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Combining Willow Compost and Peat as Media for Juvenile Tomato Transplant Production

Katarzyna Adamczewska-Sowińska [1,*], Józef Sowiński [2], Elżbieta Jamroz [3] and Jakub Bekier [3]

[1] Department of Horticulture, Wroclaw University of Environmental and Life Sciences, 50-375 Wrocław, Poland
[2] Institute of Agroecology and Plant Production, Wroclaw University of Environmental and Life Sciences, 50-375 Wroclaw, Poland; jozef.sowinski@upwr.edu.pl
[3] Institute of Soil Sciences and Environmental Protection, Wroclaw University of Environmental and Life Sciences, 50-375 Wrocław, Poland; elzbieta.jamroz@upwr.edu.pl (E.J.); jakub.bekier@upwr.edu.pl (J.B.)
* Correspondence: katarzyna.adamczewska-sowinska@upwr.edu.pl; Tel.: +48-713201732

Abstract: In 2019–2020, a study was conducted to evaluate the suitability of willow composts as a substrate or substrate component in tomato transplant cultivation. In 2019, 4-year-old chopped willow biomass (mostly chips <2 cm long) was formed into four compost prisms: S0—willow compost without additives; SN—willow compost with the addition of nitrogen; SF—willow compost with the addition of wood-decaying mycelium; and SFN—willow compost with the addition of wood-decaying mycelium and nitrogen. Willow compost was rated as a homogeneous substrate (S0, SN, SF, and SFN) and as a substrate component with peat (P), mixed in willow:peat ratios such as 25:75, 50:50, and 75:25, in the variants S0:P, SN:P, SF:P, and SFN:P. For reference, deacidified peat was used as a homogeneous substrate. The study showed that willow compost could be used as a renewable plant material replacing peat. The best parameters (plant height, leaf span, number of leaves, and especially the highest weight) were found in tomato transplants grown in the SF:P and SFN:P substrates and at a 25:75 ratio. It was found that the addition of nitrogen to the compost, in order to obtain a wide C:N ratio, negatively affected the initial growth of tomato plants.

Keywords: substrate proportion; growth dynamic; plant conditions; plant length; leaf lateral span; CIELab; LAI

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1. Introduction

Peat is one of the most widely used and at the same time the best natural substrates for horticulture production; for growing vegetables, ornamental and fruit plants, and mushrooms; and in nurseries and forestry [1]. The suitability of substrates for plant production, not only from peat, is determined by a number of characteristics such as: cation exchange capacity (CEC), dry mass by volume, wet mass by volume, porosity, air content, water capacity, and water availability [2]. The degree of substrate aeration, water, and nutrient availability are the main parameters considered for the use of organic and mineral materials as horticultural substrates [3]. The wide use of peat as a substrate, according to Van Gerrewey et al. [1], is explained by its easy availability, especially in the Northern Hemisphere, and low cost of acquisition. Peatlands account for 3% of the globe's land surface, and at the same time store 27% of carbon [4–6]. Globally, about 2000 km^2 of peatlands are exploited for horticultural purposes, which is 0.5% of the total peatland area.

Peat is now one of the world's strategic resources, and its certified exploitation necessitates land reclamation activities after its extraction. Duque-Acevedo et al. [7] highlighted that globally, peat extraction has increased by 113% since 1990, and has resulted in the production of huge amounts of waste. Based on the results of long-term studies and available data [8], it is assumed that up to 20% of the world's peatlands have been lost since the early 1900s. The negative environmental impact associated with a significant reduction in peat resources is mainly due to the consequences of changing ambient water conditions. Peatlands store 10% of the Earth's available water and, by directly feeding many rivers, they influence the hydrological cycle of many catchments, and contribute to limiting extreme phenomena such as floods [9].

Drainage of peatlands for agricultural production, or as a result of the extraction of material for horticultural substrate production, contributes to greenhouse gas emissions estimated at 1 billion metric tons of CO_2 equivalent per year [10]. Environmental degradation associated with peatland exploitation also results from the loss of unique vegetation that is important both locally and globally in maintaining genetic biodiversity of species and habitats [11].

Considering the natural importance of peatlands, the European Union, together with other organisations, has introduced radical restrictions related to the exploitation of peatlands and the extraction of peat for the production of horticultural substrates. International cooperation on peat conservation seems to be the most rational way to implement the concept of the green economy and to increase the use of renewable biomass for horticulture production [12–14]. Development of agriculture methods to reduce carbon and other the emission of other gases significantly mitigates the impact on climate change. Therefore, research related to the search for other organic biomass and mineral materials that could be used as a component of horticultural substrates should be intensified.

Among potential alternative raw material sources for peat media is lignocellulosic biomass harvested from short rotation coppice (SRC); e.g., willow (*Salix viminalis* L.). The shredded woody substrate is subjected to biotransformation processes by composting, usually using chemical and microbial stimulation to convert the lignin–cellulose complex into proper humic compounds, such as humic and fulvic acids [15–18].

The aim of this study was to evaluate the suitability of willow composts as substrates for tomato transplant cultivation. The study verified the working hypothesis of whether willow compost could be used as a substitute for peat in homogeneous form or as a peat substrate component.

2. Materials and Methods

2.1. Greenhouse Experiment Design

The study was conducted in 2019–2020. Four-year-old willow plantation (short rotation coppice—SRC) grown in the fields of the Research Station in Pawlowice, belonging to the Wroclaw University of Environmental and Life Sciences, was fragmented in February 2019 after cutting. The chips were approximately 1–3 cm long with a predominant fraction below 2 cm (about 60% by weight). From the woodchips, in April 2019, 4 compost prisms were formed, each of a volume of 5 m^3 in the following configuration (some of the results presented in this article were used in a patent filed on 28 June 2020 at the Polish Patent Office under No. P.435103. A legal procedure is currently underway):

- ✓ Willow compost (S0);
- ✓ Willow compost with the addition of nitrogen in the form of ammonium nitrate (ammonium nitrate, 32% N), added in order to narrow the C:N biomass ratio (SN);
- ✓ Willow compost with the addition of wood-decaying fungus [19], PG Poszwald *Peniophora gigantea* (SF), at a rate of 0.6 l of wood-decaying fungus/10 l water/prism. The willow lignocellulosic biomass had a wide initial C:N of ratio 118:1 [20];
- ✓ Willow compost with the addition of wood-decaying fungus and nitrogen in the form of ammonium nitrate in order to narrow the C:N ratio (SFN). The amount of fungus and nitrogen was identical to variants SN and SF.

The composting process was carried out from April to October 2019, and throughout this period the temperature, humidity, and cyclic mixing of the compost biomass were monitored. In February and March 2020, the compost was subjected to a grinding process using a Raffinatore Colibri COL/RR/2010 mill manufactured by POR Micucci System Srl BRESCIA—Italy, with the aim of obtaining a structure with a diameter fraction of less than 3 mm, porous enough for growing transplants [21].

A pot experiment was conducted from March to May 2020 under greenhouse conditions to evaluate the suitability of the produced willow composts for tomato transplant production. The study was conducted at the Research and Didactic Station in Psary belonging to the Department of Horticulture, Wroclaw University of Environmental and Life Sciences. Various willow composts with and without peat were used (Table 1). The control was the cultivation of tomato plant in deacidified peat (P). The percentage of substrate-forming components remained in volumetric proportions. They were thoroughly mixed without the addition of fertilizers.

Table 1. Horticulture media mixtures in % of volume.

Horticulture Media Code	Salix:Peat Proportion (%)	Media Type and Volume Proportion (%)				
		S0	**SN**	**SF**	**SFN**	**P**
S0	100:0	100	-	-	-	-
S0:P	75:25	75	-	-	-	25
S0:P	50:50	50	-	-	-	50
S0:P	25:75	25	-	-	-	75
SN	100:0	-	100	-	-	-
SN:P	75:25	-	75	-	-	25
SN:P	50:50	-	50	-	-	50
SN:P	25:75	-	25	-	-	75
SF	100:0	-	-	100	-	-
SF:P	75:25	-	-	75	-	25
SF:P	50:50	-	-	50	-	50
SF:P	25:75	-	-	25	-	75
SNF	100:0	-	-	-	100	-
SNF:P	75:25	-	-	-	75	25
SNF:P	50:50	-	-	-	50	50
SNF:P	25:75	-	-	-	25	75
P	0:100	-	-	-	-	100

Seeds of the tomato variety Awizo F1 (PlantiCo) were sown in rows, at a rate of 7 g m^{-2}, into boxes filled with deacidified peat. At the stage of developed cotyledons (BBCH 10), the seedlings were pricked out into pots with an upper diameter of 8 cm and a volume of 248.6 cm^3.

The experiment was conducted in a greenhouse on flood tables. The plants were provided with optimal conditions for growth. Until plant emergence, the day temperature was maintained at 20–24 °C, and after emergence at 18–20 °C. At night, the temperature was 3–5 °C lower. Plants were irrigated as required.

In the experiment, the arrangement of the blocks (combinations) on the tables was randomized. There were 10 pots within each block. The experiment was conducted under controlled conditions for a period of 45 days until the tomato plants reached transplant parameters.

2.2. Morphological Measurements and Analysis

During the juvenile tomato production, plant growth and development were monitored, and losses were marked. Morphological measurements of the plants were made at weekly intervals by determining the number of leaves, plant height, and the largest leaf span (each plant separately). The relative condition of the plants was also assessed according to a 9-degree scale:

1. No plants (died due to a phytotoxic substrate effect);
2. Damaged;
3. Wilted;
4. Very weak;
5. Weak;
6. Medium condition;

7. Fairly good condition;
8. Good condition;
9. Very good condition.

At the point when the plants reached the optimum state of development, indicating readiness for transplanting, the weight of the aboveground part of each plant was also assessed separately.

At the final stage of growth, the leaf greenness index was determined (Chlorophyll Content Meter—CCM-200 plus by Opti-Sciences). Measurements also included the determination of leaf colour expressed numerically, where: 'L'—denoted brightness from white to black, 'a'—green to red, and 'b'—blue to yellow. The determination was made on a Hunter Scan Mini Scan EZ 4500 spectrophotometer using the colour range standardised by the International Commission on Illumination (Commission internationale de l'éclairage—CIELab). The colour range was developed as a numerical index corresponding to brightness, ranging from green to red and blue to yellow [22,23].

Leaf surface area was measured using a CID Bio-Science Portable Laser Leaf Area Meter CI-202 scanner by selecting three leaves: the largest, medium, and smallest from different plants from each site. Based on the defined area and number of leaves, the leaf area per plant and Leaf Area Index (LAI) were calculated in relation to the pot area (50.3 cm^2).

Macronutrient contents of P, K, Ca, and Mg, as well as chlorophyll and dry matter, were determined in the tomato plants.

2.3. Statistical Analysis

Data from morphological measurements of plants and quantitative and qualitative evaluation collected during individual dates and before harvest were subjected to ANOVA/MANOVA analysis in Statistica software (version 13.1, StatSoft, Poland). All analyses were performed at a significance level of $p < 0.05$. One- and two-factor analyses of variance were performed to assess the effect of substrate type and varying proportions of components in the substrate mixture on the determined tomato plant parameters. The substrates and proportions in the mixture accounted for the fixed effect of the model, while the repetitions accounted for the variable effect of the model.

3. Results

On the first measurement date, tomato seedlings already were observed to languish (die) in the SN medium (Table 2). Poor plant conditions were found in SN:P and SFN substrate. The condition of tomatoes growing in peat or willow substrate with added peat (P, SF:P, SFN:P, S0:P) was good and even, mostly at the statistically same level. A significant positive effect of peat addition on tomato plant quality was shown on all measurement dates. It was found that the amount of peat added to the willow was not important for the quality of plants after pricking out. Plants grown in substrates with ratios of willow to peat of 75:25, 50:50, and 25:75 were characterised by significantly better quality than those in the peat-only substrate (0:100). After the next week of growth, the best results were obtained for tomato plants growing in the 50:50 and 25:75 mixtures; further observations, however, proved the most beneficial effect of the substrate with 75% of peat.

Table 2. The effect of media on the relative condition of the plants (average ± standard deviation).

Treatment	Plant Condition (9-Degree Scale)				
	I Measurement	II Measurement	III Measurement	IV Measurement	V Measurement
	Media type				
S0 *	6.9c ** ± 1.2	4.0bc ± 0	4.0bc ± 0	4.0bc ± 0.6	5.0c ± 0
S0:P	7.1c ± 1.1	5.3c ± 1.0	5.3cd ± 1.3	6.3ef ± 1.1	6.7d ± 1.0
SN	1.0a ± 0	1.0a ± 0	1.0a ± 0	1.0a ± 0	1.0a ± 0
SN:P	5.1b ± 2.1	5.5c ± 3.3	5.6cd ± 3.4	4.6cd ± 3.4	2.7b ± 1.8
SF	6.9c ± 1.4	4.0bc ± 0	4.0bc ± 0	4.0bc ± 0	5.0c ± 0
SF:P	7.5c ± 0.9	7.0d ± 2.2	8.0e ± 1.4	7.7f ± 1.9	6.3cd ± 1.9
SFN	4.6b ± 2.0	2.5b ± 2.4	2.8b ± 2.9	2.5b ± 2.4	2.5b ± 2.4
SFN:P	7.1c ± 1.5	7.9d ± 1.9	8.1e ± 2.0	6.3ef ± 2.2	5.5cd ± 3.0
P	8.0c ± 0	8.0d ± 0	6.0d ± 0	6.0de ± 0	5.5cd ± 1.6
LSD (p = 0.05)	1.0	1.5	1.5	1.5	1.4
	Proportion of components (salix substrate:peat)				
100:0	4.9a ± 2.8	2.9a ± 1.7	3.0a ± 1.9	2.9a ± 1.8	3.4a ± 2.1
75:25	6.2b ± 2.1	4.3b ± 2.4	5.0b ± 2.8	4.4b ± 2.4	4.3b ± 2.1
50:50	6.8b ± 1.7	7.2c ± 2.1	6.8c ± 2.2	5.8c ± 2.3	3.8ab ± 1.9
25:75	7.0b ± 1.1	7.8c ± 1.1	8.5d ± 0.9	8.5d ± 1.1	7.8c ± 1.6
LSD (p = 0.05)	0.9	0.8	0.9	0.8	0.9
	Media type · Proportion of component interaction				
LSD (p = 0.05)	1.1	1.2	1.3	0.8	0.8

* S0—salix compost; S0:P—salix compost + peat; SN—salix compost with mineral nitrogen; SN:P—salix compost with mineral nitrogen + peat; SF—salix compost with fungi decomposer; SF:P—salix compost with fungi decomposer + peat; SFN—salix compost with fungi decomposer and mineral nitrogen; SFN:P—salix compost with fungi decomposer and mineral nitrogen + peat; P—peat; **—means with the same letter are not significantly different at p = 0.05; LSD—least significant difference.

At the final stage of transplant production (V measurements), the plant mortality rate (percentage of plant losses) was as follows for each media type (in %): S0—0; S0:P—0; SN—100; SN:P—43; SF—0; SF:P—0; SFN—70; SFN:P—17; P—0.

The addition of peat to each of the composts resulted in faster tomato plant growth (Table 3). However, the increase in plant height compared to the sites where homogeneous substrates were used was not always statistically proven (e.g., S0:P). Plants grown in the SF:P substrate were significantly taller at the end of the cultivation period compared to SF by 42.7–54.0%, while those in the SFN:P substrate were 2.8–3.2 times taller throughout the cultivation period compared to plants from the SFN substrate.

In the majority of sites where willow compost was supplemented with peat, tomato plants, at successive measurement dates, were statistically no different in height from plants grown in deacidified peat. Taller plants were observed in the SF:P and S0:P media during the 3rd and 4th measurements. In the S0:P medium at the end of production, plants were also taller (by 25%) than those grown in peat, but this difference was not statistically significant.

It was found that the addition of peat to compost, irrespective of the amount, caused a significant increase in plant height, on average by 53.6% and 76.8% at the 2nd and 3rd measurement dates. On the next measurement dates, it was observed that when the compost to peat ratio was 25:75, the height of plants was on average 2.5–2.6 times greater than those growing in 100% compost substrate. When the peat proportion was reduced to 50% and 25%, the plant height was significantly greater, by 1.6–1.7 times.

The lateral span of tomato planting leaves remained at the same level of significance irrespective of the type of willow compost applied (Table 4). The exception was plants growing in the SFN substrate, for which the value of this trait was on average 2.2–2.8 times lower than the others. The addition of peat as a substrate component mostly did not increase the lateral plant span. It turned out that only plants growing in the SF:P medium were characterised by a significantly larger span than the others.

Table 3. The effect of horticulture media on plant growth dynamic (average ± standard deviation).

Treatment	Plant Height (cm)				
	I Measurement	II Measurement	III Measurement	IV Measurement	V Measurement
	Plant growing media type				
S0	2.8ab ± 1.0	4.6cd ± 1.0	5.5bc ± 1.2	6.8bc ± 1.4	8.0bc ± 2.0
S0:P	2.9ab ± 0.9	4.5cd ± 1.1	6.3cd ± 1.3	8.5cd ± 2.3	10.4cd ± 1.9
SN:P	3.0abc ± 0.9	3.1b ± 2.3	4.1b ± 3.1	5.8b ± 5.0	6.3ab ± 6.5
SF	3.7cd ± 1.5	5.3d ± 1.7	6.1cd ± 1.7	7.5bc ± 1.7	8.7bc ± 2.3
SF:P	3.3bc ± 0.7	5.7d ± 1.2	7.5d ± 1.5	10.7d ± 2.1	13.4d ± 2.5
SFN	4.4d ± 1.7	1.4a ± 2.2	1.7a ± 2.7	2.6a ± 4.2	3.2a ± 5.2
SFN:P	2.4a ± 0.8	3.9bc ± 1.3	5.5bc ± 1.9	7.7bc ± 3.5	8.8bc ± 5.2
P	3.0abc ± 1.1	3.6bc ± 1.8	4.4b ± 2.5	5.7b ± 2.5	8.3bc ± 4.8
LSD (p = 0.05)	0.7	1.1	1.5	2.3	3.1
	Proportion of components (salix substrate:peat)				
100:0	2.7a ± 2.1	2.8a ± 2.6	3.3a ± 3.1	4.2a ± 3.8	5.0a ± 4.6
75:25	3.0a ± 0.9	3.9b ± 2.3	5.0b ± 2.9	6.4b ± 3.8	8.0b ± 4.8
50:50	2.9a ± 0.9	4.7b ± 1.9	6.1bc ± 2.6	7.7b ± 3.8	8.1b ± 5.8
25:75	2.8a ± 0.9	4.3b ± 0.9	6.4c ± 1.8	10.5c ± 2.5	13.0c ± 2.4
LSD ($p = 0.05$)	n.s.	0.9	1.1	1.5	2.0
	Media type · Proportion of component interaction				
LSD ($p = 0.05$)	0.8	1.1	1.5	1.9	2.4

The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table. n.s.—not significant.

Table 4. The effect of horticulture media on lateral leaf span (average ± standard deviation).

Treatment	Lateral Leaf Span (cm)				
	I Measurement	II Measurement	III Measurement	IV Measurement	V Measurement
	Plant growing media type				
S0 *	4.9b ± 1.0	5.5bc ± 1.4	6.3b ± 1.7	9.0bc ± 1.9	8.4b ± 2.3
S0:P	4.7b ± 1.3	5.5bc ± 1.1	6.3b ± 1.7	10.2c ± 2.5	10.9b ± 2.0
SN:P	4.2b ± 1.5	4.4b ± 3.3	5.4b ± 4.0	6.7b ± 6.1	7.0ab ± 7.2
SF	4.7b ± 1.1	5.7bc ± 1.6	6.0b ± 1.4	8.5bc ± 1.5	8.1b ± 1.7
SF:P	4.6b ± 1.1	7.6d ± 2.7	8.6c ± 2.7	13.4d ± 3.3	14.7c ± 3.8
SFN	2.2a ± 0.9	2.2a ± 3.6	2.8a ± 4.5	3.0a ± 4.9	3.9a ± 6.5
SFN:P	4.4b ± 1.2	6.8cd ± 2.3	8.6c ± 2.9	10.6cd ± 4.9	10.6b ± 6.0
P	4.6b ± 1.4	5.6bc ± 2.1	6.5bc ± 2.6	8.0bc ± 1.6	9.1b ± 4.2
LSD ($p = 0.05$)	0.9	1.7	2.1	2.9	3.5
	Proportion of components (Salix substrate:peat)				
100:0	2.9a ± 2.2	3.4a ± 3.1	3.8a ± 3.6	5.1a ± 4.6	5.1a ± 4.9
75:25	4.3b ± 1.2	4.7b ± 2.8	5.5b ± 3.5	7.9b ± 4.9	8.4b ± 5.0
50:50	4.6b ± 1.5	6.8c ± 3.2	7.3c ± 3.3	9.1b ± 4.7	8.8b ± 6.1
25:75	4.6b ± 1.2	6.7c ± 1.2	8.8d ± 1.8	13.6c ± 3.5	15.3c ± 2.9
LSD ($p = 0.05$)	0.7	1.2	1.4	1.9	2.1
	Media type · Proportion of component interaction				
LSD ($p = 0.05$)	1.0	1.8	2.1	2.3	2.8

* The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table.

The smallest lateral leaf span throughout the growth period was characteristic of plants grown in homogeneous substrates. Increasing the amount of peat component in the substrates caused an increase in the value of this trait of plants, and with the lengthening of the cultivation period, these differences were more conspicuous. At the end of the vegetation period, the greatest span was characteristic of plants grown in a 25:75 mixture of compost and peat, and on average were 42.8–45.1% smaller, for transplants grown on 50:50 and 75:25 substrates, respectively.

The study showed that the number of leaves of tomato plants grown in the S0 and SF media throughout the plant production period was at the same level of significance as those growing in peat (Table 5). It ranged from 2.4–2.7 on the second measurement date to 3.8–4.5 in plants ready for transplanting. In the final period of transplant production, plants grown in SFN had, on average, 2.7 times fewer leaves than the others.

Table 5. The effect of horticulture media on the number of plant leaves (average ± standard deviation).

Treatment	Number of Leaves				
	I Measurement	**II Measurement**	**III Measurement**	**IV Measurement**	**V Measurement**
Plant growing media type					
S0	2.0a ± 0	2.4bc ± 0.5	2.9bc ± 0.6	3.4b ± 0.5	3.9bc ± 0.9
S0:P	2.0a ± 0	2.5bcd ± 0.5	3.1bc ± 0.6	3.9bcd ± 0.9	4.7cd ± 0.6
SN:P	2.0a ± 0	2.2b ± 1.7	2.7b ± 2.0	3.1b ± 2.5	3.1b ± 2.9
SF	2.0a ± 0	2.7bcd ± 0.5	2.8b ± 0.6	3.5bc ± 0.5	3.8bc ± 0.6
SF:P	2.0a ± 0	3.1cd ± 0.7	3.8cd ± 0.8	5.1d ± 1.3	5.6d ± 1.1
SFN	2.0a ± 0	1.0a ± 1.6	1.3a ± 2.1	1.6a ± 2.6	1.5a ± 2.5
SFN:P	2.0a ± 0	3.3d ± 1.0	4.3d ± 1.3	4.8cd ± 1.9	4.8cd ± 2.6
P	2.0a ± 0	2.7bcd ± 0.8	3.2bc ± 0.9	3.8bcd ± 1.1	4.5bcd ± 1.8
LSD (p = 0.05)	n.s.	0.8	0.9	1.2	1.4
Proportion of components (Salix substrate:peat)					
100:0	1.5a ± 0	1.5a ± 1.4	1.8a ± 1.6	2.1a ± 1.9	2.3a ± 2.1
75:25	2.0b ± 0	2.2b ± 1.3	2.7b ± 1.7	3.2b ± 1.9	3.6b ± 2.1
50:50	2.0b ± 0	3.0c ± 1.1	3.6c ± 1.3	4.1c ± 1.9	4.0b ± 2.4
25:75	2.0b ± 0	3.2c ± 0.8	4.2c ± 0.9	5.4d ± 1.2	6.1c ± 1.1
LSD (p = 0.05)	0.2	0.5	0.6	0.8	0.9
Media type · Proportion of component interaction					
LSD (p = 0.05)	n.s.	0.8	0.9	1.1	1,2

The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table.

The addition of peat to willow compost always resulted in improved plant foliage. It appeared that this positive effect was most apparent in older plants. When grown in the S0 and S0:P substrates, this difference varied from 4.2%, at the time of the second measurement, to 20.5% before planting, while in the SF and SF:N substrates, from 14.8 to 47.4%, respectively. The positive effect of peat addition was most noticeable when grown in the SFN:P substrate. The number of leaves was 3.0–3.3 times higher than in SFN.

Evaluation of the effect of proportions in which the substrate components were mixed showed that in mixtures with 75% peat, the plants had the most leaves. Reducing the peat proportion to 50% resulted in a 24–34% reduction in the number of leaves at the end of growth.

The finished tomato transplants were characterised by the highest unit weight in SF:P and SFN:P objects (Figures 1 and 2). It turned out that the homogeneous willow substrate and the willow substrate with the addition of fungi or with the participation of fungi and nitrogen produced plants with the lowest weights. In each case, the addition of peat to the willow substrate provided an increase in plant weight. An increase of 3.5 times was observed in the SF:P site compared to SF, and 3.2 times in the SFN:P site compared to SFN.

It was found that the higher the proportion of peat in the substrate, the higher the unit weight of plants. The use of 25% and 50% peat increased the weight by 66% and 100%, respectively, compared to that obtained when grown in willow alone, while the tomato plants in the medium with 75% peat had a 4.3-fold higher weight.

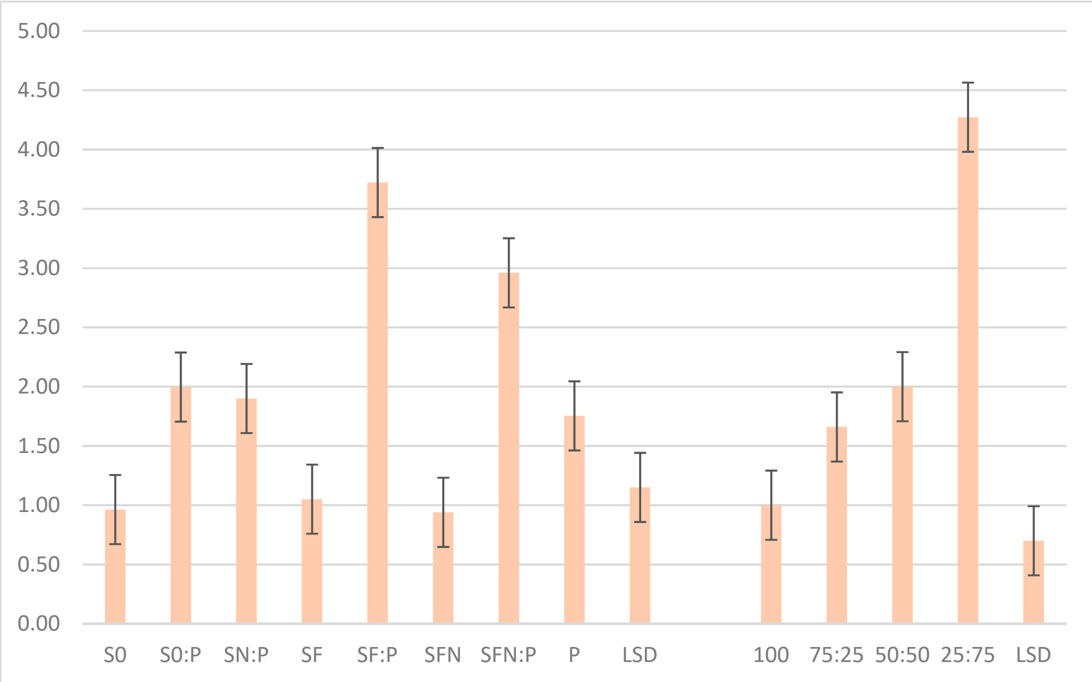

Figure 1. The effects of different media and volumetric media proportion on tomato transplant mass (in g).

Figure 2. Selected tomato transplants (S0—salix compost; SF—salix compost with fungi decomposer; SFN—salix compost with fungi decomposer and mineral nitrogen; P—peat).

The Soil Plant Analysis Development leaf greenness index (SPAD), determined with a CCM-200 plus meter, allowed indirect assessment and comparison of the state of plant nitrogen nutrition based on leaf colour. The obtained results showed that the leaves of tomato plants grown in the S0 and SF media had the lowest SPAD values (6.8 and 6.2, respectively) (Table 6). The leaf greenness index values for the SN:P and SFN substrates were in the same homogeneous group. Increasing the proportion of peat in the mixture resulted in a steady increase in SPAD values, from 8.1 (100:0) to a statistically significant 32.7 in the mixture with peat (25:75).

Table 6. The effect of horticulture media on the leaf greenness index (SPAD) and CIELab parameters.

Treatment	SPAD	Colour Parameters (CIElab)		
		L	a	b
Plant growing media type				
S0	6.8ab	37.3c	−1.0b	19.2cd
S0:P	21.9bc	33.3bc	−4.7a	16.1cd
SN:P	15.2abc	27.3a	−4.0a	11.6ab
SF	6.2ab	36.8c	−5.0a	21.5d
SF:P	22.1bc	34.2bc	−5.1a	14.0abc
SFN	19.3bc	28.3ab	−4.2a	8.6a
SFN:P	21.6bc	25.7a	−4.2a	9.6a
P	25.8c	29.3ab	−5.8a	10.5ab
LSD (p = 0.05)	14.4	5.6	2.2	5.2
Proportion of components (salix substrate:peat)				
100:0	8.1a	25.6a	−2.6b	12.3a
75:25	14.7b	32.1a	−4.0ab	15.4a
50:50	13.1b	28.6a	−4.1ab	13.7a
25:75	32.7c	29.7a	−5.3a	9.3a
LSD (p = 0.05)	6.1	r.n.	1.5	r.n.
Media type · Proportion of component interaction				
LSD (p = 0.05)	9.1	5.1	2.3	n.s.

The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table.

Colour measurement of plant material using a spectrophotometer showed significant variation between sites. The L value was highest for S0 and SF and S0:P and SF:P, ranging from 37.3 to 33.3, indicating that the leaves of plants grown in these substrates were the brightest. For the other plants, leaf colouration was significantly darker, and the L value ranged from 25.7 (SFN:P) to 29.3 (P). A negative value of 'a' indicated different shades of green colour. The lowest value of 'a' was obtained for plants grown in peat (−5.8), but in the other media, except S0, it was at the same level of significance. The high value of 'b' for S0 (19.2) and SF (21.5) indicated a high proportion of yellow colour, indicating poor nutritional transplant status.

The ratio between willow compost and peat had a significant effect only on the 'a' index. Increasing the proportion of peat resulted in a decrease in 'a' and a more intense green colour of the leaves.

Different growing conditions of tomato plants resulting from the type of substrate had a significant effect on morphological traits determined at harvest. Composted willow chips without additions (S0) and composted with fungal mycelium (SF) as substrates were unfavorable for tomato plants (Table 7). The lowest leaf weights (0.6 and 0.7 g, respectively), three-leaf surface area (16.4 and 17.4 cm^2, respectively), total leaf area per plant (21.3 and 22.0 cm^2), and LAI (0.4 each) were observed. Willow substrate with fungal mycelium mixed with peat (SF:P), as well as compost with nitrogen and fungal mycelium (SFN) and in mixture with peat (SFN:P), provided the best conditions for tomato plant growth. Weight and surface area of three leaves, leaf area per plant, and LAI reached statistically significant highest values.

Table 7. The effect of horticulture media on leaf parameters and the LAI index.

Treatment	Three-Leaf Weight (g)	Three-Leaf Area (cm^2)	Leaf Area per Plant (cm^2)	LAI
Plant growing media type				
S0	0.6ab	16.4ab	21.3ab	0.4ab
S0:P	1.2bc	35.9bc	57.5abc	1.1abc
SN:P	1.4bcd	37.7bc	60.8abc	1.2abc
SF	0.7ab	17.4ab	22.0ab	0.4ab
SF:P	2.3d	61.6c	128.7c	2.6c
SFN	2.1cd	59.3c	98.8bc	2.0bc
SFN:P	2.1cd	60.7c	124.7c	2.5c
P	1.3bc	47.0bc	78.3abc	1.6abc
LSD (p = 0.05)	0.9	28.9	76.4	1.5
Proportion of components (salix substrate:peat)				
100:0	0.9a	23.3a	35.5a	0.7a
75:25	1.3ab	33.9ab	51.9a	1.0a
50:50	1.8bc	48.4bc	83.2a	1.7a
25:75	2.1c	64.6c	143.7b	2.9b
LSD (p = 0.05)	0.7	19.6	45.4	0.9
Media type · Proportion of component interaction				
LSD (p = 0.05)	0.5	15.4	36.1	0.7

The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table.

At the end of plant production, chemical analyses of tomato plants were performed. Statistical analysis of the results showed no effect of the type of substrate used on their dry matter content (Table 8). It was noticed, however, that plants grown on a substrate containing the added fungi and on deacidified peat were characterized by less dry matter. On the other hand, plants cultivated on a mixture of willow substrate with nitrogen addition and peat stored the highest amount of potassium in their tissues. The least amount of potassium was determined in plants grown on S0 and SNF:P. However, these differences were not statistically significant. It was found that plants grown on SNF and SN:P medium contained significantly more P, Mg and Ca. They were also characterised by the highest chlorophyll content in tissues. Phosphorus was at a similar statistical level in tomato grown on SF, SN:P and P, magnesium—on SN:P, calcium—on SF, and chlorophyll—on P.

The effect of peat percentage in the substrates on the chemical composition of the grown tomato plants was not statistically confirmed. However, a tendency to increase the amount of dry matter, P, K Mg and chlorophyll was observed in plants growing on mixtures whose component was peat. Peat addition increased the dry matter by 35.5% on average, phosphorus by 5.2–16.1%, potassium by 35.2–146.5%, magnesium by 51.3% on average, chlorophyll by 19.3–86.4%.

In statistical terms, S0 had the highest pH value compared to the other substrates (Figure 3). The addition of peat lowered the pH of all initial substrates, but the effect was statistically proven only for S0. The pH of substrates prepared from 100% willow composts and with 25% peat added was 5.4 and 5.2. Increasing the peat content to 50% and 75% resulted in a decrease of this pH value to 4.6 and 4.7.

Table 8. The effect of horticulture media on transplants chemical composition.

Treatment	Dry Matter (g)	mg · 100^{-1} D.M.				
		P	K	Mg	Ca	Chlorophyll
		Plant growing media type				
S0	190a	98.0ab	750.0a	185.0a	625.0a	30.0ab
S0:P	192a	85.7ab	2083.3a	280.0ab	975.0ab	87.0ab
SN:P	188a	135.7ab	2631.7a	390.0bc	1396.0bc	146.0bc
SF	198a	144.0b	1750.0a	270.0a	1875.0c	54.0ab
SF:P	183a	82.7a	1940.0a	271.7a	1020.7ab	68.7ab
SNF	155a	126.0ab	1775.0a	425.0c	2000.0c	257.0c
SNF:P	173a	97.7ab	1000.0a	390.0bc	1516.7bc	205.3c
P	157a	130.0ab	1438.0a	240.0a	658.0a	216.0c
LSD (p = 0.05)	n.s..	47.5	n.s.	107.5	584.5	107.7
		Proportion of components (salix substrate:peat)				
100:0	136a	92.0a	1068.8a	220.0a	1125.0a	85.3a
75:25	185a	97.8a	1445.5a	325.0a	1365.8a	101.8a
50:50	183a	96.8a	1661.3a	338.8a	1219.3a	159.0a
25:75	185a	106.8a	2634.5a	335.0a	1096.3a	119.5a
LSD (p = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		Media type · Proportion of components interaction				
LSD (p = 0.05)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

The explanation of the abbreviations is provided under Table 2. Plants from the SN treatment died, and their parameters were not included in the table. n.a.—no analysis.

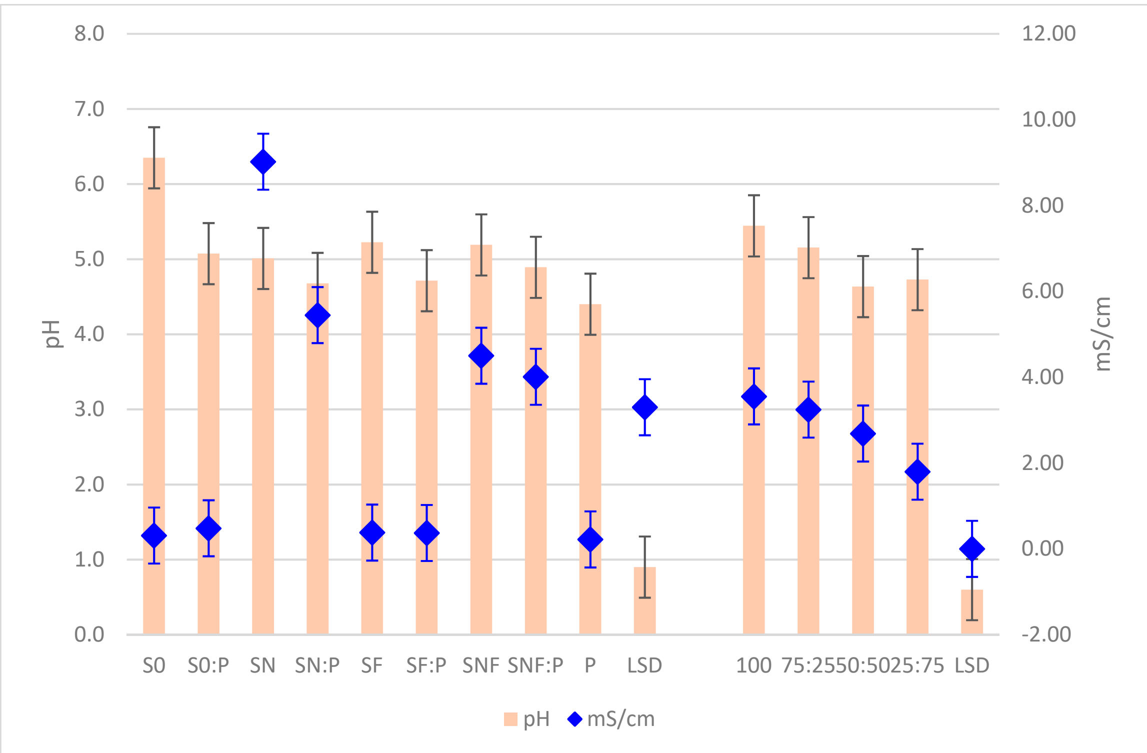

Figure 3. The effects of different media and volumetric media proportion on pH and electrical conductivity.

The addition of nitrogen to the willow compost to accelerate its decomposition processes induced a very high electrical conductivity of the SN, SNP, SNF, and SNFP substrates. It was found that the addition of peat to SN and fungi or fungi and peat caused a significant decrease in EC, from 9.02 mS cm^{-1} to 5.45, 4.5, and 4.01 mS cm^{-1}, respectively. The salinity of the other substrates used in the experiment ranged from 0.22 to 0.48 mS cm^{-1}. A decreasing trend in the salinity of the substrates was observed with increasing peat addition, but this relationship was not statistically proven.

The addition of nitrogen or fungi to composted willow biomass resulted in faster decomposition of the lignin–cellulose mass. Compared to S0, finer particles and fibres accounted for a greater proportion in these substrates. This process most likely resulted in better water retention in the substrates with these components. The high amount of nitrogen in the homogeneous SN substrate was toxic to plants, while the addition of peat contributed to the improvement of plant quality.

4. Discussion

According to Grunert et al. [24], about 95% of greenhouse vegetable production in Europe, the USA, and Canada (mainly tomato) is carried out in soilless systems using artificial horticultural substrates. Horticulture growing media have been deeply investigated in the literature [25,26]. Peat, due to its physical and chemical properties, is the most commonly used substrate [27], totaling approximately 30 million m^3 annually [28]. In recent years, the adverse environmental impact of peat mining has been under discussion. Its exploitation is associated with a large environmental footprint, and it is necessary to search for alternative materials that can replace it [29–35]. The Expert Group for Technical Advice on Organic Production (EGTOP) [36] recommends the use of peat substrate to the maximum of 80% by volume, and the remaining 20–30% of substrate volume should be replaced by compost or other organic material. In our study, composted, chipped lignin–cellulose pulp from willow grown in the SRC system was used [37,38]. Willow (*Salix viminalis* L.) is a shrubby species suitable for cultivation in short-rotation forest plantations for biomass production aimed at energy purposes in agricultural areas. Willow biomass surpluses (or in periods of declining utilisation) can be bioconverted through composting, and the final product obtained can be used as a horticultural substrate to replace peat [17]. In the study conducted, the best production results were obtained when the ratio in the substrates with the willow component and peat was 25:75, and thus close to the one recommended by EGTOP [36].

The choice of substrate is particularly important in the early stages of tomato production. Achieving healthy and vigorous plants is a major factor in determining tomato productivity and yield. The growing conditions during the germination period have a decisive role to play, as the rest of the growth period depends on the correct development of this process. The quality of horticultural medium plays a key role in the percentage of emergence, as well as plant height, number of leaves, and other morphological characteristics and yield of tomato [39,40]. The best horticultural medium for plant production should be characterized by good aeration and water-holding capacity, and high nutrient abundance [27,41]. According to Kalaivanan and Selvakumar [42], peat, wood bark, cereal waste (chaff) and cereal straw, pomace, plant waste compost, vermicompost, and sawdust are commonly used plant-based materials (along with vermiculite) for horticultural production substrates. In our study, compost substrate, depending on the type of additive in the composting process, could replace peat substrate. Willow compost with nitrogen addition used as a substrate for plant production was too toxic for the initial growth of tomato plants, and all plants died during the first few days after pricking out. In the willow compost substrate with nitrogen and mycelium addition, the toxic effect of nitrogen was lower, most likely due to better decomposition of the lignin–cellulose biomass of willow, and the percentage of plant survival was at the level of 30–75%.

A study by Atif et al. [43] showed a strong effect of tomato plant health on tomato productivity. In our study, in willow substrates without additives (S0), the condition of tomato plants at the transplant stage was the weakest on all observation dates. In the mixture with peat, with the increase of its percentage, the conditions of plants improved; and in the mixture of willow compost with peat in a ratio of 25:75, the plants were characterised by greater vigour than those obtained from the peat substrate. In willow compost (with nitrogen and fungal mycelium (SFN)) and in the mixture of willow composted substrate with nitrogen in a mixture with peat (SN:P), the condition of tomato plants was also weak. In the study of Tuzel et al. [44], increasing the proportion of olive pomace compost in the substrate mixture with peat resulted in weaker tomato plant growth. The best conditions for growth occurred when the peat share was at 50%. In our study, 75% peat in the substrate provided the best growing conditions for the tomato plants, and the tomatoes that were in the best growth condition (index 7.8 on a scale of 9), reached 13 cm in height, their lateral leaf span was 15.3 cm, and the number of leaves was 6.1. In the peat substrate, these parameters were respectively: 5.5, 8.3, 9.1, 4.5.

In the study conducted by Tuzel et al. [44], increasing the proportion of compost in the substrate resulted in an average increase in SPAD, from 30.58 (0% compost) to 31.96 (100% compost in the substrate). In the presented study, increasing the proportion of peat in the substrate improved the SPAD values in the tested plants; the differences ranged from 8.1 (100% compost) to 32.7 in the substrate with a willow compost content of 25%.

In our study, there was no significant effect of the proportion of substrate components on leaf colour as determined by CIELab. In the experiment conducted by Tuzel et al. [44], increasing the proportion of compost in the substrate significantly increased parameters 'L' and 'b', and significantly decreased the 'a' parameter.

Heuvelink et al. [45], Higashide and Heuvelink [46], and Higashide et al. [47] reported that leaf surface area is important in tomato production to absorb the light reaching its surface. Producing an LAI of up to 3.0 as soon as possible ensures that about 90% of the incoming light is absorbed. The LAI in greenhouse tomatoes should not exceed 4.0, and it is necessary to control this index and remove older leaves. LAI in tomato depends on many parameters, including the number of leaves on the stem, size of individual leaves, and planting density. In our study, 45 days after the beginning of the experiment, the LAI value was highly differentiated by both the choice of substrates and their proportions in the substrate, and the differences were as high as 6.5-fold (SF:P compared to S0).

5. Conclusions

The results of the preliminary studies aimed at assessing the usefulness of composted willow wood biomass as a horticultural substrate were promising. The findings showed a high value of biotransformed plant material, and confirmed the possibility of using it as a substrate in various modifications together with peat for the production of young tomato plants. Composted willow biomass complies with the criteria set by EGTOP and can replace up to 25% of peat volume in horticultural substrates.

Indicators characterizing the development and growth of staked tomato plants in the best substrates with willow compost were not lower than, and in the case of SFN:P (willow:peat in the proportion of 25:75%), exceeded the indicators of plants obtained on peat.

Observations of the plants and the results of the study showed the need for further experiments to optimise the composting process and to obtain a substrate that would not have a negative effect on plant growth. It turned out that the addition of nitrogen (in SN or SFN variants) had a negative effect on tomato plant growth. In homogeneous willow substrates from these treatments, plant loss or deformation, typical of the symptoms of nitrogen excess, was observed. Ensuring an optimum C:N ratio for proper composting and, at the same time, an appropriate chemical composition of the substrate is one of the most important research goals in this area.

Further research should be concerned with the possibility of replacing peat with other organic materials, with the aim of reducing peat exploitation.

6. Patents

Some of the results presented in this article were used in a patent filed on 28 June 2020 at the Polish Patent Office under No. P.435103. A legal procedure is currently underway.

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