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Characterisation of Two Direct Covers Made of PP and HDPE in the Organic Production of Zucchini

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Abstract
The aim of the research conducted in 2016-2018 at the University of Agriculture in Krakow was to assess the effect of the direct covering of 'Partenon' F1 zucchini plants with polypropylene nonwoven fabric (PP 20 g/m^{-2}) and polyethylene netting (HDPE 38 g/m^{-2}). While the covers were in place, measurements of environmental factors were taken. The air temperature and humidity during that period were on average by 2.1 °C and 13% and by 1.4 °C and 7.9% higher on the plots covered with the nonwoven and the net, respectively, compared to the control. Uncovered plants formed the smallest number of leaves and produced the lowest marketable yield. Weed infestation was greater on the plots with the covers by 43% and 56% for the HDPE net and the PP nonwoven, respectively, compared to the control. Laboratory analyses of the zucchini fruit did not show any significant differences in its chemical composition.

Key words: *Cucurbita pepo L. convar. giromontina Greb., direct covers, agrotextiles, yield, fruit chemical composition, weed infestation.*

Introduction

Intensive agriculture based on the use of plastics is nearly 70 years old. From the early 1950s to 2017, the world's production of plastics increased by 22.233% [1]. Along with mulching the soil around plants, cultivation under cover is one of the fastest growing branches of horticulture due to independence from external conditions and the possibility of production almost all year round. According to the available government statistical references, updated to January 2018, the global protected agriculture vegetable area that includes mulches, row covers, greenhouses, and any type of method or structure used to extend the growing season of plants is 3.414.353 ha [2]. It is estimated that the area of vegetables cultivated under direct cover in Poland in 2018 was 7.000 ha. Agriculture based on the use of plastics makes it possible to obtain higher yields of better-quality crops compared to traditional methods, and to reduce the use of pesticides and water. Despite environmental pollution, it has become, due to its versatile applications, an inseparable element of the food economy in many countries in a relatively short time and is still gaining importance in the era of limited agricultural land. An alternative to permanent supporting structures is the direct covering of plants, which is cheaper and less troublesome to implement [3, 4]. The basic properties of agrotextiles that have allowed them to be widely used are, among others, strength, porosity, and resistance to sunlight and harsh environmental conditions [5]. Direct (flat) covering stabilises the temperature around the plants, protects them from overheating, excessive transpiration, wind, hail, and heavy rain, and reduces ground-level frosts. Improvement of the microclimate also affects the duration of seedling adaptation and the capacity and rate of seed germination [6, 7]. However, the improved conditions also favour weed infestation, which can be several times greater. Weeds with higher thermal requirements may emerge and develop earlier, e.g. *Echinochloa crus-galli* L. and *Galinsoga parviflora* Cav. [8].

In Poland, accelerated cultivation of vegetables under direct covers in the spring is widespread. In the years of a rapidly changing climate, there has been a decline in interest in perforated 50 µ thick foil covers with 100-500 holes, under which the microclimate is subject to large fluctuations, and the crop plants become overdelicate and susceptible to unfavourable conditions after the covers are removed. Currently, polypropylene (PP) nonwovens are most often used for this purpose, one of the best features of which is their low weight (17-23 g m^{-2}) and high airiness. Moreover, their surface mass is on average 2.5 times lower than that of perforated foil, so that it does not hinder the development of plants [9-11]. The layers of polypropylene fibres have a low structural strength. Under the influence of UV radiation, the bonds between the fibres are broken, which leads, inter alia, to an increase in the air and water vapour permeability of nonwovens [12]. Compared to netting, nonwoven fabrics, especially heavy ones, are rapidly destroyed by long-lasting strong winds [13]. Uniform environmental conditions also prevail under nets, most often made of rigid high-density polyethylene (HDPE). They are made of threads joined together to form a regular and porous knitted and woven structure. Knitted nets are obtained by the method of warp knitting with raschel machines. Nets produced by the techniques of making openwork warp-knitted fabrics with an openwork weave and openwork-weft weave are characterised by high durability and preservation of the mesh structure. Fixing them with UV stabilisers increases their resistance to degradation by ultraviolet radiation, ensuring their durability to 5-6 years in a mild climate (e.g. Mediterranean). They are used, for example, in greenhouses and tunnels, as well as in orchards and vineyards as shade cloths and protection against pests and hail. Their colour depends on that of the pigment used. Transparent nets are characterised by the highest light transmission and are recommended for crops that do not require shading [14, 15]. Among coloured nets with a shading coefficient of 30%, the highest PPFD (400-700 nm) transmittance values have been recorded for red and blue nets [16]. After colour, the second most important factor affecting permeability is porosity. Plastic netting can be regarded as a translucent material with equivalent optical parameters (refractive and absorption indices) [17]. At present, a lot of emphasis is put on the production and use of biodegradable plastics in agriculture [11], but this does not apply to nets. The need for new and advanced technologies to develop biodegradable plastic nets, free of plasticisers, was postulated by Maraveas [18], pointing to the electrospinning technique as a method enabling their introduction into circulation.

Zucchini plants, like those of cucumber, positively respond to the improvement in environmental conditions resulting from the influence of covers made of polymer materials. Optimisation of the microclimate accelerates their growth and development, which is favourable to obtaining a higher, especially early, yield. The aim of the research was to evaluate the physical properties of covers and the response of zucchini plants (*Cucurbita pepo* L. convar. *giromontina* Greb.) as a result of using two direct covers in the form of PP nonwoven fabric and HDPE netting.

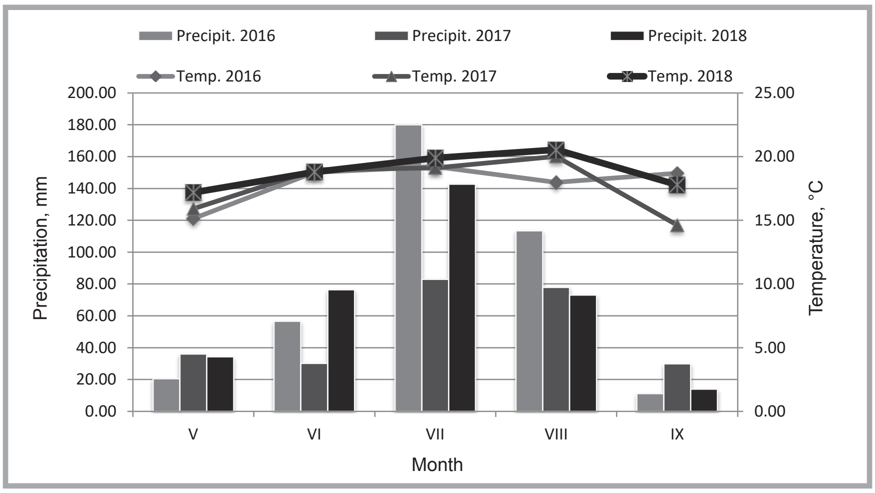

***Figure 1.** Weather conditions over the course of the study.*

Materials and methods

Experimental site

The experiments were carried out during the years 2016-2018 at the Experimental Station of the University of Agriculture in Krakow, south Poland (N 51°13', E 22°38'). The climate of the Experimental Station is humid continental (Dfb) according to Köppen's classification [19]. The soil type is Fluvic Cambisol (Humic).

Experimental design and treatments

The experimental material consisted of two types of direct covers: PP nonwoven (20 g m^{-2}) and a transparent knitted net with triangular holes, 4.9 × 1.5 × 5.1 mm, made of UV-stabilised HDPE (38 g m^{-2}). They were used to cover zucchini seedlings (produced in a standard way) of the cultivar 'Partenon' F1 (HILD Samen) immediately after planting in the second half of May (16 May 2016, 18 May 2017, and 15 May 2018). The experiment was set up in a split-block design with 4 replications. Each experimental plot included 32 plants planted at a distance of 100 × 80 × 100 cm. Plants not covered with the synthetic materials served as the control. The covers were removed on 6 June 2016, 10 June 2017, and 7 June 2018, before the first harvest. The fruit were harvested three times a week, every other day, and divided into 3 size classes: 10-14 cm, 15-21 cm, and > 21 cm. The fruit harvesting periods were: 13 June – 12 September 2016, 10 June – 7 September 2017, and 7 June – 12 September 2018. The fruit collected in the first 1/3 of all the harvests was regarded as an early yield. Non-marketable fruit were not included in the total yield due to their incidental occurrence. The marketable yield was determined in accordance with Polish Standard PN-R-75541: UN/ECE FFY-41 [20] – healthy fruit of a regular shape, without disease symptoms, and no mechanical or pest damage.

Fertilisers and plant protection products meeting the requirements of organic farming were used in the experiment. The frequency and amount of water supplied depended on the distribution and amount of precipitation. The plants were weeded mechanically.

Agri-environmental conditions

The weather conditions (mean air temperature and total precipitation) during zucchini vegetation are presented in ***Figure 1*** based on data from the National Environmental Satellite (NOAA) (www.ncdc.noaa.gov) for the Kraków-Balice meteorological station. Throughout the experiment, hourly soil temperature measurements were performed from the transplantation date to the removal of covers date in each year at a depth of 10 cm using HOBO U12-001 autonomous sensors (Onset Comp. Corp., Bourne, MA, USA) placed vertically in the central part of each treatment plot. Daily soil temperatures were calculated, and the data then presented as mean daily temperatures. Other parameters measured each year (6 June 2016, 10 June 2017, 7 June 2018) included photosynthetically active radiation (PAR) (spectroradiometer LI-COR 189B, USA), the relative humidity of air (Hygromer A1, Rotronic Ag, Germany), and the CO_2 content of the air (Telaire 7001, Onset Comp. Corp., USA). In addition, soil moisture measurements (HH2 Moisture Meter, Delta-T Devices, England) were performed at the same depth in four replications on 6 June 2016, 26 July 2017, and 7 June 2018, on average 3 days after rainfall.

Zucchini growth indicators and weed assessment

Assessments of zucchini plant development were performed on 7 June 2016, 12 June 2017, and 2 June 2018, and included 12 randomly selected plants from each experimental treatment. The number of true leaves and that of male and female flowers (buds) were counted for each plant.

Weed infestation was assessed once in June (8 June 2016, 22 June 2017, and 14 June 2018) using the frame-weight method with a 25 × 25 cm frame in three randomly selected locations. The number of individual weed species and the total fresh biomass were estimated directly in the field.

Plant development and laboratory fruit analysis

Chemical analyses were performed on 17-18 cm long fruit. They were ov-

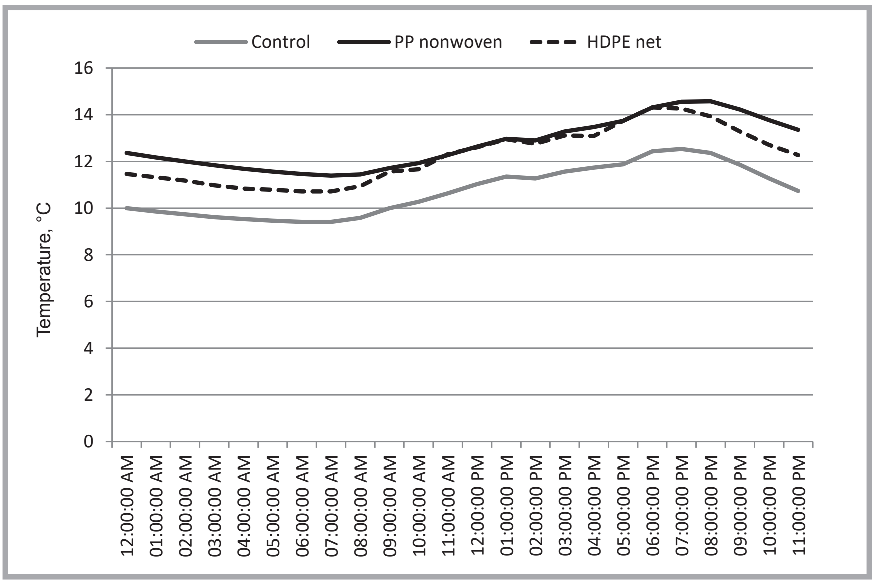

Figure 2. *Soil temperature during the coolest day of the experiment (18.05.2016).*

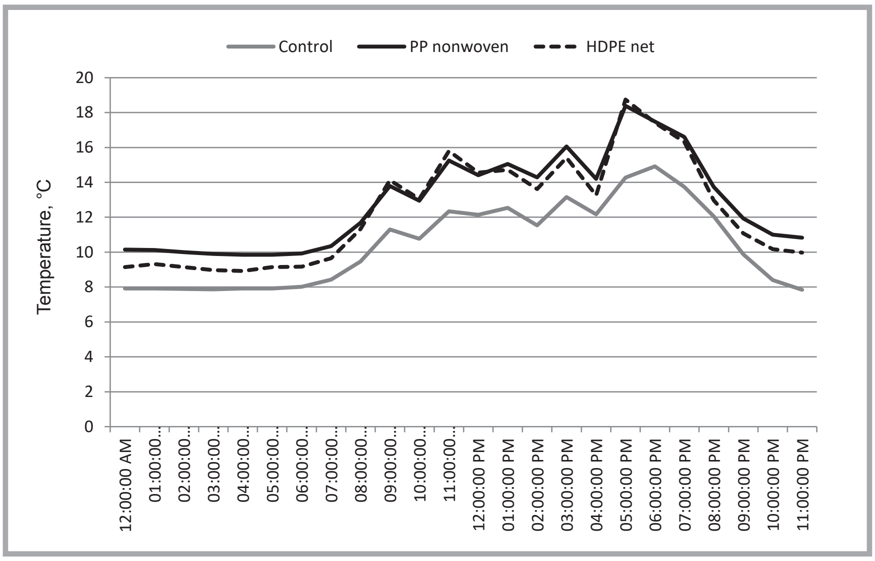

Figure 3. *Air temperature during the coolest day of the experiment (18.05.2016).*

en-dried at 65 °C, and the dry weight was measured with a laboratory balance (A120S, Sartorius AG, Goettingen, Germany). Soluble sugars were determined by the anthrone method after the extraction of plant material with 25 cm^3 of 80% ethanol. Absorbance was measured at 625 nm using a Helios Beta spectrophotometer (Thermo Fisher Scientific Inc., Waltham, USA). The total soluble sugar content was read from the calibration curve. Ascorbic acid content was determined by the Tillmans method. Plant extracts in 1% oxalic acid, after filtration and centrifugation, were titrated with Tillman's reagent (2,6-dichlorophenolindophenol). An excess of dye in an acidic environment produces a pink colour and marks the end point of the titration. The concentrations of chlorophylls (*a* and *b*) and carotenoids were determined using the peel of zucchini fruit to weigh out 0.5 g of plant material, which was ground with the addition of sand and magnesium carbonate. The pigments were extracted in 80% (v/v) aqueous acetone (25 cm^3), and after filtration the absorbance of the extracts was read at 470, 646, and 663 nm, respectively, using a Helios Beta UV-VIS spectrophotometer (Thermo Fisher Scientific Inc., USA). Phenolic compounds were extracted from plant tissues with 80% methanol solutions. Then a 2% Na_2CO_3 solution and F-C reagent were added. The reaction results in a blue compound that produces maximum absorption at 750 nm. The absorption intensity at this wavelength is proportional to the amount of phenolic compounds in the sample.

Antioxidant activity (AA) was measured using 2,2-diphenyl-1-picrylhydrazyl (DPPH). Plant material was mixed with 80% methanol. The DPPH changed the violet colour to yellow, and the decrease in absorbance over time was measured with a UV-VIS Helios Beta spectrophotometer at 517 nm relative to the reference solution. Antioxidative activity was expressed as the percentage of residual DPPH not reduced by the antioxidants contained in the sample.

Statistical analysis

The results were statistically analysed by one-way ANOVA. The significance of differences was determined by the Tukey test at the significance level of p = 0.05. All statistical analyses were performed using STATISTICA 13.3**.**

Results and discussion

Meteorological and microclimatic conditions

More favourable meteorological conditions prevailed in 2017 and 2018 than in 2016 (***Figure 1***). In 2016, the zucchini plants, after being planted permanently, were exposed to cooler weather with less rainfall. In addition, in July and August of the same year, a total of almost 300 mm of rain was recorded, and the mean temperature in August was only 18.0 °C, which was over 2 °C lower than in the following years. The year 2017 was warm, but with the least amount of precipitation, while 2018 was exceptionally warm and humid, especially in the spring and early summer.

For the example of the coolest day, soil temperature analysis showed that, regardless of the type of material used, the soil temperature in the hottest period (between 10 AM to 6 PM) under covered objects was on average 1.6 °C higher than in the control group (***Figure 2***).

The temperature of air at the same hours were 2.69 °C and 2.53 °C higher, respectively, under PP nonwoven and a HDPE net compared to non-covered objects (***Figure 3***). At 5 PM was recorded the highest air temperature under covered plots (medium 18.6 °C). During other hours, it was warmer under PP nonwoven than a HDPE net.

The mean values for the 3 years of the study indicate that both the soil and air temperatures in the protected plots were

1.75 °C higher than in the uncovered field (***Table 1***). The most favourable conditions for the plants were under the PP nonwoven fabric, under which the soil and air temperatures were 2.2 °C and 2.1 °C higher, respectively, than in the control. Increases in the temperature of soil (0.1 °C) and air (3 °C) on covered plots had also been reported by Gordon et al. [21]. A slightly lower temperature was recorded under the HDPE net (an increase by 0.5-2.5 °C). The temperature values for the covered plots in 2017 were similar. The analysis of data obtained from sensors shows that the increase in temperature under the plastic covers was particularly pronounced during cold periods, which was confirmed in a review by Wadas [10] on potato cultivation for early harvest. Mean soil temperatures at a depth of 10 cm in early spring cultivation of butter lettuce under PP nonwoven (20 g m^2) were 0.8 °C and 3.6 °C higher in a warm year and in a cool and humid year, respectively, compared to the control, as found by Siwek et al. [22], and depended also on the thermal insulation of the material. Technical analyses showed that the physical properties of nonwovens are strongly correlated with thermal parameters. With the increase in mass, air permeability significantly decreases, and thermal diffusivity is proportional to the weight attributed to the volume fraction of fibres in the nonwoven fabric [23].

Table 1. *Mean soil and air temperatures in zucchini cultivation with floating row covers from the time of planting seedlings until the removal of the direct covers.*

Year	Type of cover	Soil temperature, °C	Air temperature, °C
2016	Control	18.1	19.2
	PP nonwoven	20.9	22.5
	HDPE net	20.1	21.7
2017	Control	–	20.9
	PP nonwoven	21.9	21.8
	HDPE net	21.6	22.0
2018	Control	22.4	23.6
	PP nonwoven	24.0	25.8
	HDPE net	23.0	24.1

Table 2. *Microclimatic conditions in zucchini cultivation under floating row covers in 2016-2018.*

Year	Type of cover	PAR, μmol m^{-2} s^{-1}	Air humidity, %	CO_2, ppm	Soil moisture, %
2016	Control	3014	21.8	434	21.2
	PP nonwoven	2675	42.3	437	20.4
	HDPE net	2738	42	436	21.9
2017	Control	589	54.3	450	16.4
	PP nonwoven	235	67.7	528	15.0
	HDPE net	268	59.3	475	17.6
2018	Control	2521	27.3	413	14.7
	PP nonwoven	1791	33.4	419	12.2
	HDPE net	1783	25.8	406	13.4

The transmission of PAR radiation (400-700 nm) varied markedly between the control plot and the covered plots (***Table 2***). The HDPE net transmitted more solar radiation than the nonwoven fabric, but the differences were not significant. The plastic covers had an average transmission of 90% on a sunny day (2016), 43% on a cloudy day (2017), and 71% in 2018. In another experiment, the same nonwoven fabric had transmitted 83% of PAR radiation [24]. The results obtained did not differ significantly from the transmission of thin nonwovens made of PP, photodegradable (0.02%) PP, and PLA with a surface weight of 20 g/m^{-2}, for which the estimated range was 74.5-83.4% [25]. In an experiment conducted in Spain, a PP nonwoven (17 g/m^{-2}) produced by the spun-bonded method transmitted from 85 to 65% of PPFD (Photosynthetic Photon Flux Density) depending on the amount of dust covering it and condensation of water vapour on the underside facing the plants [26]. In the first year of the study, in sunny and warm weather, air humidity under the covers was almost twice as high as in the control plot. In the following years, similar values were recorded under the net and in the open field, while air humidity under the nonwoven fabric was 13.4% and 6.1% higher than in the control. Other studies indicated an increase in soil temperature at a depth of 5 cm of 5.1 °C and in air humidity of 5.1% on average, as well as a reduction in the radiation reaching plants of 13% as a result of covering with PP nonwoven fabric (17 g/m^{-2}) and perforated foil (500 holes per 1 m^{-2}) [27].

The levels of CO_2 in the air around the plants in 2016 and 2018 were similar on all the plots and did not depend on the type of cover. In 2017, a higher level of this compound was recorded under both covers, with as much as 78 ppm more of it under the PP nonwoven than on the control plot. In 2016, soil moisture on each experimental plot exceeded 20%. Covering with the HDPE net was found to have a beneficial effect on soil water accumulation in 2016 and 2017 (increase of 0.7 and 1.2%). The soil in the treatment with PP nonwoven fabric was less moist by 0.8-2.5%, which may have been caused by water retention on polypropylene fibres, especially during periods with low amounts of low-intensity precipitation.

Table 3. *Growth indicators of zucchini plants cultivated under floating row covers in 2016-2018.* ***Note:*** ** – mean separation by one-way analysis, Tukey's test at p = 0.05. Means followed by the same letter within a column are not significantly different.*

Type of cover	Number of leaves				Number of female flowers (buds)				Number of male flowers (buds)			
	2016	2017	2018	Means for treatments	2016	2017	2018	Means for treatments	2016	2017	2018	Means for treatments
Control	7.9 a*	9.7 a	9.6 a	9.1 A	3.4 a	5.0 a	4.3 a	4.2 A	5.9 a	7.3 a	4.9 a	6.0 A
PP nonwoven	11.8 c	14.1 c	12.9 c	12.9 C	4.6 a	5.5 ab	5.3 ab	5.1 A	5.9 a	10.7 b	5.5 a	7.7 A
HDPE net	9.4 b	12.8 b	12.1 b	11.4 B	3.4 a	6.9 b	5.9 b	5.4 A	6.9 b	9.3 ab	5.8 a	7.0 A
Mean for years	9.7 A	12.2 B	11.5 B		3.8 A	5.8 B	5.2 B		6.2 A	9.1 B	5.4 A	

Table 4. Weed infestation [g] in dependence on different soil cultivation methods in zucchini production. ***Note:*** ** – mean separation by one-way analysis, Tukey's test at p = 0.05. Means followed by the same letter within a column are not significantly different.*

Type of cover	Weed infestation, g			
	2016	2017	2018	Mean for treatments
Control	235 a*	52 a	32.7 a	107 A
PP nonwoven	250 a	184 a	67.3 a	167 A
HDPE net	275 a	118 a	67.7 a	153 A
Mean for years	253 B	118 A	56 A	

Zucchini plant growth and weed infestation under direct covers

As a result of covering zucchini plants, a clear acceleration in growth in the form of a greater number of leaves was recorded in all the years of the study (***Table 3***). The plants growing under the PP nonwoven had the most leaves (12.9), regardless of the year. Vegetables with a short growing season, covered with PP nonwovens, are characterised by a higher leaf area index (LAI) and a greater production of thinner leaves, which contributes to an improvement in the quality of leaf vegetables [26]. The use of covers had resulted in faster growth of summer squash plants; however, they had a smaller shoot diameter [21]. Anyszka and Dobrzański [28], in turn, noted a positive effect of covering with PP nonwoven fabric on the size and mass of the first true leaf of head cabbage. The zucchini plants growing under the two covers also had more male and female buds, but these differences were not confirmed statistically in the mean values for the years. The largest number of female flowers were produced by the zucchini plants under the HDPE net: 6.9 (2017). The same cover significantly contributed to the formation of more male flowers in 2016 (6.9). The highest values determining the phenological state of plants were recorded in 2017 (especially for the number of male flowers), which was caused by a later time of observation than in the other years. According to Zawiska and Siwek [29], cucumber plants under biodegradable covers produce longer roots.

In the consecutive years of the experiment, weed infestation decreased from 253 g (2016), to 118 g (2017), and to 56 g in 2018 ***(Table 4)***. Similar levels of weed biomass in the experimental plots were estimated in 2016 (235-275 g). However, there were no statistically significant differences between the treatments in any of the years. Weed infestation increased by 43% and 56% for the HDPE net and PP nonwoven, respectively, compared to the control. The weeds were dominated by thermophilic species (*Galinsoga* sp., *Echinochloa crus-galli* L., *Amaranthus retroflexus* L.) and dicotyledonous weeds emerging in early spring (*Chenopodium album* L., *Capsella bursa-pastoris* (L.) Medik. and *Thlaspi arvense* L.) (data not shown). The results obtained confirm the correctness of the statements made in this respect by other authors [8, 28].

Zucchini crop yield and quality

In 2017 and 2018, the total marketable yield was 85% and 70% higher than in

Table 5. Effect of using direct covers on early and marketable yields of zucchini [t ha^{-1}], and on the dry matter content in fruit [%]. ***Note:*** ** – mean separation by one-way analysis, Tukey's test at p = 0.05. Means followed by the same letter within a column are not significantly different.*

Type of cover	Early yield, t ha^{-1}				Total marketable yield, t ha^{-1}				Dry mass, %			
	2016	2017	2018	Mean for treatments	2016	2017	2018	Mean for treatments	2016	2017	2018	Mean for treatments
Control	30.8 a*	24.6 a	22.1 a	25.8 A	66 a	138 a	95.7 a	99.8 A	5.29 a*	6.02 c	5.67 a	5.66 A
PP nonwoven	40.2 b	26.9 ab	28.6 b	32 B	80.6 b	144 a	148 b	124.1 A	5.50 b	5.90 b	6.15 c	5.85 A
HDPE net	41.5 b	30.7 b	33.2 c	35.2 B	82 b	141 a	147 b	123.3 A	5.65 c	5.59 a	5.94 b	5.73 A
Mean for years	37.5 B	27.4 A	28.0 A		76.2 A	141 B	130 B		5.48 A	5.84 B	5.92 B	

Table 6. Chemical composition of zucchini fruit cultivated under floating row covers. ***Note:*** ** – mean separation by one-way analysis, Tukey's test at p = 0.05. Means followed by the same letter within a column are not significantly different.*

Type of cover	Ascorbic acid, mg 100 g^{-1} FW			Mean for treatments	Total phenols, mg 100 g^{-1} FW			Mean for treatments	Sugars, % of FW			Mean for treatments
	2016	2017	2018		2016	2017	2018		2016	2017	2018	
Control	12.6 a*	24.5 a	26.8 a	21.3 A	62.9 a	67.7 a	80.1 a	70.3 A	2.50 b	2.12 a	1.73 a	2.12 A
PP nonwoven	17.5 b	24.5 a	32.3 b	25.5 A	80.6 b	67.4 a	74.3 a	74.1 AB	2.20 a	1.90 a	1.82 b	1.97 A
HDPE net	18.8 b	24.5 a	34.4 c	25.2 A	77.7 b	68.5 a	91.0 b	79.1 B	2.39 ab	1.98 a	1.81 b	2.06 A
Mean for years	16.3 A	24.5 B	31.2 C		73.7 A	67.9 A	81.8 B		2.36 C	2.0 B	1.79 A	

Table 7. Chemical composition of zucchini fruit cultivated under floating row covers. ***Note:*** ** – mean separation by one-way analysis, Tukey's test at p = 0.05. Means followed by the same letter within a column are not significantly different.*

Type of cover	Karotenoids, µg g^{-1} FW			Mean for treatments	Chlorophyls *a* and *b*, µg g^{-1} FW			Mean for treatments	Antioxidant activity, %			Mean for treatments
	2016	2017	2018		2016	2017	2018		2016	2017	2018	
Control	30.7 a*	39.0 ab	31.1 c	33.6 A	143 a	142 a	124 c	136 A	2.60 a	1.38 a	4.17 a	2.72 A
PP nonwoven	40.4 b	41.9 b	21.2 a	34.5 A	141 a	167 b	74,1 a	128 A	3.12 b	1.19 a	5.67 c	3.33 A
HDPE net	31.9 ab	36.3 a	27.4 b	31.9 A	112 a	144 a	108 b	121 A	2.53 a	1.79 a	5.10 b	3.14 A
Mean for years	34.3 B	39.1 C	26.5 A		132 B	151 B	102 A		2.75 B	1.45 A	5.0 C	

2016 (***Table 5***). The three-year average indicates an increase in the total marketable yield of approx. 24% as a result of plant covering; but this increase was not statistically confirmed. The highest fruits yield were harvested in 2018 from the plot with PP nonwoven (148 t ha^{-1}). A different correlation was noted for the early yield, which was the highest in the first year of the study (37.5 t ha^{-1} on average), compared to the others. The direct covers positively influenced the level of the early yield in all the years of the experiment. In this respect, the HDPE net proved to be a cover somewhat more effective than the PP nonwoven. Positive effects of covering with perforated foil (with 50, 100, and 500 holes per 1 m^{-2}) and PP nonwoven (17 g/m^{-2}) on yield were demonstrated in the cultivation of Chinese cabbages, kohlrabi, broad beans, and melons [27, 30-32]. Covering melon plants contributed to the obtaining of heavier and more elongated fruit [33].

On mulched plots and those covered directly with nonwoven fabric and perforated foil, the average early yield was 2.18 times higher and the total yield 16 t ha^{-1} higher in cucumber cultivation [34], while the early yield of zucchini increased by 47.9% [35].

The harvested zucchini fruit contained 5.29-6.15% dry matter (***Tables 5***). In 2016 and 2018 there was significantly more dry matter in the fruit from the covered plots than from the control. The fruit harvested in 2016 contained significantly more water and less ascorbic acid (***Table 6***). There were no differences between the treatments in terms of the concentration of the latter component in 2017. Increases in the accumulation of L-ascorbic acid were found in the successive years of the study (of 8.2 and 14.9 mg 100 g^{-1} FW on average). An inverse relationship was found for the amount of sugars, the highest level of which was in the zucchini fruit in 2016 (2.36% of FW), and the lowest in 2018 (1.79% of FW). The highest concentration of carotenoids in the fruit was recorded in 2017 (on average 39.1 μg g^{-1} FW) (***Table 7***). Their level varied between the treatments over the years. The concentrations of chlorophylls in 2016 and 2017 were comparable and higher than in 2018 (102 μg g^{-1} FW). The highest variation between the treatments was found in 2018 (74.1-124 μg g^{-1} FW). In the same year, the zucchini fruit were characterised by an antioxidant activity about three and a half times higher than in 2017 (1.45%) and nearly twice more than in 2016 (2.75%). The weather conditions in 2018 were favourable for the synthesis of phenolic compounds in zucchini fruit, which were observed to contain on average 81.8 mg 100 g^{-1} FW. Significantly greater amounts of phenols were found on the plot with HDPE netting than on the control plot. For the treatment with nonwoven fabric, intermediate values were recorded (74.1 mg 100 g^{-1} FW). Laboratory analyses of the fruit over the three years did not show any differences between the treatments in terms of the concentrations of components (except phenolic compounds). The significant differences in the chemical composition of the fruit between the treatments, although not reproducible over the years, suggest that the influence of the plant cover on the quality of the crop depends on the meteorological conditions. In another experiment with zucchini, fruit of similar length (16-22 cm) harvested from plants covered with PP nonwoven (17 g/m^{-2}) contained 22.3 mg vitamin C, 83 mg nitrates, 0.91% P, 6.4% K, and 1.20 mg 100 g^{-1} of dry matter [35]. According to Biesiada [30], flat covering of kohlrabi plants contributed to a decrease in the amounts of dry matter and sugars, but did not affect the concentration of vitamin C. By comparison, romaine lettuce covered with PP nonwovens (17 and 50 g/m^{-2}) accumulated less K and more Mg, without changes in the dry matter content, total N, Ca, or P [36]. As a result of covering melon plants with PP nonwoven and PE perforated foil, the melon fruit were characterised by a lower dry matter content than in the control, but contained more dry matter when the plants were simultaneously mulched with black PE foil. Moreover, using plant covers contributed to the accumulation of greater amounts of nitrates ($N\text{-}NO_3^-$ mg kg^{-1} FW) by 43 and 68% on the plots covered with foil and nonwoven fabric, respectively [37]. Kalisz et al. [24] showed that the use of degradable covers made of PP photo and PLA resulted in lower amounts of dry matter and soluble sugars in cucumbers, which was probably caused by rapid fruit growth. In the cultivation of the same species, biodegradable materials inhibited the accumulation of nitrates (NO_3^- mg kg^{-1} FW), while the three-year average showed that the amounts of dry matter and soluble sugars were comparable to those in the fruit from the control plot [29]. The same authors reported no differences in the concentrations of dry matter, soluble sugars, nitrates, chlorophylls and carotenoids in lettuce covered with nonwoven fabric and from the control [22].

Conclusions

1. The increase in air and soil temperatures as a result of direct covering is particularly evident in cool years. PP nonwoven fabric proved to be more effective in this respect than HDPE netting. Covering zucchini plants with these materials reduced the transmission of PAR reaching the plants.

2. The favourable microclimate conditions under flat covers contributed to faster growth of zucchini plants, mainly in the form of a greater number of leaves. The higher temperature promoted greater weed infestation.

3. Both types of cover significantly contributed to obtaining a higher early yield. The total yield from the plots covered with the nonwoven and the net increased on average by 24.3% and 23.5%, respectively.

4. Direct covering of zucchini plants at the initial stage of their development did not significantly affect the chemical composition of the fruit, except for the concentration of phenolic compounds. The content of these compounds increased as a result of covering the plants (especially the HDPE net).

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Conflict of interest

The authors declare no conflict of interest.

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