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Original Research Paper

Effect of biodegradable nonwoven covers on yield and chemical composition of overwintering onion

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Abstract: Floating row covers are important pre-harvest factors for maximizing the yield of vegetable crops grown under open-field conditions. It is necessary to replace oil-based nonwoven covers with biodegradable ones that are environmentally friendly. The aim of this study was to investigate the effects of biodegradable nonwoven covers, made of aliphatic-aromatic copolyesters, with or without fatty acid dimers (SB20/13, SB21/13, and SB28/13), on yield and chemical composition of 'Glacier' and 'Swift' winter onions. In the first experiment, we observed a higher total marketable yield and higher harvest index for onions covered with SB21/13 (by 24% and 3%, respectively) when compared to the control (polypropylene nonwoven). The SB20/13 cover significantly decreased mean bulb weight by 15.3% than in control. Bulbs harvested from the plots covered with SB21/13 had lower dry weight by 3.2-3.7% and those covered with SB28/13 showed the lowest L-ascorbic acid content when compared to all other treatments (by 6.3-10.3%). The lowest total sugar content was found in control onion bulbs, but it was significantly different only from bulbs covered by SB20/13, which had more sugar by 10.6%. In the second experiment, plants covered with the SB28/13 had a 1st grade yield of onions higher by 47% than that of the control. The highest mean bulb weight was obtained from plants covered with the SB21/13 nonwoven. Covering with nonwovens caused a decrease in dry weight (SB20/13 and SB21/13, by 1.3-1.7%, respectively) and L-ascorbic acid (all nonwovens, by 15.6% for SB21/13 up to 22% for SB20/13) in onion bulbs in comparison to the control. Since the tested biodegradable nonwovens covers did not cause any decrease in the yield of winter onions compared to polypropylene nonwovens, the former appear to be a suitable environmental-friendly solution for the open-field cultivation of this important vegetable crop.

Keywords: *Allium cepa* L.; aliphatic-aromatic polymers; biodegradability; plant biomass; winter production; L-ascorbic acid; yields

1. Introduction

Plant row covering with nonwovens is a beneficial factor for growth, providing crops with better thermal and humidity conditions in winter and early spring. Covers also protect the crops from frost damage in the Central European climate, which is defined as continental with warm summers and cold winters. Nonwoven materials can be used to directly cover plants and mulch the soil around plants (Fontana et al., 2006; Marasovic and Kopitar, 2019). Polypropylene nonwovens are used in a growing number of vegetable crops, however oil-based polymers are often left in the field, burying with the soil or burned at the end of the season, thus they accumulate in the environment becoming pollutants (Briassoulis, 2007; Goldberger et al., 2019). Plastic debris may adsorb and transfer toxic substances from environment to the food chain and adversely impact human health, disrupt shoot and root development of subsequent crops, affect negatively soil biota and crucial soil properties (Thompson et al., 2009; Kasirajan and Ngouajio, 2012; Boots et al., 2019). Due to the high volume of plastics required by the European cropping systems (1741 thousand tons in 2018; PEMRG, 2018), the use of non-biodegradable materials represents a serious issue.

Nonwovens can be made from degradable polymers and used as a floating row covering and as mulch in vegetable crops. These may be a suitable alternative to the currently used polypropylene and polyethylene plastics because biomaterials decompose faster and do not pose a threat to the environment (Scarascia-Mugnozza et al., 2006). Siwek et al. (2019) divided degradable polymers into: (i) oxo- and photodegradable plastics made of low density polyethylene (LDPE), polypropylene (PP), or polystyrene (PS) with metal salts; (ii) compostable plastics made of polylactic acid (PLA) or aliphatic polyester from maize starch, tapioca roots, or sugar cane; (iii) biodegradable plastics made of polybutylene succinate (PBS) or PLA (with biodegradation proceeding at high temperature). Another classification of biodegradable materials was reported in detail by Bergeret (2011). According to that work, biodegradable polymers consist of the following groups: (i) biomass products (polysaccharides, proteins etc.), (ii) biopolyesters obtained either by synthesis from bio-derived monomers (PLA) or by extraction from microorganisms (polyhydroxyalkanoate – PHA) or by synthesis from synthetic monomers (polycaprolactone – PCL, aromatic and aliphatic copolyesters – PBAT, PBSA etc.). An environmental friendly solution would be for full degradation of the polymer to occur, not fragmentation. A fully biodegradable polymer is defined as a polymer that is completely converted by microorganisms to carbon dioxide or methane, water, minerals, and biomass without any potentially harmful substances (Kyrikou and Briassoulis, 2007). This is problematic because some novel plastics are not efficiently biodegradable (Adhikari et al., 2016).

Several biodegradable polymers have been proposed for the agricultural production (Kasirajan and Ngouajio, 2012). The prevalence of such materials has been debated because of the possibility for their production from renewable raw materials and the option of leaving them in the field for complete decomposition, with lower costs of additional disposal (Goldberger et al., 2013). The biggest obstacle to achieving good mechanical behavior is adapting the durability of biodegradable covers to the length of the plant cultivation period while ensuring optimal conditions for plant growth and development and providing the same yield-forming effects as traditional oil-based covers. This created a need for subsequent field tests to determine the positive effects on plant growth and yield (Scarascia-Mugnozza et al., 2011). Most of these studies, however, are focused on the use of mulches and low tunnels in plant production (Kasirajan and Ngouajio, 2012; Martín-Closas et al., 2017; Siwek et al., 2019). Some reports reported the issues related to the non-constructive covering of plants (floating row covers) with biodegradable materials, based on polylactic acid (PLA) or aliphatic-aromatic copolyesters (ACC) (Siwek et al., 2012; Siwek et al., 2013; Zawiska and Siwek, 2014; Kalisz et al., 2019).

ACC materials are biopolyesters obtained by synthesis from synthetic monomers and are known to be fully biodegradable under composting conditions (Chen et al., 2008; Twarowska-Schmidt et al., 2016). Based on the above considerations, the aim of the current study was to assess the effects of covering winter onion with materials made from aliphatic-aromatic copolyesters, with or without the addition of fatty acid dimmers, on yield, yield components and the chemical composition of two onion cultivars.

2. Materials and Methods

2.1. Plant material and experimental conditions

This study was carried out on two onion (*Allium cepa* L.) cultivars, 'Glacier' and 'Swift', both designated for fresh market and originated from Bejo Zaden (Konotopa, Poland). These cultivars are recommended for winter production in Central Europe. The field experiment began on 12 August 2013 (experiment I) or 19 August 2014 (experiment II). Sowing was done with a mechanical seeder, straight into the field, in a farm located close to Kraków, southern Poland (50°04′N, 19°51′E). Farming practices (irrigation, fertilization, plant protection, weeding) were performed according to standard recommendations published by PIORIN (2005). Fertilization before sowing was based on soil analysis, to achieve (mg dm^{-3} soil): nitrogen 80-120, phosphorus 70-90, potassium 180-250, magnesium 60-80, calcium 800-1000. The dose of nitrogen was divided into three parts. The first application was done before sowing, whereas the other two applications were done in spring. The following fertilizers were applied: nitrochalk and ammonium sulphate, single superphosphate, potassium sulphate, dolomite lime. The soil type at the experimental field is a Fluvic Cambisol, using the classification from the World Reference Base for Soil Resources. The soil had pH = 6.5 and C_{org} = 2%. Onions received prophylactically fungicides (Ridomil Gold MZ Pepite and Scorpion 325 SC) against diseases (mainly white rot and downy mildew), plants were protected against pests (Mospilan 20 SP), weeded by hand and irrigated as needed. The climate is continental with warm summers and cold winters (marked as Dfb according to Köppen's classification).

2.2. Experimental design and nonwovens

The following spun-bonded biodegradable fabrics were evaluated: SB20/13, SB21/13, and SB28/13. SB20/13 and SB21/13 were made from an AAC with Pripol 1009, a fatty acid dimer from Croda, Gouda, Netherlands. The SB/28/13 fabric was also made from AAC, but with an additional modifier obtained from corn starch. The polymers and nonwovens were made by the Institute of Biopolymers and Chemical Fibres and Polmatex-Cenaro Central Research and Development Centre of Textile Machines (Łódz, Poland). Detailed physical and mechanical properties of the biodegradable nonwovens tested in this experiment were described previously by Kalisz et al. (2019). A non-degradable commercial PP nonwoven material (50 g m^{-2}) was used as a control. The covers were stretched over the onion plants on 21 November 2013 and 28 November 2014 and maintained on the plots until mid-March of the following year. In each experiment new nonwovens were used. The experimental design was a split-block plot with three replicates. Each plot was four meters long and 1-meter-wide and consisted of four rows (plant spacing was 25 cm × 4 cm; 100 plants per m^2). Only plants from two internal rows were analyzed for harvest and chemical data.

2.4. Yield, and yield component measurement

Onions were harvested at the beginning of June 2014 (experiment I) and in the second half of June 2015 (experiment II). Leaves were cut off from the bulbs and weighed separately in each plot. Bulbs were divided into grades: 1st grade (healthy, firm and compact, typical shape and color for the cultivar), 2nd grade (small bulbs, slightly deformed), and non-marketable ones. The number and fresh weight of the bulbs were measured. Marketable yield consisted of 1st and 2nd grade bulbs, classified according to UNECE Standard FFV-25 (2010). Total yield comprised both marketable and waste production. The quality structure (the number of plants in a given quality class by the total number of plants harvested) of the total yield was determined. The average bulb weights and the harvest index were also calculated.

2.5. Plant sampling and laboratory analysis

Plants (marketable bulbs) were sampled during harvest and immediately transferred to the laboratory. They were oven-dried at 65 °C and dry weight was measured with a laboratory balance (A120S, Sartorius AG, Goettingen, Germany). Soluble sugars were determined by the anthrone method (Yemm and Willis, 1954). In brief, plant material was mixed with 80% ethanol to extract sugar. The anthrone reagent was added to diluted solutions of plant material and the probes were kept at 100 °C in a water bath for 30 minutes, then cooled to 20-22 °C. Absorbance was determined at 625 nm using a Helios Beta spectrophotometer (Thermo Fisher Scientific Inc., Waltham, MA, USA). The L-ascorbic acid concentration was estimated by Tillman's titration method (Krełowska-Kułas, 1993). Plant material (50 g) was homogenized with 200 cm^3 acetic acid and filtrated. The extract was quickly titrated using 2,6-dichlorophenolindophenol until a pink color appeared.

2.6. Statistical analysis

Statistical analyses were performed using the software Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). A two-way analysis of variance (ANOVA) was performed in experiment I to determine the main effects of nonwoven type and onion genotype, as well as interactions between two experimental factors. In experiment II, data were analyzed by a one-way ANOVA, considering the nonwoven type as an experimental factor. Homogenous groups were separated with Fisher's test, at a significance level of $p \leq 0.05$.

3. Results

2.1. Experiment I (2013/2014)

Floating covers affected the marketable and 1st grade yield of overwintering onion (Table 1). In both cases, the highest yield was obtained from plants covered by the SB21/13 nonwoven and yield was 27% and 24% higher than the control treatment, respectively. Plants covered with the other biomaterials had a yield not significantly different from the control (2.52 kg m^{-2}). 'Swift' was a higher-yielding cultivar than 'Glacier'. There was a significant interaction between nonwoven type and cultivar; 'Glacier' had the lowest 1st grade yield when covered by SB20/13 and 'Swift' had the highest under SB21/13. 'Swift' with the SB21/13 covering also had the lowest 2nd grade yield and the highest marketable yield, the biggest differences occurred in relation to SB20/13 nonwoven used over 'Glacier' plants.

Yield of 1st grade onions, based on the number of harvested bulbs, was influenced by the nonwoven type (Table 2). Using the SB21/13 nonwoven cover increased 1st grade yield more than other nonwoven treatments and yield was 39% higher than the control. No effect of the nonwovens was observed in 2nd grade yield. The highest marketable yield was obtained from plants covered with the SB21/13 nonwoven (by 30% in comparison to the control) and was not significantly different from SB20/13. The marketable yield of 'Swift' was similar among all nonwoven treatments, but the marketable yield of 'Glacier' was the highest with the SB21/13 nonwoven.

Table 1. Effect of nonwoven covers on the yield of marketable bulbs (kg m^{-2}) of onion cultivars, 'Glacier' and 'Swift', in the season 2013/2014 (experiment I).

Source of variation		Marketable yield (kg m^{-2})		
		1st grade	2nd grade	Total
Cultivar				
Glacier		2.04 ± 0.52 B	0.16 ± 0.07 A	2.20 ± 0.52 B
Swift		2.80 ± 0.45 A	0.18 ± 0.11 A	2.98 ± 0.41 A
Nonwoven type				
SB20/13		2.10 ± 0.57 B	0.20 ± 0.08 A	2.30 ± 0.61 B
SB21/13		3.01 ± 0.55 A	0.12 ± 0.10 A	3.13 ± 0.45 A
SB28/13		2.22 ± 0.52 B	0.20 ± 0.10 A	2.42 ± 0.60 B
Control		2.36 ± 0.48 B	0.16 ± 0.07 A	2.52 ± 0.52 B
Cultivar	Nonwoven type			
Glacier	SB20/13	1.65 ± 0.42 d	0.15 ± 0.07 ab	1.80 ± 0.35 c
	SB21/13	2.62 ± 0.51 b	0.19 ± 0.10 a	2.81 ± 0.43 ab
	SB28/13	1.89 ± 0.42 d	0.16 ± 0.06 ab	2.05 ± 0.46 c
	Control	1.99 ± 0.26 cd	0.12 ± 0.05 ab	2.11 ± 0.31 c
Swift	SB20/13	2.54 ± 0.23 bc	0.25 ± 0.05 a	2.79 ± 0.28 b
	SB21/13	3.39 ± 0.22 a	0.05 ± 0.02 b	3.44 ± 0.20 a
	SB28/13	2.54 ± 0.41 bc	0.24 ± 0.14 a	2.78 ± 0.54 b
	Control	2.73 ± 0.32 b	0.19 ± 0.07 a	2.92 ± 0.28 ab

Mean values ± SD (n = 3). Within each column, values followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$: capital letters are referred to the main effects; lowercase letters to the interaction effect.

Table 2. Effect of nonwoven covers on the number of marketable onion bulbs per area unit (no. of bulbs m^{-2}) of onion cultivars, 'Glacier' and 'Swift', in the season 2013/2014 (experiment I).

Source of variation		Marketable yield (no. of bulbs m^{-2})		
		1st grade	2nd grade	Total
Cultivar				
Glacier		22.84 ± 6.12 B	4.50 ± 1.91 A	27.33 ± 6.79 B
Swift		30.44 ± 6.01 A	5.11 ± 3.07 A	35.55 ± 6.81 A
Nonwoven type				
SB20/13		25.00 ± 7.49 B	6.11 ± 3.14 A	31.11 ± 9.99 AB
SB21/13		33.45 ± 5.37 A	3.67 ± 2.63 A	37.12 ± 3.54 A
SB28/13		24.00 ± 6.25 B	5.00 ± 2.49 A	29.00 ± 8.12 B
Control		24.11 ± 5.71 B	4.44 ± 1.56 A	28.55 ± 7.10 B
Cultivar	Nonwoven type			
Glacier	SB20/13	18.67 ± 4.00 d	3.78 ± 1.68 bc	22.45 ± 2.34 c
	SB21/13	29.56 ± 3.29 abc	5.56 ± 2.52 ab	35.12 ± 0.77 ab
	SB28/13	21.33 ± 6.36 cd	4.89 ± 2.52 abc	26.22 ± 7.78 bc
	Control	21.78 ± 6.33 cd	3.78 ± 1.02 bc	25.56 ± 7.34 bc
Swift	SB20/13	31.33 ± 2.00 ab	8.44 ± 2.34 a	39.77 ± 4.34 a
	SB21/13	37.33 ± 4.00 a	1.78 ± 0.39 c	39.11 ± 4.34 a
	SB28/13	26.67 ± 6.00 bcd	5.11 ± 3.01 abc	31.78 ± 9.00 abc
	Control	26.44 ± 5.00 bcd	5.10 ± 1.93 abc	31.54 ± 6.71 abc

Mean values ± SD (n = 3). Within each column, values followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$: capital letters are referred to the main effects; lowercase letters to the interaction effect.

Covering with SB20/13 negatively affected mean bulb weight, decreasing it by 15% in comparison to the control (Figure 1A). The two other nonwovens did not change the weight of marketable bulbs. There was no significant effect of cultivar on bulb weight. A similar bulb weight in 'Glacier' was observed regardless of the nonwoven used, but for 'Swift' plants under the SB20/13 nonwoven, bulb weight was 26% lower than in the control. The tested nonwovens influenced the harvest index; among nonwoven covers the highest harvest index was noted for SB21/13, while 'Swift' covered with SB28/13 had the lowest harvest index in all treatments (Figure 1B). 'Glacier' plants had significantly higher harvest index than 'Swift'.

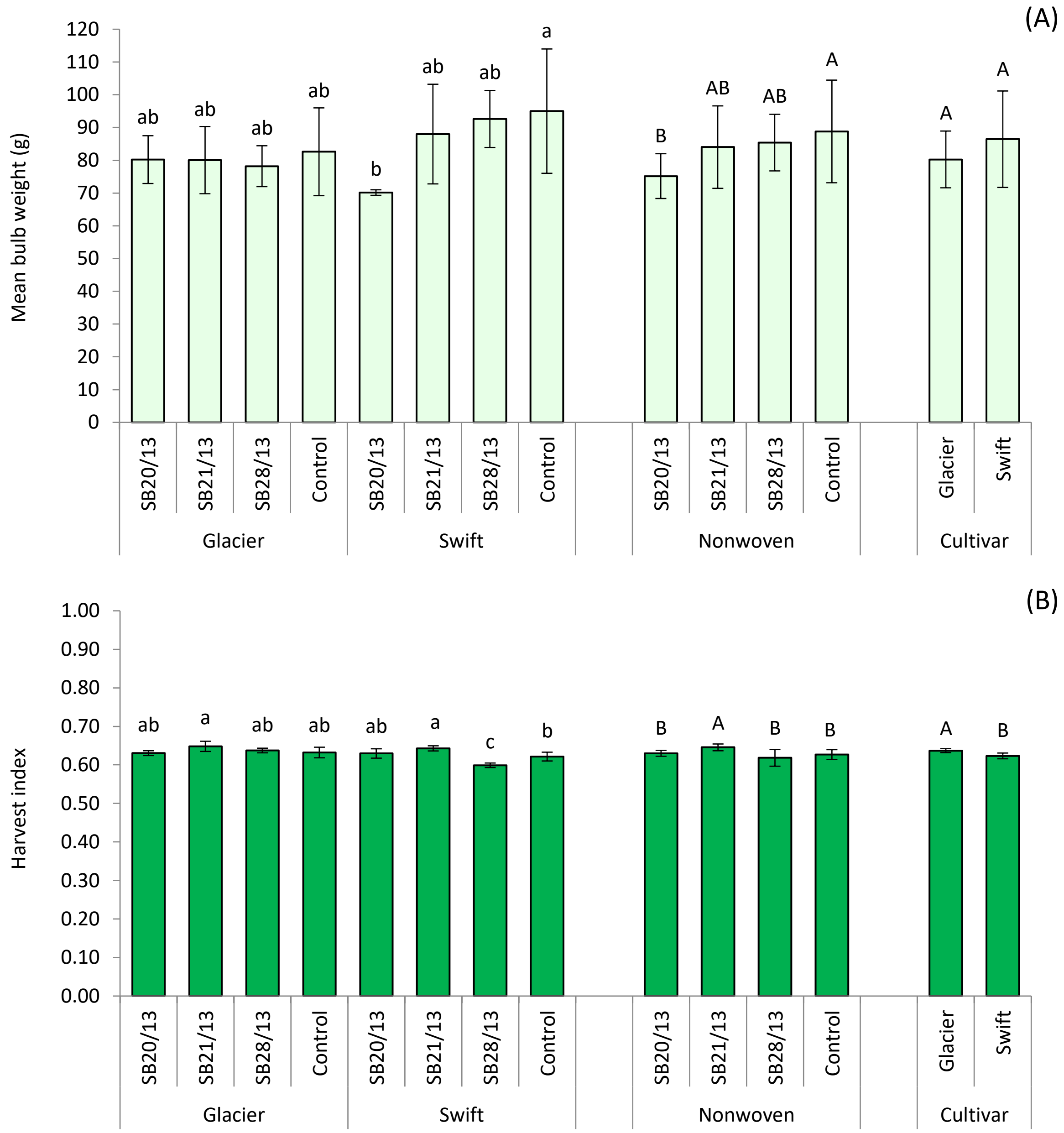

Figure 1. Mean weight of marketable bulb (A) and harvest index (B) of onions 'Glacier' and 'Swift' in the season 2013/2014 (experiment I) using different nonwoven covers (N) and cultivars (C). Means followed by different letters (capital letters for nonwoven or cultivar effects and lowercase letters for interaction effects, N × C) are significantly different according to Fisher's test at $p \leq 0.05$, n = 3. Error bars represent ± standard deviation (SD).

In cultivar 'Glacier', there was not a significant difference in the percentage of highest quality onion bulbs between the control and SB21/13 nonwoven (Figure 2A), however for 'Swift', in the same treatment a significantly higher yield of first quality bulbs was noted, surpassing the other experimental treatments. In 'Swift', plants covered with the control fabric had an 18% lower 1st grade bulb yield than those covered with the SB21/13 nonwoven (Figure 2B). This cover also ensured the lowest share of 2nd grade bulbs in 'Swift'. In the case of this cultivar, SB20/13 nonwoven induced a better quality structure of the total yield than in the control (10% more 1st grade bulbs). SB28/13 and control plants were comparable in their yield of non-marketable bulbs (around 31% of total yield). 'Glacier' plants had the lowest number of 2nd grade bulbs when covered by the control fabric, whereas the SB21/13 nonwoven lowered the yield of non-marketable bulbs.

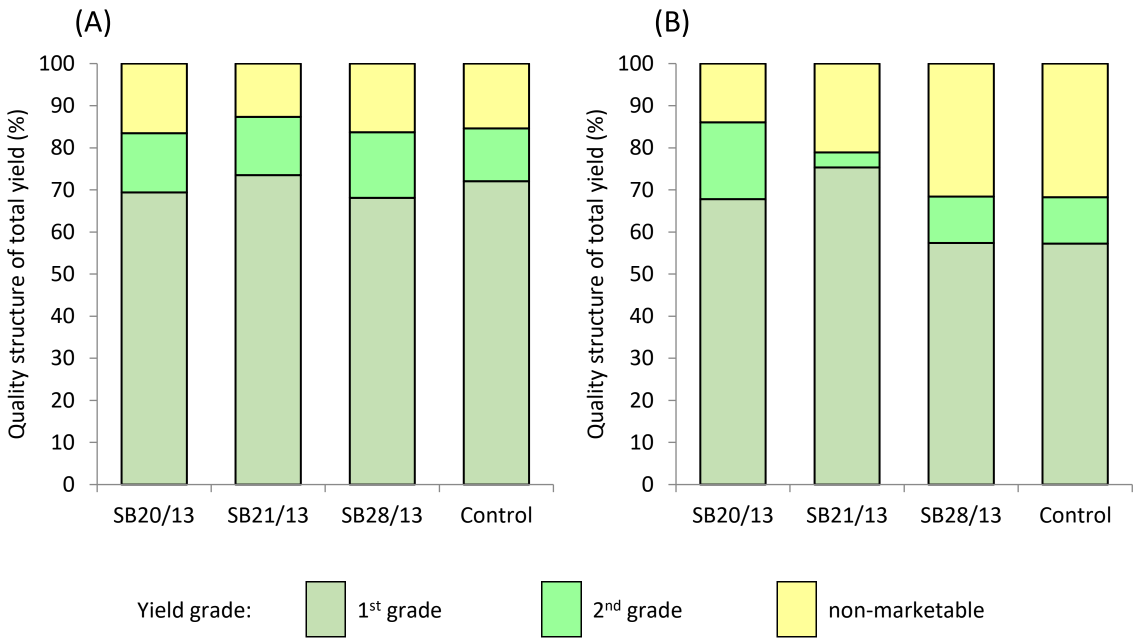

Figure 2. Quality structure of total yield in onion cultivars, 'Glacier' (A) and 'Swift' (B), for the season 2013/2014 (experiment I) based on nonwoven type.

Bulbs of the plants covered with SB21/13 had a lower dry weight (by 3.2-3.7%) than the other treatments (Table 3). 'Swift' cultivar had a higher dry weight than 'Glacier'. The interaction between nonwoven type and cultivar was significant; the lowest dry weight was noted for 'Glacier' covered with SB21/13 and the highest was found in 'Swift' under SB28/13. In the cultivar 'Swift', no significant effect of nonwoven cover on dry weight was observed. The lowest total sugar content in bulbs was measured in control onions, but it was only significantly different from the SB20/13 cover (which had 10.6% more sugar). 'Glacier' bulbs had a higher total sugar content than 'Swift'. In both cultivars, most of the treatments had a similar total sugar content. However, 'Glacier' plants covered with SB20/13 formed bulbs with the highest concentration of these constituents. Bulbs collected from plots with the SB28/13 cover had a lower L-ascorbic acid level by 6.3% than those in control plots and those under nonwovens SB20/13 and SB21/13 (by 10.3 and 7.5%, respectively). Bulbs from plots covered with SB20/13 had more L-ascorbic acid by 4.4% than those covered by the control. 'Swift' cultivar had a higher concentration of L-ascorbic acid than 'Glacier' bulbs. A significant interaction between nonwoven type and cultivar caused the lowest L-ascorbic acid concentration in bulbs of both onion cultivars covered with SB28/13.

Table 3. Effect of nonwoven covers on dry weight, total sugar, and L-ascorbic acid content in the bulbs of onion cultivars, 'Glacier' and 'Swift', in the season 2013/2014 (experiment I).

Source of variation		Dry weight (% FW)	Total sugars (% FW)	L-ascorbic acid (mg 100 g^{-1} FW)
Cultivar				
Glacier		10.44 ± 0.32 B	3.03 ± 0.35 A	21.64 ± 1.19 B
Swift		11.42 ± 0.16 A	2.73 ± 0.15 B	22.33 ± 1.10 A
Nonwoven type				
SB20/13		11.01 ± 0.42 A	3.04 ± 0.42 A	22.99 ± 0.59 A
SB21/13		10.65 ± 0.80 B	2.90 ± 0.40 AB	22.30 ± 1.20 AB
SB28/13		11.06 ± 0.55 A	2.84 ± 0.12 AB	20.63 ± 0.63 C
Control		11.00 ± 0.42 A	2.75 ± 0.09 B	22.02 ± 0.78 B
Cultivar	Nonwoven type			
Glacier	SB20/13	10.67 ± 0.03 c	3.41 ± 0.13 a	22.92 ± 0.83 a
	SB21/13	9.92 ± 0.07 d	3.12 ± 0.45 ab	21.53 ± 0.28 bc
	SB28/13	10.56 ± 0.07 c	2.81 ± 0.17 c	20.28 ± 0.72 d
	Control	10.62 ± 0.02 c	2.78 ± 0.11 c	21.81 ± 1.05 bc
Swift	SB20/13	11.35 ± 0.27 b	2.66 ± 0.17 c	23.06 ± 0.32 a
	SB21/13	11.38 ± 0.10 ab	2.67 ± 0.19 c	23.07 ± 1.32 a
	SB28/13	11.55 ± 0.07 a	2.86 ± 0.04 bc	20.97 ± 0.28 cd
	Control	11.38 ± 0.11 ab	2.72 ± 0.06 c	22.22 ± 0.45 ab

Mean values ± SD (n = 3). Within each column, values followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$: capital letters are referred to the main effects; lowercase letters to the interaction effect.

2.2. Experiment II (2014/2015)

There was a significant difference in 1st grade yield between control plants and plants covered with SB28/13 (Table 4). The yield and number of bulbs in onions covered by SB28/13 was higher by 47% and 64% than in the control, respectively. However, there was no significant effect of biodegradable covers on the total marketable or 2nd grade yield.

Table 4. Effect of nonwoven covers on marketable bulb yields of onion cultivar 'Swift' in the season 2014/2015 (experiment II).

Nonwoven type	Marketable yield (kg m^{-2})		
	1st grade	2nd grade	Total
SB20/13	1.08 ± 0.18 ab	0.57 ± 0.01 a	1.66 ± 0.18 a
SB21/13	1.20 ± 0.12 ab	0.78 ± 0.25 a	1.98 ± 0.35 a
SB28/13	1.38 ± 0.09 a	0.58 ± 0.05 a	1.96 ± 0.14 a
Control	0.94 ± 0.24 b	0.57 ± 0.17 a	1.51 ± 0.41 a
Nonwoven type	**Marketable yield (no. of bulbs m^{-2})**		
	1st grade	2nd grade	Total
SB20/13	28.44 ± 5.00 ab	23.33 ± 3.33 a	51.78 ± 8.34 a
SB21/13	23.56 ± 4.07 b	28.44 ± 7.19 a	52.00 ± 8.08 a
SB28/13	34.00 ± 4.67 a	33.33 ± 6.67 a	67.33 ± 11.33 a
Control	20.67 ± 6.00 b	28.44 ± 11.67 a	49.11 ± 17.67 a

Mean values ± SD (n = 3). Values within a column followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$.

The highest mean bulb weight was obtained from plants covered with the SB21/13 nonwoven and was 24% higher than that of the control (Figure 3A). SB20/13 and SB28/13 covers did not affect bulb weight in the 2014/2015 season. None of the nonwoven coverings caused a change in the harvest index when compared to control treatment (Figure 3B).

A significantly higher amount of 1st grade bulbs were harvested from plants covered with SB20/13 and SB28/13 than from the control (17.6% and 13.3%, respectively; Figure 4). The number of 1st grade bulbs were not significantly different from SB21/13 and control plots. All treatments did not significantly differ from each other in terms of number of 2nd grade bulbs (about 40%). Only 13–14% of bulbs harvested from plots covered with SB20/13 and SB28/13 were not marketable, whereas 24–28% of bulbs from plants covered with SB21/13 and the control were not suitable for market.

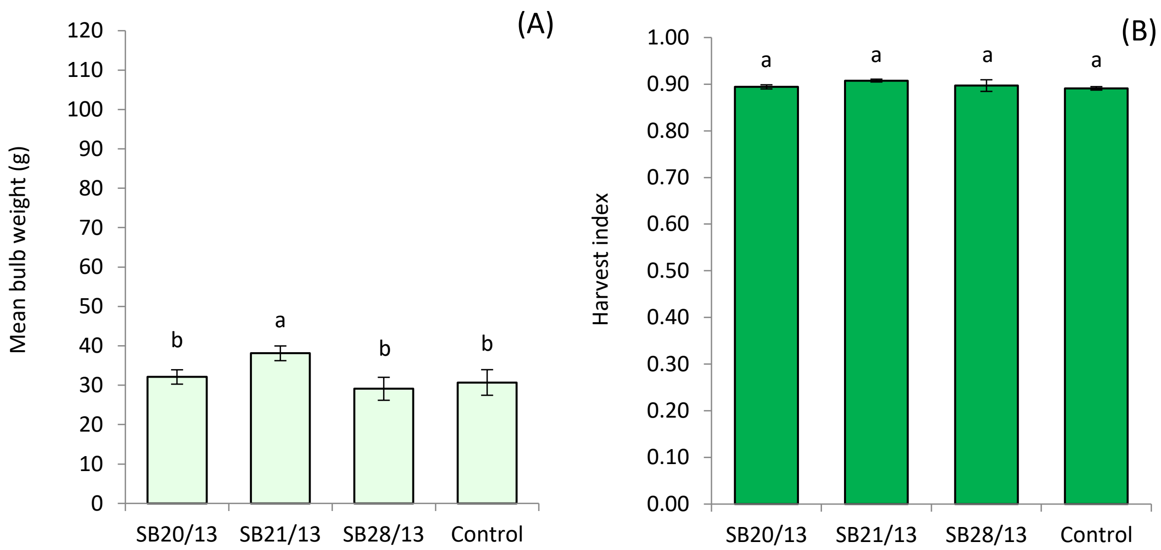

Figure 3. Mean weight of marketable bulb (A) and harvest index (B) of onion cultivar 'Swift' in the season 2014/2015 (experiment II) based on nonwoven type. Means followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$, n = 3. Error bars represent ± standard deviation (SD).

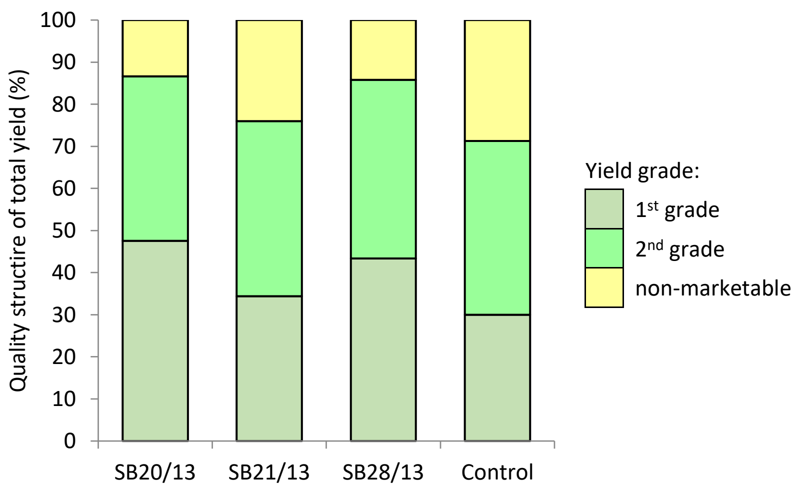

Figure 4. Quality structure of total yield in onion cultivar 'Swift' for the season 2014/2015 (experiment II) based on nonwoven type.

The dry weight of bulbs harvested from plots covered with SB28/13 and control plots was not significantly different from each other (Table 5). Covering with the SB20/13 and SB21/13 biodegradable nonwovens caused a significant decrease in dry weight, by 1.3-1.7%, respectively. All biodegradable nonwovens decreased the level of L-ascorbic acid content in the bulbs when compared to the control, a 15.6% reduction in SB21/13 up to a 22% reduction in SB20/13 covered plants.

Table 5. Effect of nonwoven covers on dry weight and L-ascorbic acid content in the bulbs of onion cultivar 'Swift' in the season 2014/2015 (experiment II).

Nonwoven type	Dry weight (% FW)	L-ascorbic acid (mg 100 g^{-1} FW)
SB20/13	9.34 ± 0.05 b	14.29 ± 0.66 b
SB21/13	9.30 ± 0.09 b	15.43 ± 1.98 b
SB28/13	9.55 ± 0.04 a	14.86 ± 1.63 b
Control	9.46 ± 0.03 a	18.29 ± 0.82 a

Mean values ± SD (n = 3). Values within a column followed by different letters are significantly different according to Fisher's test at $p \leq 0.05$.

4. Discussion

Introducing degradable polymers into horticultural production can reduce the risk of environmental pollution and lessen problems created by the disposal of oil-based polymeric materials. Such polymers have already been tested as mulches on many crops (including cucumber, zucchini, melon, lettuce, tomato, pepper, eggplant, leeks, and sweet corn) and have also been introduced into commercial production (Kasirajan and Ngouajio, 2012; Adhikari et al., 2016; Siwek et al., 2019). Research investigations on biodegradable nonwovens used as floating covers are uncommon (Kalisz et al., 2018). Due to the different physical and chemical properties of each nonwoven prototype, they must be tested under experimental conditions before being launched into commercial production on a large scale. The most important features required from these materials are: ensuring yield not significantly different from that of non-degradable covers, no adverse effects on the chemical composition of vegetable crops, creating optimal thermal and humidity conditions around the plant surroundings, mechanical strength allowing the use of covers for a minimum of one production cycle, and complete biodegradability in compost soil.

In experiment I, we observed an increase in marketable yield in comparison to the control as an effect of covering onion plants with the SB21/13 nonwoven. An increase in 1st grade yield was observed in the 'Swift' and 'Glacier' cultivars under the SB21/13 nonwoven. Similarly, 'Glacier' had a higher total marketable yield than the control when under the SB21/13 covering. In experiment II, there was no significant effect of biodegradable nonwovens on total marketable yield, but 1st grade yield increased when the SB28/13 covering was used. Nonwoven covers protect overwintering plants against frost and modify the microclimate in plant surroundings contributing to a more favorable environment (temperature, humidity) for plant growth and development than in open field (Olle and Bender, 2010). Microclimate under covers depends on the physical properties specific to each of the nonwovens, hence they may affect the microclimate differently, causing some differences in crop yielding. Kalisz et al. (2019) tested the same types of polymeric materials as used in our present experiment for physical properties, PAR permeability and air temperature under cover compared to PP nonwoven. They found that PAR transmission under biodegradable covers was lower by around 30% compared to polypropylene nonwoven, but minimum temperature under biopolymers was higher by 0.6-0.8 °C. In particular, better protection against low temperatures is important when carrying out winter production, because onions not protected by covers, especially during snowless winters, easily freeze. Lower PAR transmission of the biodegradable covers did not seem to be so important in that case, as plants had significantly slowed down their metabolism during late autumn and winter. All biodegradable covers had higher mass per unit area (74.2-81.9 g m^{-1}) and were thicker than control nonwoven (mass per unit area: 50 g m^{-2}) which contributed to better protection of plants against winter temperatures. Biopolymer SB20/13 gave similar yield to the control, but this was due to the tendency to crumble onions on plots covered with this non-woven fabric (as observed in experiment I). Our findings showed that prototype degradable covers, even those made of AAC with an additional modifier from plant biomass (corn starch), did not affect onion plants adversely and they even have the potential to increase yield. Conversely, Siwek et al. (2013) did not show significant differences in the marketable yield of 'Glacier' in winter production, when plants were covered with AAC covers (50 and 75 g m^{-2}) and compared to polypropylene nonwoven covers. In another experiment on lettuce, Siwek et al. (2012) found an increase in marketable yield of plants covered with AAC nonwovens in one experimental year and no effect in the next one. Materials similar to the one used in our present study have also been tested as direct covers in radish cultivation (Kalisz et al., 2019). The biodegradable covers decreased radish yield in the spring, but in autumn, the marketable yield was comparable to that of the control. Our results indicate the need to choose an appropriate period of use for specific type of cover, which are characterized by a high unit weight and, thus, are well suited to cover plants in winter. For spring crops, which grow intensively and are more delicate than autumn and winter crops, these covers are less advantageous.

Covering onion plants with biodegradable materials had an effect on the content of nutritional components in the bulbs. Particularly, L-ascorbic acid and total sugar content were increased in the onions of experiment I covered with nonwoven fabric SB20/13, which is a beneficial effect of covering with this material. However, when in experiment II plants were covered with SB20/13 and SB21/13, dry weight decreased. Moreover, all biodegradable covers also decreased L-ascorbic acid content and this indicates an adverse effect of these biomaterials on biological value of onion plants. Data from experiments on radish (Kalisz et al., 2019) showed that the SB20/13 cover contributed to an increase in L-ascorbic acid and total sugar content. Conversely, polymeric materials made of AAC have shown inconsistent effects on dry weight in radish (Kalisz et al., 2019) and butterhead lettuce (Siwek et al., 2012). As reported by Siwek et al. (2013) in bulbs of 'Glacier' cultivar, the concentration of vitamin C, soluble sugar, and dry weight were not significantly different or decreased after covering with AAC nonwovens (namely IBWCh) compared to commercial polypropylene nonwoven (Agrotextile). PP nonwoven covers can change the chemical composition of plants, but usually their effect is compared to plants grown in the open field, and not with other types of floating covers (Olle and Bender, 2010). This creates some difficulties in interpreting the results of our experiment. In our opinion, some of the differences observed in the content of constituents in plants grown under biodegradable covers can be associated with specific microclimatic conditions under a particular cover, which could cause some permanent changes in plant growth after covering. It could also cause changes in some metabolic processes occurring in plants and then in the chemical composition of onions.

5. Conclusions

We recorded a similar and in some cases higher yield of plants covered with the tested biodegradable nonwovens when compared to the control. Our findings indicate the possibility of using prototype polymers in field crop production, instead of polypropylene nonwovens. The impact of biodegradable covers is, however, closely dependent on the climatic conditions, which was proven by the affect the results obtained in the two experiments. The adverse effect of covering onion plants with biodegradable covers was observed with some coverings; in addition to increasing the nutritional value of onions, the reduction in the content of some compounds (e.g. L-ascorbic acid) was also noted. It is necessary to continue research in this area to select the type of polymer best suited for further improvement and implementation in horticultural practices.

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