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Effects of Plant Covers and Mulching on the Biometric Parameters, Yield and Nutritional Value of Tomatillos (*Physalis ixocarpa* Brot. Ex Hornem.)

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Abstract: The aim of this study, which involved a field experiment conducted in north-eastern Poland, is to evaluate the phytometric parameters, yield, and biological value of fruit of three tomatillo cultivars grown in soil mulched with black PE (polyethylene) film and covered with PE film and non-woven PP (polypropylene) fabric. A two-factor field experiment was conducted in 2015 and 2017–2018 in the Agricultural Experiment Station owned by the University of Warmia and Mazury in Olsztyn. In the control treatment, tomatillo plants were grown without protective covers or mulch. Tomatillo fruits were harvested gradually, upon physiological maturity, which was determined based on changes in the color of the peel and calyx, and the aroma. The growth and development of tomatillos were evaluated based on plant measurements performed in the field. The chemical composition of tomatillo fruits was analyzed at the stage of full fruiting. During the three-year study, the weight, vertical diameter, and horizonal diameter of fruit were highest in cv. 'Rio Grande Verde' and lowest in cv. 'Purple'. The combined use of mulch and plant covers accelerated fruit ripening. The total and marketable yields of tomatillo fruit were highest in cv. 'Rio Grande Verde' and lowest in cv. 'Purple'. The fruit of cv. 'Purple' had the highest content of dry matter, total sugars, extract, β-carotene, and total polyphenols.

Keywords: temperature; yield; dry matter; total sugars; extract; β-carotene; polyphenols

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1. Introduction

According to Engels et al. [1], Robledo-Torres et al. [2], Ramírez-Godina et al. [3], Ramos-López et al. [4], and Ramos-López et al. [5], the tomatillo (*Physalis ixocarpa* Brot. ex Hornem.), also known as the Mexican husk tomato, is native to Mesoamerica where it was grown by the indigenous peoples before the arrival of Europeans. Tomatillos are widely cultivated and consumed in many regions of the world. However, tomatillos are not highly popular in Poland, despite their high nutritional value, a high content of biologically active components, and an attractive flavor, which is increasingly appreciated by consumers [6–9]. Tomatillo fruits regulate and improve digestion. Additionally, they are a source of bioactive substances that neutralize free radicals and slow down aging processes.

Tomatillos have high temperature requirements, and thus may be difficult to cultivate in Poland. Tomatillos are grown only amateurs. Protective covers (perforated PE film non-woven PP fabric) and soil mulching can effectively protect thermophilous vegetable species grown in the field against adverse environmental conditions [10,11]. Vegetable species respond differently to protective covers. Majkowska-Gadomska [11], Kaniszewski et al. [12], and Krzysztofik [13] found that plant covers had a beneficial influence on the productivity and quality of thermophilous vegetables. Both PE film and PP fabric help control the microclimate around plants, thus accelerating their growth and increasing yields. Non-woven PP fabric well adheres to plants and is water-permeable [14]. It is also lighter than PE film and does not deform plants or make them too vulnerable at the time of cover removal [15]. Mulching provides a physical barrier to evaporation, contributes to weed control and protects plants against soil contaminants. It also promotes more efficient nutrient utilization by plants and improves soil structure [16].

The following research hypotheses were tested in the present study:

- Tomatillo plants of the analyzed cultivars will respond differently to protective covers and soil mulching.
- Tomatillo plants of the analyzed cultivars grown in mulch and covered with PE film will be characterized by higher yields and quality of fruit, in comparison with the remaining treatments.
- The use of non-woven PP fabric and soil mulching will contribute to higher yields and the best quality of tomatillo fruit, in comparison with the remaining treatments.

The aim of this study, which involved a field experiment conducted in north-eastern Poland, was to evaluate the phytometric parameters, yield, and biological value of fruit of three tomatillo cultivars grown in soil mulched with black PE film and covered with PE film and non-woven PP fabric.

2. Materials and Methods

2.1. Study Sites and Experimental Factors

A two-factor field experiment was conducted in 2015 and 2017–2018 in the Agricultural Experiment Station owned by the University of Warmia and Mazury in Olsztyn. Tomatillo plants were grown in the Experimental Garden of the University of Warmia and Mazury in Olsztyn, located in the central part of Olsztyn Lakeland (125 m a.s.l) which belongs to the physiographic region of Eastern Baltic-Belorussian Lowland (20°45′ E, 53°75′ N). The area features two ground elevations with adjacent depressions, and it is surrounded by Lake Kortowskie (surface area: 0.9 km^2; maximum depth: 17.2 m) in the south. The plants were grown on typical loamy sand through the entire profile, classified as Haplic Cambisol (Eutric) according to WRB (2014) [17].

The experiment had a randomized block design with three replications. The first experimental factor was tomatillo cultivar (A):

- 'Purple': Plants reach a height of 1.2 m. Fruits are purple and should be harvested when the husk changes color from green to brown. Fruit weight is 20–40 g. Fruits are more pungent than green-colored tomatillos. Plants begin to bear fruit 70 days after seeding.
- 'Toma Verde': Plants reach a height of 2.0 m. Fruits are green should be harvested when the husk begins to crack. Fruit weight is 20–40 g. Fruits have a mild flavor. Plants begin to bear fruit 90 days after seeding.
- 'Rio Grande Verde': Plants reach a height of 2.0 m. Fruits are green and should be harvested when husk changes color from bright green to yellow-green. Fruit weight is around 60 g. Fruits have a mild, yet tart flavor. Plants begin to bear fruit 90 days after seeding.

The second experimental factor was the use of protective covers (B):

- Perforated PE film with 100 openings per m^2 for covering field beds (PE) (Figure 1a).
- Non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds (PP) (Figure 1b).
- Black PE film with a thickness of 0.05 mm for mulching (Mulching) (Figure 1c).
- Black PE film with a thickness of 0.05 mm for mulching + perforated PE film with 100 openings per m^2 for covering field bed (Mulching + PE) (Figure 1d).
- Black PE film with a thickness of 0.05 mm for mulching + non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds (Mulching + PP) (Figure 1e).

In the control treatment, tomatillo plants were grown without protective covers or mulch (C) (Figure 1f).

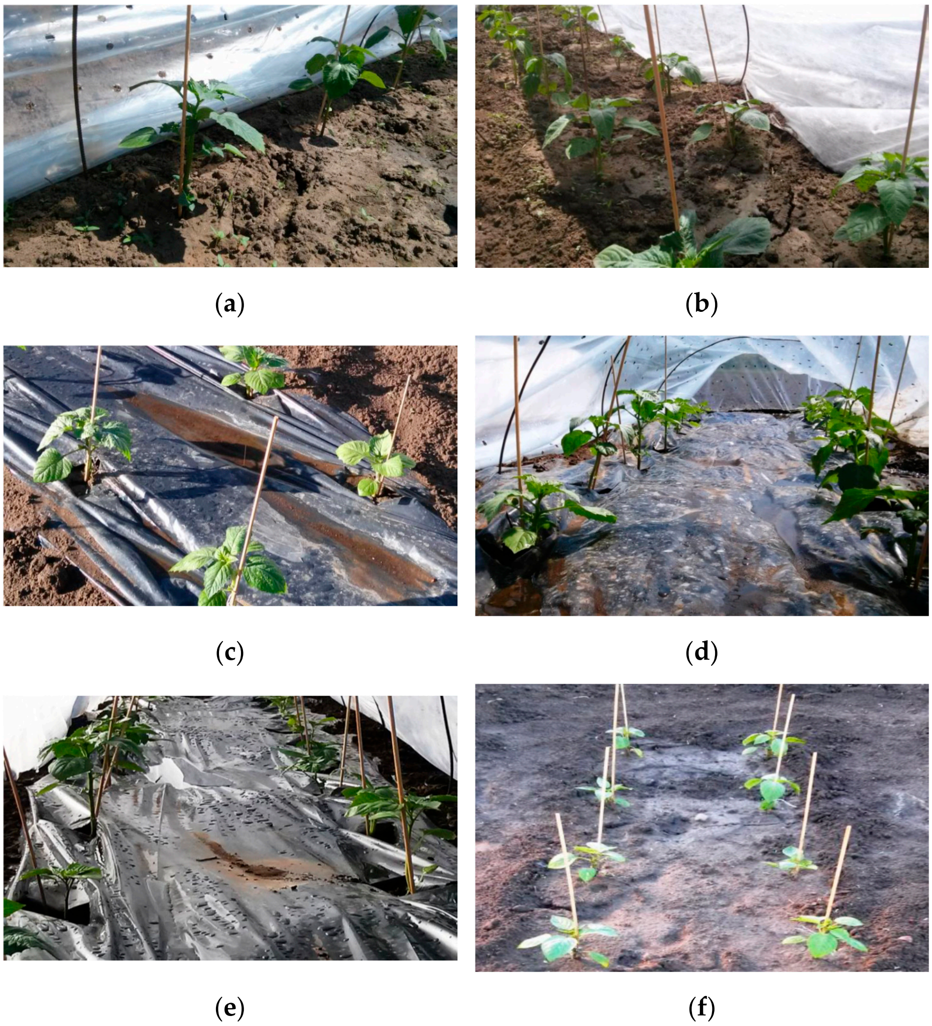


Figure 1. (**a**) Perforated PE film with 100 openings per m^2 for covering field beds (PE), (**b**) non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds (PP), (**c**) black PE film with a thickness of 0.05 mm for mulching, (**d**) mulching + PE, (**e**) mulching + PE, (**f**) control treatment.

2.2. Greenhouse Cultivation

Tomatillo seedlings were grown in pots placed on movable flood tables in a heated greenhouse, in accordance with the generally observed standards for tomato cultivation. Each year, between 20 and 24 April (approximately four weeks before transplanting), two tomatillo seeds were sown per pot with a diameter of 10 cm. Tomatillo seeds were purchased from Seed 27 Needs LLC in the first year of the study. Before the experiment, chemical analyses of the substrate were performed by standard methods. The content of N-NO_3 was determined by the colorimetric method with the use of phenol disulfonic acid (UV-1201V spectrophotometer, Shimadzu Corporation, Kyoto, Japan). Phosphorus content was determined by the vanadium molybdate yellow colorimetric method (UV-1201V spectrophotometer, Shimadzu Corporation, Kyoto, Japan), the content of calcium and potassium was determined by atomic emission spectrometry (AES) (BWB Technologies UK Ltd. Flame Photometers). Magnesium was extracted with 0.01 M $CaCl_2$, and its content was determined by atomic absorption spectrophotometry (AAS) (AAS1N, Carl Zeiss Jena, Germany). Salinity was determined by the conductometric method (N5773 conductivity meter, Teleko, Wrocław, Poland), and pH in H_2O was determined by the potentiometric method. The substrate was sphagnum peat saturated with minerals: N-NO_3—100, P—80, K—215, Ca—1240, and Mg—121 (mg·dm^{-3}), pH in H_2O of 5.9, and salt concentration of 1.5 g·dm^{-3} (Table 1).

Table 1. Substrate for seedling production.

pH in H_2O	$N\text{-}NO_3$	P	K	Ca	Mg	Salt Concentration
	mg·dm^{-3}					g NaCl·dm^{-3}
5.9	100.0	80.0	215.0	1240.0	121.0	1.5

Tomatillo plants emerged 5–9 days after sowing, depending on cultivar and year. The weaker seedling was removed from each pot 7 days after sowing. Seedlings were properly watered with municipal water and monitored. They were not fertilized. When the leaves of plants in adjacent pots began to overlap, the pots were arranged in chessboard fashion at a spacing of 0.1 × 0.2 m to prevent contact between leaves. Approximately one week before transplanting to the field, the plants were hardened off by lowering the temperature to 18–19 °C during the day and at night, and implementing restricted watering. When the first symptoms of Crescent-marked lily aphid infestation were observed, the seedlings were sprayed with Kohinor 200SL (ADAMA Poland Ltd., Warsaw, Poland) at a concentration of 0.4%.

Two days before transplanting, 1-m strips of black PE film were spread over the soil surface. Immediately before transplanting, the substrate in all pots was saturated with water to facilitate the removal of roots. Eight seedlings were planted per plot, at a spacing of 0.5 × 0.5 m. In plots mulched with black PE film, openings were made by crosswise incisions, and seedlings were planted in the openings. After transplanting, 2.5-wide strips of PE film and non-woven PP fabric, stretched over metal arcs, were used for covering two rows of tomatillo plants. The height of the plastic tunnel was 40 cm. The edges of the covers were buried in soil to prevent the plastic from being blown away by the wind. New covers were applied each year. Strips of bare soil, 0.5 m wide, were left between strips of PE film and non-woven PP fabric to enable rainwater to soak into the soil. Plot size for harvest was 2 m^2 (Figure 2). The covers were removed when the first flowers appeared on plants. Flowering began 55 days after sowing (14 June) in 2015, 43 days after sowing (7 June) in 2017, and 49 days after sowing (11 June) in 2018. The main agronomic treatments in tomatillo cultivation are presented in Table 2.

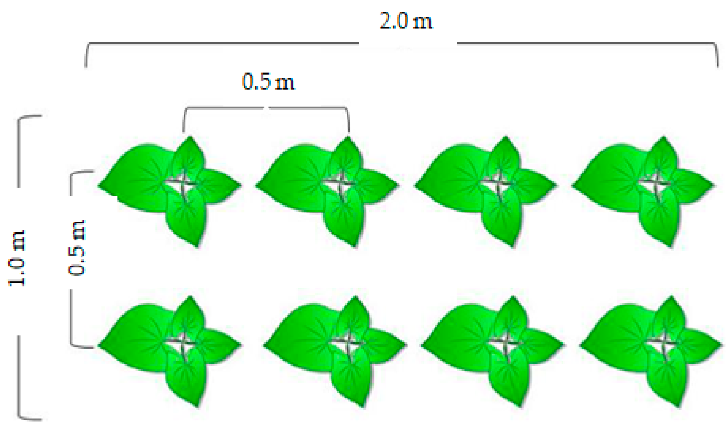


Figure 2. Planting tomatillo seedlings in plots.

Table 2. Agronomic activities and observations in tomatillo cultivation.

Agronomic Treatments	Year					
	2015		2017		2018	
	A	*B*	*A*	*B*	*A*	*B*
Sowing seeds in pots	20 April		25 April	-	23 April	-
Emergence	26–28 April	7–9	30 April–4 May	5–9	29 April–1 May	6–8
Appearance of first true leaves	4 May	14	6 May	11	5 May	12
Hardening off	18–25 May	28–35	12–18 May	17–23	14–22 May	21–29
Mulching	22 May	32	16 May	21	20 May	27
Transplanting	25 May	35	18 May	23	22 May	29
Application of covers	25 May	35	18 May	23	22 May	29
Onset of flowering	14 June	55	7 June	43	11 June	49
Removal of covers	15 June	56	8 June	44	12 June	50
First harvest	14 August	116	20 August	117	12 August	111
Last harvest	24 October	187	22 October	180	26 October	186
End of experiment	25 October	188	23 October	181	28 October	188

Stems (0.5 m in height) were supported with bamboo stakes to prevent their bending over or breaking off. In the middle of the growing season, stakes with a diameter of 2 cm and a height of 1.5 m were used to support plants weighted down with heavy fruits.

The field experiment was set up on layered proper brown soil developed from slightly loamy sand on medium-heavy silty loam underlain by loose sand, of quality class IVb and good rye complex according to the Polish soil classification system (5B pgm·ps:gsp:.pl). The morphological characteristics of soil were described based on taxonomic criteria and the research findings of the Department of Soil Science, University of Warmia and Mazury in Olsztyn. Before commencing the experiment, the mineral content of soil was analyzed and the results were presented as means for the years of the study since only minor differences were noted (Table 3).

Table 3. Chemical composition of soil under tomatillos in the first year of the study.

pH in H_2O	$N\text{-}NO_3$	P	K	Ca	Mg	B	Mn	Cu	Zn	Fe	Pb	Salt Concentration
	$mg\cdot dm^{-3}$											$g\ NaCl\cdot dm^{-3}$
6.3	38.0	85.0	157.0	1840.0	194.0	2.9	125.0	8.5	41.0	632.0	0.15	0.8

Chemical analyses of soil were performed in the Chemical and Agricultural Research Laboratory in Olsztyn, under Accreditation Certificate no. AB 277 issued by the Polish Center for Accreditation in Warsaw. The soil was abundant in phosphorus, potassium, calcium, and magnesium, and no supplemental fertilization with these elements was needed throughout the experiment. Due to the low nitrate nitrogen content of soil, nitrogen was applied at 100 $kg\cdot ha^{-1}$ as ammonium nitrate before the seedlings were transplanted to the field. The nitrogen requirements of tomatillos were determined based on those of field-grown tomatoes because both plants belong to the same botanical family and have similar nutrient requirements. The fertilizer was thoroughly mixed with soil and the field surface was levelled with a cultivation unit. Tomatillos were grown after carrots as a forecrop. Symptoms of pathogenic infections or pest infestations were not observed during the three-year study, and therefore plant protection agents were not applied.

Weather conditions during the growing season of tomatillos were described based on the data provided by the Hydrological and Meteorological Station in Olsztyn. The following formula was used:

$$K = \frac{P}{0.1 \sum t} \quad (1)$$

where:

P is total monthly precipitation;
∑t is the sum of mean daily temperatures for each day of a month;
K is Selyaninov's hydrothermal coefficient [18] calculated for the growing season of tomatillos, where:
K < 0.5 denotes severe drought;
K = 0.51–0.69 denotes drought;
K = 0.70–0.99 denotes slight drought;
K = 1.00–2.00 denotes moist;
K > 2.01 denotes wet.

2.3. Fruit Harvest and Quality

Tomatillo fruits were harvested gradually, upon physiological maturity which was determined based on changes in the color of the peel and calyx, and the aroma. The fruits were harvested when they fell to the ground upon gentle touch. During the last harvest, all fruits were collected, including the unripe ones. The growth and development of tomatillos were evaluated based on plant measurements performed in the field. Leaf greenness (SPAD) was measured on day 15 of each month with the SPAD-502 chlorophyll meter (Konica Minolta Inc., Wrocław, Poland). The measurements were performed on the three youngest, fully developed leaves of five plants, selected randomly in each treatment, and the results were averaged.

Total yield and marketable yield per m^2 [kg], average fruit weight [g], and the vertical and horizontal diameters of fruit [cm] were determined to the nearest 1 g using the Radwag PST 750 R2 laboratory precision balance (Radwag, Radom, Poland) to evaluate the effects of the experimental factors on tomatillo yields. The fruits were sorted based on the Mexican Standard NMX-FF-54-1982 (www.colpos.mx, accessed on 19 March 2021), according to which total yield comprises fruits with a minimum diameter of 1.6 cm. The percentage share of marketable yield in total yield was calculated.

2.4. Chemical Analyses

Representative fruit samples (10 variously sized fruits) were collected for laboratory analyses from each plot during the third harvest. In each treatment, fruits were collected from the marketable yield to prepare average samples in accordance with Polish Standard PN-72/A-75050. The chemical composition of tomatillo fruits was analyzed at the stage of full fruiting in the laboratory of the Department of Horticulture of the University of Warmia and Mazury in Olsztyn to determine the content of: dry matter (DM) by drying to constant weight at 105 °C (*Dry matter determination by the gravimetric method*, PN-90/A-75101/03); total sugars by the Luff-Schoorl method (*Determination of the content of sugars and reducing sugars*, PN-90/A-75101/07); extract by the refractometric method (PN-90A-75101/02) with the use of the Conbest Abbe Kern ORT 1RS refractometer (Kern Optics, Germany); β-carotene by column chromatography (*Processed fruits and vegetables*, PN-90/A-75101/12); total polyphenols by the spectrometric method (UV-1201V spectrophotometer, Shimadzu Corporation, Kyoto, Japan) with the use of Folin–Ciocalteu reagent (gallic acid equivalent method), as described by Singleton and Rossi [19].

2.5. Statistical Analysis

The results were presented as means for the years of the study since only minor differences were noted. A two-way analysis of variance (ANOVA) was performed to determine significant differences between each of the experimental treatments and the control treatment for both experiments. The differences between group means were pooled using Tukey's test with a 0.05 probability level. All calculations were performed using SAS (Statistical Analysis System) software, version 12 [20]. For the selected resulting data presented in the tables, standard errors (SE) were calculated.

3. Results

3.1. Environmental Conditions

The weather conditions during the field experiments differed from the long-term average of 1981–2010, but they were conducive to the growth and development of tomatillo plants.

Mean air temperature in May deviated from the long-term average, ranging from 11.8 °C in 2015 to 15.5 °C in 2018. Each year, mean air temperature increased in June to reach 16.1 °C, while mean air temperatures in July and August were 18.0 °C and 18.9 °C, respectively. In 2017–2018, air temperature decreased in September. During the three-year study, the highest mean air temperature was noted in August 2015 (Table 4), when it reached 19.9 °C, and this was 2.0 °C higher than the long-term average. Air temperature was also higher than the long-term average of 1981–2010 in September 2015 (by 0.7 °C) and in all experimental months of 2018.

Table 4. Mean ten-day and monthly air temperatures during the study according to the Hydrological and Meteorological Station in Tomaszkowo (°C).

Month	Decade	Year		
		2015	2017	2018
May	I	10.8	8.2	14.1
	II	12.6	13.1	15.6
	III	12.0	14.8	17.3
Mean		11.8	12.1	15.5
Mean 1981–2010			13.5	
June	I	15.9	14.4	18.4
	II	15.5	16.3	18.1
	III	15.0	16.3	15.1
Mean		15.5	15.7	17.2
Mean 1981–2010			16.1	
July	I	19.5	15.3	17.1
	II	16.6	16.8	20.0
	III	16.6	18.1	21.9
Mean		17.6	16.7	19.7
Mean 1981–2010			18.7	
August	I	21.5	19.5	22.5
	II	20.1	18.1	18.9
	III	18.0	15.0	16.5
Mean		19.9	17.5	19.3
Mean 1981–2010			17.9	
September	I	14.4	14.3	16.8
	II	15.0	12.4	16.4
	III	11.1	11.7	10.3
Mean		13.5	12.8	14.5
Mean 1981–2010			12.8	

Total precipitation was insufficient to meet the water requirements of tomatillos, and rainfall distribution was unfavorable in all years of the study (Table 5, Figure 3), particularly in the last ten days of May, when the seedlings were transplanted to the field. Therefore, the plants had to be watered each year. This period was classified as drought based on the values of the Selyaninov's hydrothermal coefficient. In 2015 and 2017, soil moisture content increased due to rainfall in the last ten days of July (Table 5). In September 2017, precipitation (K = 1.5) was not conducive to fruit ripening and harvest. In 2018, total precipitation was low throughout the growing season, and irrigation was required.

Table 5. Total ten-day and monthly precipitation during the study according to the Hydrological and Meteorological Station in Tomaszkowo (mm).

Month	Decade	Rok		
		2015	2017	2018
May	I	7.0	18.5	2.9
	II	16.7	0.0	5.0
	III	6.0	6.6	17.1
Mean		9.9	8.4	8.3
Mean 1981–2010			58.5	
June	I	0.2	14.1	1.3
	II	8.8	17.9	1.4
	III	20.5	42.5	2.7
Mean		9.8	24.8	1.8
Mean 1981–2010			80.4	
July	I	8.3	23.9	0.3
	II	19.0	23.1	11.7
	III	54.6	60.6	2.0
Mean		27.3	35.9	4.6
Mean 1981–2010			74.2	
August	I	3.2	22.8	0.6
	II	0.0	18.2	3.1
	III	11.1	22.1	0.7
Mean		4.8	21.0	1.5
Mean 1981–2010			59.4	
September	I	30.3	81.3	0.0
	II	32.7	84.3	0.4
	III	0.8	2.50	1.7
Mean		21.3	56.0	0.7
Mean 1981–2010			56.9	

Mean cloud cover during the growing season of tomatillos was analyzed on a 10-point scale, and it ranged from 0.5 on 10–20 August 2015 to 9.2 on 1–10 September 2017 (Table 6). Throughout the experiment, September was the most cloudy month (6.0 on average), whereas August was the least cloudy (3.4 on average), which promoted flowering and fruiting.

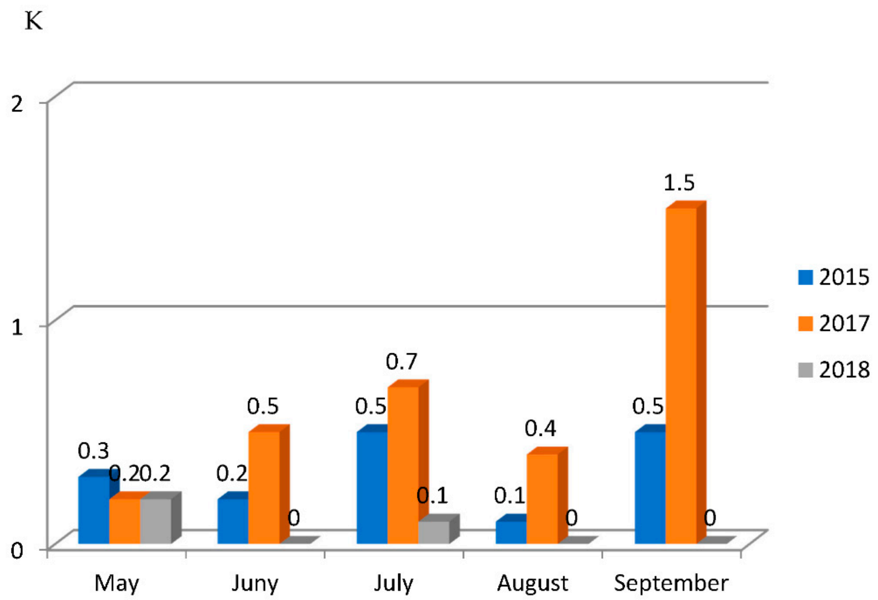


Figure 3. The Selyaninov's hydrothermal coefficient in months and years of the study (K < 1.0—drought; K = 1.0–2.0—moist; K > 2.01—wet).

Table 6. Mean cloud cover during the growing season of tomatillos according to the Institute of Meteorology and Water Management on a 1–10° scale (1°—no clouds, 10°—totally cloudy).

Month	Decade	Year		
		2015	**2017**	**2018**
May	I	5.6	6.0	4.9
	II	5.3	2.2	1.7
	III	5.2	3.7	2,9
Mean		5.4	4.0	3.2
Average 1981–2010			5.3	
June	I	3.5	6.1	2.2
	II	6.2	4.0	4.8
	III	7.1	6.6	7.4
Mean		5.6	5.6	4.8
Mean 1981–2010			5.3	
July	I	2.6	6.5	6.2
	II	6.6	3.9	8.0
	III	6.4	6.4	3.3
Mean		5.2	5.6	5.8
Mean 1981–2010			5.3	
August	I	1.4	3.6	1.7
	II	0.5	6.0	3.5
	III	4.5	4.0	5.2
Mean		2.1	4.5	3.5
Mean 1981–2010			5.3	
September	I	7.1	9.2	2.0
	II	6.8	7.4	4.9
	III	6.3	5.0	5.0
Mean		6.8	7.2	4.0
Mean 1981–2010			5.3	

Average soil temperature at a depth of 5 cm was higher in all experimental treatments than in the control treatment (Table 7). Each year, soil temperature was higher (by 2.6 °C on average, relative to the control treatment) in the treatment where mulching was combined with covering plants with PE film. The treatment where soil was mulched and plants were covered with PE film was characterized by a higher temperature of soil at a depth of 10 cm in all years of the study, compared with the remaining treatments (Table 8). Soil temperature in the control treatment was 3.1 °C lower on average. In the remaining treatments, the average temperature of mulched soil was also higher than the temperature of unmulched soil. Mulching increased soil temperature from 0.8 °C in 2017 to 1.6 °C in 2018. Soil temperature increased by 1.2–1.7 °C when plants were covered with PE film, by 0.5–2.2 °C when plants were covered with non-woven PP fabric, and by 1.5–2.7 °C when soil was mulched and plants were covered with non-woven PP fabric.

Table 7. The effects of plant covers and soil mulching on the average temperature of soil at a depth of 5 cm (°C).

Plant Cover and Mulch *	Time of Measurement								
	8:00 a.m.	2:00 p.m.	Mean	8:00 a.m.	2:00 p.m.	Mean	8:00 a.m.	2:00 p.m.	Mean
	26–31 May 2015			1–8 June 2017			8–15 June 2018		
C	15.9	21.2	18.6	16.0	21.2	18.6	17.4	21.7	19.6
PE	16.8	22.7	19.8	17.3	22.4	19.9	19.0	22.8	20.9
PP	16.6	24.1	20.4	17.4	23.6	20.5	18.7	22.1	20.4
Mulching	16.3	21.5	18.9	17.3	22.2	19.8	18.3	22.4	20.4
Mulching + PE	17.5	24.7	21.1	18.2	24.1	21.2	20.1	24.5	22.3
Mulching + PP	16.8	22.7	19.8	17.9	21.2	19.6	19.8	23.2	21.5
Mean	16.7	22.8	19.7	17.4	22.5	19.9	18.9	22.7	20.7

* Explanation: C—control; PE—perforated PE film with 100 openings per m^2 for covering field beds (PE); PP—non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds; Mulching—black PE film with a thickness of 0.05 mm for mulching; Mulching + PE—black PE film with a thickness of 0.05 mm for mulching + perforated PE film with 100 openings per m^2 for covering field bed; Mulching + PP—black PE film with a thickness of 0.05 mm for mulching + non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds.

Table 8. The effects of plant covers and soil mulching on the average temperature of soil at a depth of 10 cm (°C).

Plant Cover and Mulch *	Time of Measurement								
	8:00 a.m.	2:00 p.m.	Mean	8:00 a.m.	2:00 p.m.	Mean	8:00 a.m.	2:00 p.m.	Mean
	26–31 May 2015			1–8 June 2017			8–15 June 2018		
C	16.1	20.1	18.1	18.7	21.0	19.9	17.8	19.8	18.8
PE	17.1	21.4	19.3	19.2	22.9	21.1	19.5	21.4	20.5
PP	17.3	23.3	20.3	19.0	21.8	20.4	19.3	20.5	19.9
Mulching	17.0	21.3	19.2	19.3	22.1	20.7	18.8	21.9	20.4
Mulching + PE	18.1	24.3	21.2	21.2	23.8	22.5	20.5	24.1	22.3
Mulching + PP	17.0	22.9	20.0	19.4	23.4	21.4	20.3	22.7	21.5
Mean	17.1	22.2	19.7	19.5	22.5	21.0	19.4	21.7	20.4

* Explanation as in Table 7.

3.2. Plant Morphology

The use of protective covers affected the values of the leaf greenness index (SPAD), which was lowest in the control treatment.

The average height of tomatillo plants was not affected by the experimental factors or their interaction, and it ranged from 1.19 to 1.44 m at the end of the growing season (Table 9).

A statistical analysis demonstrated that the average vertical and horizontal diameters of tomatillo fruit, determined for the three-year study, were significantly affected only by cultivar, ranging from 3.70 cm in cv. 'Purple' to 4.73 cm in cv. 'Rio Grande Verde' (Figure 4). The fruit of cv. 'Rio Grande Verde' was characterized by the largest horizontal diameter (5.69 cm). According to the Mexican Standard NMX-FF-54-1982, the analyzed tomatillo fruit belonged to class A.

Table 9. The effects of cultivar, plant covers andmulching on the biometric parameters of tomatillo plants (means of 2015, 2017–2018).

Cultivar	Plant Covers and Mulch *	Plant High m	Fruit Weight g
'Purple'	C	1.19 ± 0.3a	31.84 ± 1.5a
	PE	1.26 ± 0.3a	46.60 ± 1.9b
	PP	1.28 ± 0.2a	37.44 ± 1.6a
	Mulching	1.40 ± 0.2a	37.00 ± 1.8a
	Mulching + PE	1.41 ± 0.3a	37.02 ± 1.5a
	Mulching + PP	1.39 ± 0.3a	41.59 ± 1.9a
	Mean	1.32 ± 0.3a	38.58 ± 1.4a
'Toma Verde'	C	1.21 ± 0.2a	57.25 ± 2.1b
	PE	1.20 ± 0.4a	52.11 ± 1.8b
	PP	1.23 ± 0.2a	52.00 ± 1.8b
	Mulching	1.32 ± 0.2a	67.63 ± 2.3c
	Mulching + PE	1.39 ± 0.2a	51.78 ± 1.7b
	Mulching + PP	1.43 ± 0.2a	52.50 ± 1.8b
	Mean	1.30 ± 0.2a	55.55 ± 2.0b
'Rio Grande Verde'	C	1.19 ± 0.2a	67.96 ± 3.2c
	PE	1.23 ± 0.3a	60.52 ± 3.0c
	PP	1.27 ± 0.5a	72.70 ± 4.2d
	Mulching	1.36 ± 0.6a	78.56 ± 3.6d
	Mulching + PE	1.44 ± 0.3a	60.53 ± 3.2b
	Mulching + PP	1.43 ± 0.5a	78.36 ± 4.2d
	Mean	1.32 ± 0.4a	69.77 ± 3.6c
Mean	C	1.20 ± 0.2a	52.35 ± 2.3a
	PE	1.23 ± 0.3a	53.08 ± 2.3a
	PP	1.26 ± 0.3a	54.05 ± 2.5a
	Mulching	1.36 ± 0.3a	61.06 ± 2.6b
	Mulching + PE	1.41 ± 0.3a	49.78 ± 2.1a
	Mulching + PP	1.42 ± 0.3a	57.48 ± 2.6b

* Explanation as in Table 7. Means with the same letter do not differ significantly at $p < 0.05$ in Tukey's honestsignificant difference (HSD) test.

In all years of the study, average fruit weight was 17.5% higher in cv. 'Rio Grande Verde' than in cv. 'Purple' (Table 9). An analysis of the effects exerted by plant covers and mulch revealed a significant increase in single fruit weight. Single fruit weight reached 52.35 g in the control treatment, and this was 16.6% lower than in the mulched treatments. Mulching combined with covering plants with PE film, as well as the use of PE film alone brought unsatisfactory results.

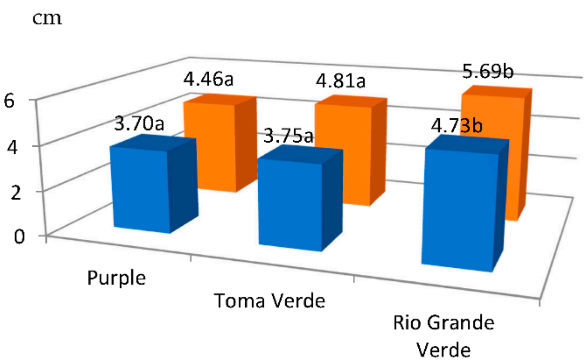


Figure 4. The effects of cultivar, plant covers and soil mulching on the vertical and horizontal diameters of tomatillo fruit) (means of 2015, 2017–2018).

3.3. Tomatillo Fruit Yield

The number of days between transplanting seedlings to the first harvest of tomatillo fruit varied across years and ranged from 80 to 94 (Figures 5–7). During the three-year study, the fruit of cvs. 'Rio Grande Verde' and 'Toma Verde' ripened faster (84 days) than the fruit of cv. 'Purple' (Figure 5). The fruit of cvs. 'Toma Verde' and 'Rio Grande Verde' grown under protective covers in mulch were harvested earlier.

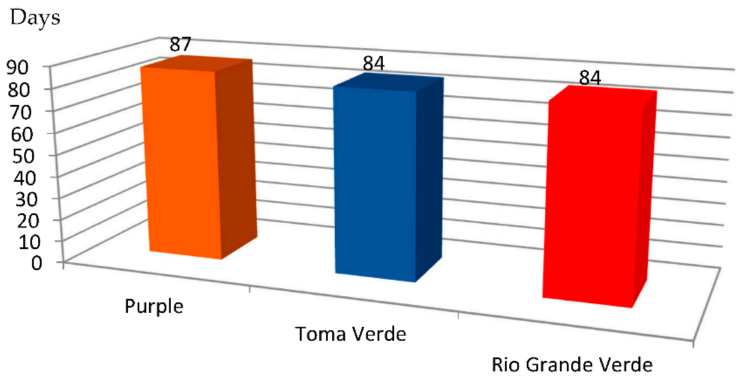


Figure 5. The effects of cultivar, plant covers and soil mulching on the number of days between transplanting seedlings to the first harvest of tomatillo fruit) (means of 2015, 2017–2018).

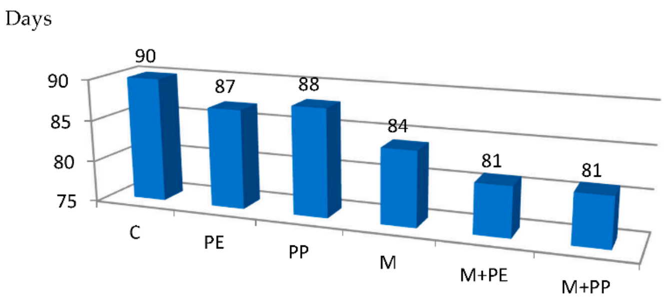


Figure 6. The effects of plant covers and soil mulching on the number of days between transplanting seedlings to the first harvest of tomatillo fruit) (means of 2015, 2017–2018) (means of 2015, 2017–2018). Explanation: C—control; PE—perforated PE film with 100 openings per m^2 for covering field beds (PE); PP—non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds; M—black PE film with a thickness of 0.05 mm for mulching; M + PE—black PE film with a thickness of 0.05 mm for mulching + perforated PE film with 100 openings per m^2 for covering field bed; M + PP—black PE film with a thickness of 0.05 mm for mulching + non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds.

The use of mulch and plant covers accelerated fruit ripening. Tomatillo fruit ripened faster in the treatments where mulch and plant covers were used (81 days on average), and slower in the control treatment (Figure 6).

Tomatillo plants of cv. 'Rio Grande Verde' were characterized by the highest total yield (Table 10), which was higher than the yields of cv. 'Toma Verde' and cv. 'Purple' by 7.2% and 6.5%, respectively. The use of mulch and non-woven PP fabric covers had a particularly beneficial effect on total yield, which increased by 26.6–28.0% on average, relative to the control treatment. Throughout the study, total yields were higher in cvs. 'Rio Grande Verde' and 'Toma Verde' grown in mulch and covered with non-woven PP fabric (2.83 and 2.62 kg·m^{-2}, respectively).

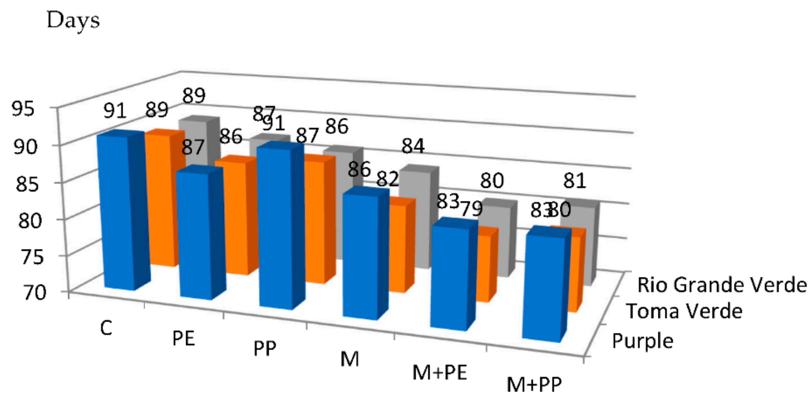


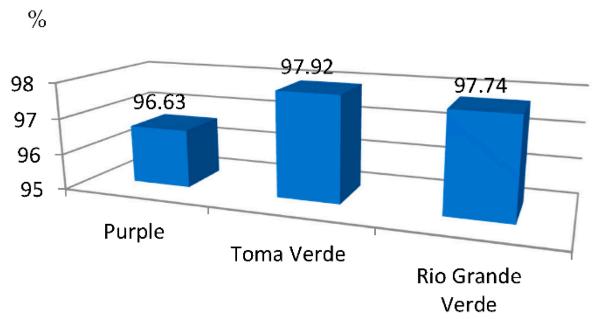
Figure 7. The effects of cultivar, plant covers and soil mulching on the number of days between transplanting seedlings to the first harvest of tomatillo fruit) (means of 2015, 2017–2018). Explanation: C—control; PE—perforated PE film with 100 openings per m^2 for covering field beds (PE); PP—non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds; M—black PE film with a thickness of 0.05 mm for mulching; M + PE—black PE film with a thickness of 0.05 mm for mulching + perforated PE film with 100 openings per m^2 for covering field bed; M + PP—black PE film with a thickness of 0.05 mm for mulching + non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds.

Table 10. The effects of cultivar, plant covers and mulching on the total tomatillo fruit yield (kg·m^{-2}) (means of 2015, 2017–2018).

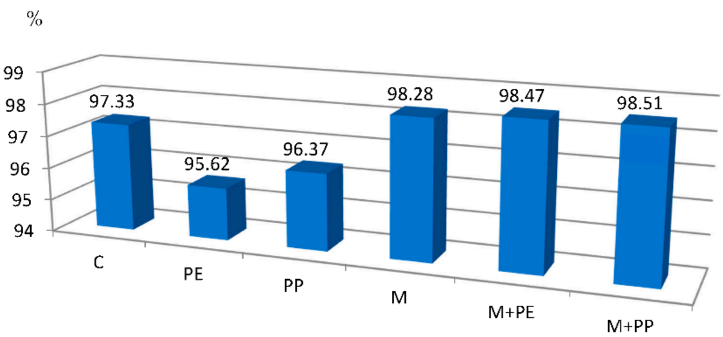
Cultivar	Plant Covers and Mulch *	Total Yield	Marketable Yield
'Purple'	C	1.20 ± 0.2a	1.03 ± 0.2a
	PE	1.31 ± 0.4a	1.18 ± 0.4a
	PP	1.29 ± 0.3a	1.13 ± 0.3a
	Mulching	1.43 ± 0.2a	1.25 ± 0.2a
	Mulching + PE	1.60 ± 0.3b	1.52 ± 0.3b
	Mulching +PP	1.66 ± 0.3b	1.50 ± 0.3b
	Mean	1.42 ± 0.3a	1.27 ± 0.3a
'Toma Verde'	C	1.40 ± 0.2a	1.22 ± 0.2a
	PE	1.66 ± 0.3b	1.53 ± 0.3b
	PP	2.20 ± 0.4d	2.01 ± 0.4c
	Mulching	2.01 ± 0.4d	1.79 ± 0.3b
	Mulching + PE	2.00 ±0.3d	1.82 ± 0.3b
	Mulching +PP	2.62 ± 0.5e	2.50 ± 0.3d
	Mean	1.98 ± 0.4b	1.81 ± 0.3b
'Rio Grande Verde'	C	1.69 ±0.3b	1.46 ± 0.3b
	PE	2.18 ± 0.5d	1.95 ± 0.4c
	PP	1.96 ± 0.2c	1.77 ± 0.3b
	Mulching	1.99 ± 0.2c	1.81 ± 0.3b
	Mulching + PE	2.18 ± 0.4d	2.03 ± 0.4c
	Mulching +PP	2.83 ± 0.3e	2.65 ± 0.2d
	Mean	2.14 ±0.3c	1.95 ± 0.3b
Mean	C	1.43 ± 0.2a	1.24 ± 0.2a
	PE	1.72 ± 0.4b	1.55 ± 0.4a
	PP	1.82 ± 0.3b	1.64 ± 0.3a
	Mulching	1.81 ± 0.2b	1.62 ± 0.3a
	Mulching + PE	1.83 ± 0.3b	1.79 ± 0.3a
	Mulching +PP	2.37 ± 0.4c	2.22 ± 0.3a

* Explanation as in Table 7. Means with the same letter do not differ significantly at $p < 0.05$ in Tukey's honestsignificant difference (HSD) test.

Tomatillo plants of cvs. 'Rio Grande Verde' and 'Toma Verde' were characterized by a higher marketable yield, which was significantly lower in cv. 'Purple'. The marketable yield of tomatillo fruit was significantly affected by the type of plant cover and soil mulching, and it reached 2.22 kg m^{-2} in the treatment where soil was mulched and plants were covered with non-woven PP fabric. During the three-year study, the marketable yield had the highest and the lowest share of the total yield of tomatillo fruit in cvs. 'Toma Verde' and 'Purple'—97.92% and 96.63%, respectively (Figure 8a). Mulching combined with short-term plant protection with PE film and non-woven PP fabric had a beneficial influence on marketable yield expressed as a percentage of total yield 98.47% and 98.51%, respectively (Figure 8b).



(**a**)



(**b**)

Figure 8. The effects of cultivar (**a**), plant covers and mulching (**b**) on the marketable yield of tomatillo fruit expressed as a percentage of total yield (means of 2015, 2017–2018). Explanation: C—control; PE—perforated PE film with 100 openings per m^2 for covering field beds (PE); PP—non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds; M—black PE film with a thickness of 0.05 mm for mulching; M + PE—black PE film with a thickness of 0.05 mm for mulching + perforated PE film with 100 openings per m^2 for covering field bed; M + PP—black PE film with a thickness of 0.05 mm for mulching + non-woven PP fabric with surface density of 17 g m^{-2} for covering field beds.

3.4. Dry Matter

During the three-year study, the DM content of tomatillo fruit ranged from 7.82% (cv. 'Toma Verde' in the treatment where soil was mulched and plants were covered with PE film) to 9.84% (cv. 'Purple' in the control treatment), but it was significantly affected only by cultivar (Table 11). The fruit of 'Purple' was most abundant in DM.

Table 11. The effects of cultivar, plant covers and mulching on the dry matter content of tomatillo fruit (%) (means of 2015, 2017–2018).

Cultivar	Plant Cover and Mulch *	Dry Matter
'Purple'	C	9.84 ± 0.2a
	PE	8.68 ± 0.2a
	PP	9.11 ± 0.1a
	Mulching	9.57 ± 0.2a
	Mulching + PE	9.59 ± 0.1a
	Mulching + PP	9.42 ± 0.3a
	Mean	9.39 ± 0.2b
'Toma Verde'	C	8.80 ± 0.1a
	PE	8.32 ± 0.2a
	PP	9.47 ± 0.2a
	Mulching	8.45 ± 0.2a
	Mulching + PE	7.82 ± 0.2a
	Mulching + PP	9.01 ± 0.3a
	Mean	8.65 ± 0.2a
'Rio Grande Verde'	C	8.52 ± 0.2a
	PE	8.09 ± 0.4a
	PP	8.32 ± 0.2a
	Mulching	8.49 ± 0.2a
	Mulching + PE	9.44 ± 0.2a
	Mulching + PP	8.40 ± 0.3a
	Mean	8.54 ± 0.2a
Mean	C	9.05 ± 0.2a
	PE	8.39 ± 0.2a
	PP	8.97 ± 0.2a
	Mulching	8.84 ± 0.2a
	Mulching + PE	8.95 ± 0.2a
	Mulching + PP	8.94 ± 0.3a

* Explanation as in Table 7. Means with the same letter do not differ significantly at $p < 0.05$ in Tukey's honestsignificant difference (HSD) test.

3.5. Chemical Composition of Tomatillo Fruit

The effects of cultivar, plant cover and soil mulching on the content of basic nutrients in tomatillo fruit are presented in Table 12. During the three-year study, average total sugar content was significantly highest in the fruit of cv. 'Purple' (3.90 g·100 g^{-1} fresh weight). The total sugar content of tomatillo fruit was significantly affected by the type of plant cover and soil mulching. The fruit of plants grown in mulch and covered with PE film or non-woven PP fabric had a significantly higher content of total sugars (3.31 and 3.66 g·100 g^{-1} fresh weight). The interaction between the experimental factors was also significant. An analysis of the mean values in the years of the study revealed that total sugar content was highest in the fruit of cv. 'Purple' in the treatment where soil was mulched and plants were covered with non-woven PP fabric (3.90 g·100 g^{-1} fresh weight). Non-woven PP fabric, soil mulching, and a combination of mulching and plant covering with PE film had a beneficial influence on total sugar content in the fruit of cv. 'Purple', whereas a combination of mulching and plant covering with non-woven PP fabric positively affected total sugar content in the fruit of cvs. 'Toma Verde' and 'Rio Grande Verde' (3.54 and 3.55 g·100 g^{-1} fresh weight).

Table 12. The effects of cultivar, plant cover and soil mulching on the totalsugar extract, *polyphenols and* β-carotene of tomatillo fruit (means of 2015, 2017–2018).

Cultivar	Plant Covers and Mulch *	Total Sugar (g·100 g^{-1} św.m.)	Extract (%)	Polyphenols (mg· 100 mg s.m.)	β-carotene (µg·100 g^{-1} św.m.)
'Purple'	C	3.11 ± 0.1b	7.2 ± 0.1a	9.73 ± 0.2b	730 ± 20a
	PE	3.26 ± 0.1b	6.9 ± 0.1a	8.96 ± 0.2b	843 ± 22a
	PP	3.58 ± 0.2c	6.7 ± 0.1a	8.87 ± 0.2b	774 ± 24a
	Mulching	3.83 ± 0.2d	6.9 ± 0.1a	10.88 ± 0.2c	990 ± 21b
	Mulching + PE	3.77 ± 0.2d	6.8 ± 0.1a	10.11 ± 0.2c	1003 ± 22b
	Mulching +PP	3.90 ± 0.2d	6.9 ± 0.1a	11.46 ± 0.2c	753 ± 20a
	Mean	3.90 ± 0.2b	6.9 ± 0.1c	10.00 ± 0.2b	849 ± 21a
'Toma Verde'	C	3.07 ± 0.1b	6.6 ± 0.1a	7.93 ± 0.1a	977 ± 15b
	PE	3.28 ± 0.2b	6.5 ± 0.1a	11.40 ± 0.2d	1030 ± 22c
	PP	3.02 ± 0.1b	6.8 ± 0.2a	10.72 ± 0.2c	1013 ± 19c
	Mulching	2.75 ± 0.1a	6.5 ± 0.1a	10.15 ± 0.1c	915 ± 12b
	Mulching + PE	2.91 ± 0.1a	6.8 ± 0.1a	8.57 ± 0.2a	876 ± 12b
	Mulching +PP	3.54 ± 0.1c	7.1 ± 0.2a	9.46 ± 0.2b	1047 ± 28c
	Mean	3.10 ± 0.1a	6.7 ± 0.1b	9.71 ± 0.2b	977 ± 18b
'Rio Grande Verde'	C	2.50 ± 0.1a	5.9 ± 0.1a	10.34 ± 0.2c	915 ± 25b
	PE	2.78 ± 0.2a	6.0 ± 0.1a	7.75 ± 0.2a	987 ± 34b
	PP	2.83 ± 0.1a	6.0 ± 0.1a	7.90 ± 0.1a	998 ± 12b
	Mulching	3.16 ± 0.1b	5.9 ± 0.1a	9.28 ± 0.1b	972 ± 28b
	Mulching + PE	3.26 ± 0.1b	6.0 ± 0.1a	7.06 ± 0.2a	976 ± 18b
	Mulching +PP	3.55 ± 0.1c	5.8 ± 0.1a	7.80 ± 0.2a	1009 ± 32c
	Mean	3.01 ± 0.1a	5.9 ± 0.1a	8.36 ± 0.2a	976 ± 25b
Mean	C	2.89 ± 0.1a	6.6 ± 0.1a	9.33 ± 0.2a	927 ± 20a
	PE	3.11 ± 0.1b	6.5 ± 0.1a	9.37 ± 0.2a	953 ± 26a
	PP	3.14 ± 0.1b	6.5 ± 0.1a	9.16 ± 0.2a	928 ± 18a
	Mulching	3.25 ± 0.1c	6.4 ± 0.1a	10.10 ± 0.2a	959 ± 15a
	Mulching + PE	3.31 ± 0.1c	6.5 ± 0.1a	8.58 ± 0.2a	953 ± 17a
	Mulching +PP	3.66 ± 0.1d	6.6 ± 0.1a	9.57 ± 0.2a	936 ± 27a

* Explanation as in Table 7. Means with the same letter do not differ significantly at $p < 0.05$ in Tukey's honestsignificant difference (HSD) test.

The fruit of cv. 'Purple' were most abundant in extract, whereas extract content was significantly lower in the fruit of cv. 'Rio Grande Verde' in all years of the study. The extract content of tomatillo fruit did not differ significantly in response to the cultivation method or the interaction of experimental factors in each year of the study and throughout the experiment. The concentrations of total polyphenols varied across cultivars, and they were higher in the fruit of cv. 'Purple' (10.00 mg·100 mg^{-1} DM on average) and cv. 'Toma Verde' (9.71 mg·100 mg^{-1} DM on average), compared with cv. 'Rio Grande Verde'. The content of total polyphenols in tomatillo fruit did not differ significantly in response to the cultivation method, ranging from 8.58 (plants covered with non-woven PP fabric) to 10.10 mg·100 mg DM (soil mulched with black PE film). An interaction between the experimental factors was found for the content of total polyphenols in tomatillo fruit, which was highest in cv. 'Purple' in the treatment where soil was mulched and plants were covered with non-woven PP fabric (11.46 mg·100 mg^{-1} DM). Soil mulching alone and in combination with PE film covers also exerted a positive effect on the concentrations of total polyphenols (10.88 and 10.11 mg 100 mg DM, respectively). The content of total polyphenols in tomatillo fruit was also high in cv. 'Toma Verde' grown in the treatments where plants were covered with PE film or non-woven PP fabric and soil was mulched as well as in cv. 'Rio Grande Verde' in the control treatment.

The β-carotene content of tomatillo fruit was significantly higher in cvs. 'Rio Grande Verde' and 'Toma Verde' than in cv. 'Purple'. The concentration of β-carotene was not significantly affected by the type of plant cover or mulch, and its mean values ranged from

927 (control treatment) to 959 μg·100 g^{-1} fresh weight (mulched treatments). An interaction between the experimental factors for β-carotene content was also noted: it was higher in the fruit of cv. 'Toma Verde' in all treatments except for that where soil was mulched and plants were covered with non-woven PP fabric. The concentration of β-carotene in tomatillo fruit was also high in cv. 'Purple' in the treatment with soil mulching and in the treatment where soil was mulched and plants were covered with PE film, and in cv. 'Rio Grande Verde' in all treatments.

4. Discussion

Total precipitation in the region of Warmia and Mazury is 550–650 mm on average [21]. Wet spells are followed by dry spells. The interactions between the above factors affect weather conditions in Warmia, which plays a key role in crop production. According to Smith et al. [22], the optimal temperature for tomatillo growth and development is 18.3 °C. A drop in temperature during the growing season leads to growth inhibition and a decrease in fruit yield and quality. The water requirements of tomatillos vary across growth stages, but they are considered to be high. A higher demand for water is observed during fruit development. In the present experiment, plants were watered in periods of precipitation deficit. Precipitation during fruit ripening in September 2017 exerted adverse effects. Protective covers (perforated PE film and non-woven PP fabric) promoted root growth in newly transplanted seedlings and during their initial growth in the field, which was also observed in previous studies of zucchini [23], cucumber [24,25], sweet pepper [26], eggplant [27], melon [11], and sweet maize [28]. The cited authors found that weather factors mulch and plant covers play an important role in the field cultivation of thermophilous vegetables. They contribute to a rise in air temperature around the plants. They also conserve heat emitted by the soil and plants and release it slowly at night [29]. When protective covers were used, mean air temperature ranged from 14.7 °C in the last ten days of May to 16.2 °C in the first ten days of June, and it was modified by the covers. Winiarska [30] demonstrated that the difference between ambient temperature and the temperature under non-woven PP fabric reached 1–2 °C. In a study by Siwek [15], the above difference was 1.4 °C at 8:00 a.m. and 2.7 °C at 2:00 p.m. The optimal root zone temperature (RZT) for tomatoes, whose temperature requirements are comparable with those of tomatillos, is 25.4–26.3 °C [31]. Previous research shows that the optimal soil temperature during the growing season of tomatillos is 27.3 °C [7,31]. During the three-year study, soil temperature was highest (21.7 °C) in the treatment where soil was mulched and plants were covered with PE film, and lowest in the control treatment (18.9 °C). Similar results were reported by Díaz-Pérez and Dean Batal [7], Díaz-Pérez et al. [31], Majkowska-Gadomska [11], Ashrafuzzaman et al. [29] and Mohamed et al. [32], who found that mulching increased soil temperature. In the present study, soil temperature measured at 8:00 a.m. was 17.6 °C and 22.6 °C at a depth of 5 cm and 10 cm, respectively. The values noted at 2:00 p.m. at a depth of 5 cm and 10 cm were 18.6 °C and 22.1 °C, respectively (mean of three years). Similar temperatures were reported by Kęsik and Maskalaniec [33] who found that in the morning, the temperature of soil covered with black plastic was by 0.8 °C and 2.0 °C higher at a depth of 5 cm and 15 cm, respectively, relative to bare soil. Similar relationships were noted by Ochmian et al. [34] who demonstrated that black plastic mulch increased soil temperature at a depth of 5 cm by 2.6 °C during the day. Díaz-Pérez et al. [7] analyzed the effect of plastic film mulch on RZT and observed that mulching promoted tomatillo growth and increased fruit yield in the summer, compared with bare soil, and that it increased RZT to 30.2 °C on average. Díaz-Pérez and Dean Batal [30] found that RZT was higher by up to 4.0 °C in mulched soil, compared with bare soil. Similar observations were made by Lamont et al. [35] and Naumova et al. [36]. According to Rabinowitch and Currah [37], flat covers (PE film and PP fabric) can accelerate harvest and increase crop yields. In the current experiment, the average time interval between transplanting seedlings to the first harvest of tomatillo fruit was 80 days, and it was longer by 20 days than that reported by Singh et al. [38]. The fruit of cv. 'Toma Verde' ripened first (75 days). Soil and plant covers significantly speeded up fruit ripening. Tomatillo plants grown in mulch and under protective covers began to bear fruit first, and control plants grown in bare soil without covers began to bear fruit last. According to Siwek [15], an increase in air temperature under non-woven PP fabric covers accelerated watermelon flowering and fruiting. Grudzień and Rumpel [39], Anyszka and Dobrzański [40], Francke [41], Biesiada [42], Rekowska [43], and Krzysztofik [13] also found that protective covers, especially applied at the beginning of the growing season, acceleraated crop maturation. In a study by Siwek and Lipowiecka [25], cucumbers grown under non-woven PP fabric covers accelerated harvest by 12 days, compared with unprotected plants. Tendaj and Misiak [44] demonstrated that non-woven PP fabric covers accelerated Welsh onion ripening by 10–15 days, relative to control plants.

The average height of tomatillo plants was 1.31 m. In general, plant height was positively affected by protective covers and mulch. The growth of vegetative plant parts was promoted by a combination of mulch and non-woven PP fabric covers (1.42 m), which created favorable thermal conditions. In this treatment, plant height was 14.89% higher, compared with the height of control plants. In the experiment conducted by Singh et al. [38], the height of husk tomato (*Physalis ixocarpa* Brot. ex Hormen.) plants ranged from 0.70 m to 1.68 m, depending on genotype, and it reached 1.04 m. in another study by Singh et al. (2014). Rekowska [43] demonstrated that covering soil and stem lettuce plants with non-woven PP fabric increased their height. Helaly et al. [45] found that PE mulch had a beneficial influence on the height of *Physalis pubescens* plants. Similar results were reported by Ashrafuzzaman et al. [29].

The fruit of the analyzed tomatillo cultivars differed in biometric parameters. Single fruit weight ranged from 38.58 g in cv. 'Purple' to 69.77 g in cv. 'Rio Grande Verde'. Similar values were reported by Singh et al. [46] with 29.33–37.67 g, Ramírez-Godina et al. [3] with 27.46 g, and Singh et al. [46] with 26.54 g. Average fruit weight was 13.13 g in a study by Curi et al. [47], 11.8 g (cv. 'Toma Verde') in a study by Díaz-Pérez et al. [7], and 31.10 g in a study by Freyre and Loy [48]. The authors also noted that average fruit weight in cv. 'Purple' was 24.10 g. The fruit harvested from plants grown in mulch were heavier (61.06 g), which is consistent with the findings of Helaly et al. [45]. In the present experiment, heavier fruit were harvested when tomatillo plants cv. 'Rio Grande Verde' were grown in mulch under non-woven PP fabric covers. Similar results were reported by Ramos-López et al. [5], who found that plant covers had a significant effect on the weight of husk tomato fruit which ranged from 26.10 g in cv. 'Rendidora' to 52.29 g in cv. 'Tecozautla' grown under field conditions. Siwek [15] observed that watermelons protected with non-woven PP fabric covers were 1.1 kg heavier than the fruit harvested in the control treatment. In a study by Michalik [26], sweet peppers grown in the field under non-woven PP fabric covers were heavier than those grown without covers. In contrast, Dobromilska [49] found that non-woven PP fabric covers had no significant effect on the weight of sweet peppers. Rekowska [50] demonstrated that the use of non-woven PP fabric and PE film increased the size of garlic bulbs. In the present study, tomatillo plants produced class A fruit according to the Mexican Standard NMX-FF-54-1982 [http://dof.gob.mx/nota_detalle.php?codigo=4788109&fecha=31/12/1982 (accessed on 19 May 2021)]. The average vertical and horizontal fruit diameters were 4.17 cm and 5.15 cm, respectively. The values of vertical diameter were higher when tomatillos were grown without soil and plant covers. Similar values were reported by Ramos-López et al. [5]—3.84 cm to 4.90 cm, depending on husk tomato cultivar and cultivation method. Singh et al. [38] reported a diameter of 2.27–3.73 cm for *Physalis ixocarpa* Brot. ex Hormen. In a later study by Singh et al. [46], fruit width and length reached 2.74 cm and 3.13 cm, respectively. In a study by Ramírez-Godina et al. [3], the equatorial and polar diameters of husk tomato fruit were 4.65 cm and 3.99 cm, respectively. Curi et al. [48] reported average fruit length of 2.61 cm. Freyre and Loy [47] found that tomatillo diameter ranged from 2.6 cm in cv. 'De Milpa' to 3.7 cm in cv. 'PI 270459'. Franczuk et al. [51] confirmed that mulch had a positive effect on the length of sweet peppers. Rekowska and Skupień [52] observed that onions protected with PE film and non-woven PP fabric had greater diameters than unprotected onions. In the experiment conducted by Helaly et al. [45], PE mulch had a beneficial influence on the parameters of *Physalis pubescens* fruit. In contrast, tomatoes grown in soil mulched with black PE film were smaller than control tomatoes [53].

The average total yield of tomatillo fruit reached 1.85 kg·m^{-2}, and it was higher than that reported by Smith et al. [22], i.e., 0.4–0.9 kg·m^{-2}, and similar to those determined by Maynard [54], 2.0–2.4 kg·m^{-2}, and Ramos et al. [55], 2.52 kg·m^{-2}. In a study by Ramos-López et al. [5], fruit yield was 4.84 kg·m^{-2} and 2.10 kg·m^{-2} when *Physalis ixocarpa* Brot. ex Hornem. cv. 'Rendidora' was grown under greenhouse and field conditions, respectively. The total yield of tomatillo fruit in this study was lower than those reported by Singh et al. [38], Mamedov and Engalichev [56], and Naumova et al. [36], but the cited studies were conducted under more favorable environmental conditions. Plant and soil covers contributed to a significant increase in tomatillo fruit yields (by 27.90–65.73% on average), compared with the control treatment. Total yield was highest when soil was mulched and plants were covered with non-woven PP fabric, at 2.37 kg·m^{-2}. Similar results were obtained by Abak et al. [57] when tomatillos were grown in a plastic tunnel (1.90–2.67 kg·m^{-2}) and in the open field (1.32–2.76 kg·m^{-2}), depending on the year of study. A beneficial influence of covers on the yields of other vegetable species were also observed by Anyszka and Dobrzański [40], Rekowska [50], Rekowska and Skupień [52], Michalik [26], and Majkowska-Gadomska [11]. Kołota and Adamczewska-Sowińska [58] demonstrated that flat PP covers contributed to an increase (by 26.70%) in the total yield of zucchini fruit, compared with the control treatment. Similar observations were made by Grudzień and Rumpel [39], and Michalik [26].

The marketable yield of tomatillo fruit ranged from 1.35 to 2.09 kg·m^{-2}, depending on cultivar. The average marketable yield in the treatment where soil was mulched and plants were covered with non-woven PP fabric reached 2.33 kg·m^{-2}, and it was by 0.94 kg·m^{-2} higher than in the control treatment. In a study by Díaz-Pérez et al. [7], the average marketable yield of tomatillo fruit in the treatment with plastic film mulch reached 1.4 kg·plants^{-1}, and it was by 7% lower than in the control treatment. In the current study, the marketable yield accounted for 96.63% to 97.92% of the total yield. Similar values were reported by Díaz-Pérez et al. [7], with 100.00% in cv. 'Toma Verde' and 84.21% in cv. 'Verde Puebla'. In the present study, this parameter was determined at 98.51% on average when soil mulching was combined with covering plants with non-woven PP fabric. Díaz-Pérez et al. [7] found that the marketable yield of tomatillo fruit expressed as a percentage of total yield ranged from 85.71% to 93.33%. In the work of Grudzień and Rumpel [39], the marketable yield of peppers grown under non-woven PP fabric covers accounted for 78.3% of total yield, and it was by 4.6% higher than in unprotected plants. Słodkowski and Rekowska [59] also noted a positive effect of covering broccoli, butterhead lettuce and cabbage with non-woven PP fabric for four weeks on the percentage share of marketable yield in total yield, relative to the control treatment.

The health benefits and high nutritional value of tomatillos as well as the growing interest in Mexican cuisine have contributed to their increasing popularity among consumers. Tomatillo fruit is a rich source of health-promoting minerals and bioactive compounds whose content varies depending on cultivar and growing conditions [7,49]. The effects of plant covers and mulch on nutrient accumulation in vegetables have been documented by numerous authors [11,28,60].

Water is the main component of the edible parts of vegetables, and DM constitutes the remaining portion. The average DM content of tomatillo fruit is 8.86%. In the present study, DM content was highest in the fruit of cv. 'Purple' (9.39%) and in the control treatment (9.05%). Similar DM content of tomatillo fruit was reported by Naumova et al. [36] with 8.7–9.3% ± 1.2% and Ostrzycka et al. [61] with 7.0–10.0%. In the cited studies, DM percentage was lower when tomatillos were grown under cover, compared with the control treatments. Previous research shows that plants covers and mulch exert varied effects on the DM content of vegetables. Franczuk et al. [51] found that DM content was lower in peppers grown in synthetic mulch. In experiments involving kohlrabi [42] and melon [11], the fruit of plants covered with non-woven PP fabric had lower DM content than those grown in the open field. In a study by Błażewicz-Woźniak [62], the DM content of fennel bulbs decreased in response to PE film and non-woven PP fabric covers.

According to the USDA, the total carbohydrate content of tomatillo fruit is 3.93 g·100 g^{-1} fresh weight (https://ndb.nal.usda.gov/ndb/foods, accessed on 19 March 2021). In the present study, the average content of total sugars ranged from 2.50 to 3.90 g·100 g^{-1} fresh weight, depending on the experimental factors. The content of total sugars was significantly highest in the fruit of cv. 'Purple'. Similar values were reported for tomatillo fruit by Ostrzycka et al. [61], from 3.24 g·100 g^{-1} fresh weight in cv. 'Antocyjanowa' to 4.12 g·100 g^{-1} fresh weight in cv. 'Bujna'. Differences in the concentrations of total sugars in the fruits of the Solanaceae were also observed by Dobromilska [49] and Michalik [26]. The levels of total sugars in tomatillo fruit were affected by plant covers and soil mulching, and the combined use of mulch and non-woven PP fabric covers was particularly beneficial (3.66 g·100 g^{-1} fresh weight). Growing tomatillo plants of cv. 'Purple' in mulch and under non-woven PP fabric had a positive effect on the total sugar content of fruit. In studies by Kostnera et al. [60], Franczuk et al. [51], and Helaly et al. [45], synthetic mulches contributed to the accumulation of total and reducing sugars in the analyzed vegetable species. In contrast, Biesiada [42] and Michalik [26] observed no significant effect of plant covers on the total sugar content of the edible parts of vegetables.

The content of total polyphenols in tomatillo fruit varied across cultivars, similarly to the experiments conducted by Gonzalez-Mendoza et al. [63,64] where it ranged from 5.30 to 10.08 mg 100 mg DM, and from 4.68 to 9.65 mg·100 mg^{-1} DM. The value reported by Khan et al. [65], i.e., 165.77 mg· g^{-1} DM, is consistent with the findings of Cruz-Álvarez et al. [66] who analyzed purple tomatillos. A lower concentration of total polyphenols (78.91 mg 100 mg DM) was noted by Silva et al. [67]. In the current experiment, the fruit of cv. 'Purple' contained the highest amounts of total polyphenols. Mulching had a beneficial influence on the content of total polyphenols in tomatillo fruit (10.10 mg 100 mg^{-1} DM), but the observed differences were not significant.

5. Conclusions

Tomatillos were found to be suitable for cultivation under the agroecological conditions of north-eastern Poland. Fruit quality was affected by cultivar, cover type, and mulching. A combination of mulching and plant covering with PE film had the most beneficial influence on soil temperature at a depth of 5 cm and 10 cm, and it improved the thermal conditions in the root zone. During the three-year study, the weight, vertical diameter, and horizonal diameter of fruit were highest in cv. 'Rio Grande Verde' and lowest in cv. 'Purple'. The combined use of mulch and plant covers accelerated fruit ripening and harvest by nine days on average, compared with the control treatment.

The total and marketable yields of tomatillo fruit were highest in cv. 'Rio Grande Verde' and lowest in cv. 'Purple'. The fruit of cv. 'Purple' had the highest content of DM, total sugars, extract, β-carotene, and total polyphenols.

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