. This is inconsistent with our results as we did not find any significant alterations in chlorophyll *a* and chlorophyll *b* concentrations due to growing season. Kalisz et al. [2012] determined more carotenoids in pak choy plants grown from earlier planting (plantings were performed in the middle and at the end of August). In present experiment, the effect of growing season on the ratio of carotenoids to chlorophylls was associated with higher concentrations of carotenoids in plant tissues in spring season.

Meanwhile, direct covering may play important role in manipulating the microclimate surrounding plants and affects plant metabolism. Some reports showed that different floating nonwoven covers may decrease or increase chemical constituent levels in plants [Siwek et al. 2012, Siwek et al. 2013, Zawiska and Siwek 2014]. In our experiments we found significant differences in the content of dry weight, L-ascorbic acid (Exp. I and II), and chlorophyll *a* (Exp. I) in plants grown under different covers. Siwek et al. [2012] reported ambiguous effects of biodegradable nonwovens on dry weight content of lettuce plants in particular experimental years in comparison to PP nonwoven. In previous report [Kalisz et al. 2019], we found an increase in dry weight and L-ascorbic acid content in roots of the radish covered with SB20/13 during autumn cultivation and no effects on these constituents in the spring when compared to PP nonwoven. This suggests that the mechanical and structural properties of the covers by setting a specific microclimatic conditions affect the chemical composition of the plants, but it depends on plant species too.

The dependence of mass loss in the polymer 26 + 33 + 34 + 35/30/13 granules and SB28/13 nonwoven on the length of time for the biodegradation process was investigated in Experiment III (Fig. 3). The percentage of biodegradation of these materials was always higher for SB28/13 nonwoven material. Differences in biodegradation were especially evident between 4 to 16 weeks. The difference between SB28/13 and the 26 + 33 + 34 + 35/30/13 polymer reached 26.6% at week 12. The biodegradation tests of the samples lasted 24 weeks and at the end of the tests 40.5% (26 + 33 + 34 + 35/30/13) or 54.4% (SB28/13) mass loss was found. Full degradation of the samples requires more time, particularly in the case of 26 + 33 + 34 + 35/30/13 polymer.

Table 6 presents changes in the appearance of the polymer 26 + 33 + 34 + 35/30/13 granules and nonwoven SB28/13 over the course of biodegradation. The nonwoven sample began to fragment after 4 weeks, while the polymer structure was more compact (granules). Colour changes on the samples' surfaces became visible after 8 weeks for the polymer and nonwoven and the most striking colour changes occurred on the surface were observed after 20-24 weeks of biodegradation.

The biodegradability of AAC polymers depends on their composition, i.e. on the mutual contribution of aliphatic and aromatic components. Polymers containing a majority of aliphatic components are almost completely biodegradable, but with an increase in the proportion of aromatic components, the biodegradability decreases [Chen et al. 2008]. Polymer 26 + 33 + 34 + 35/30/13 contained about 57% aliphatic components. In comparison with 26 + 33 + 34 + 35/30/13 granules, the nonwoven SB28/13 is more susceptible to biodegradation due to the much more developed surface.

CONCLUSIONS

Biodegradable polymers may contribute to the sustainability of vegetable crop production if their performance is not worse than that showed by non-degradable polypropylene fleece. Marketable yield of lettuce covered with degradable materials was lower in comparison to PP nonwoven in the spring season, however, in the autumn cycle the yields were not significantly different between treatments. Delicate and rapidly growing plants in the spring were overwhelmed by the heavier degradable covers resulting in a decrease in their market quality. Our recommendation is to reduce the unit weight of polymeric biomaterials. This does not exclude the use of such covers at specific crop development stages. Some positive effects of degradable polymers on the biological value of lettuce were observed.

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