Potato Research
https://doi.org/10.1007/s11540-024-09747-8

Effect of Different Covering Treatments on Chemical Composition of Early Potato Tubers

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Received: 18 July 2023 / Accepted: 2 June 2024

Abstract

Potatoes hold a significant position as one of the most important crops. Their value lies not only in their nutritional composition but also in their function as raw materials for various processing purposes. Furthermore, the cultivation of early potatoes carries considerable agrotechnical importance due to their ability to serve as the initial crop in intensive crop rotation, optimizing the utilization of agricultural soil. The primary objective of its production is to reach a consistent and high yield of premium quality. Additionally, the aim is to enter the market as early as possible and maximize profitability. To achieve these goals, producers utilize specific covering treatments such as mulching and plant covering to ensure earlier and safer production, thus maximizing profits. Our research aimed to determine the impact of different covering treatments (biodegradable mulch, agrotextile, low tunnel) on the chemical composition of early potato tubers. A 3-year field experiment was managed in Begeč (Serbia) with two early potato cultivars, Cleopatra and Riviera. The tested covering treatments significantly influenced the quality of early potatoes, by increasing the content of dry matter, starch, vitamin C, cellulose, and ash in the tubers and by reducting sugar and nitrate content.

Keywords Agronomic techniques · Early potatoes · Mulching · Nutritional composition · Plant covering

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Published online: 29 July 2024

Introduction

Due to its high nutritional value and ability to thrive in challenging environments, the potato is a highly significant tuber crop that plays a crucial role in providing food security for the growing global population. As such, it has the potential to become the third staple food worldwide (Devaux et al. 2021).

Unpeeled raw potato contains 18.4% carbohydrates, 2.0% protein, 2.2% dietary fiber, 0.8% sugars, and 0.1% fat. Furthermore, its tuber is a valuable dietary source of calcium, iron, manganese, and vitamins C, B3, and B6. The most recent review study reveals potato's role in diverse disease prevention, like diabetes, hypertension, cancer, obesity, hyperlipidemia, and its great anti-inflammatory potential and positive effect on intestinal health (Raigond et al. 2023).

Potatoes are used in industry on a large scale, especially in the food industry, where the main products are chips and French fries, as well as in the starch and alcohol industry (due to high starch content). For this reason, the chemical composition of potatoes is of primary importance. The dry matter content should be high to avoid too much fat absorption. On the other hand, the content of reducing sugars (glucose and fructose) must be low since high concentrations lead to the appearance of the undesirable dark brown color of the product. Therefore, reducing sugar content variation represents a major problem for processors (Gikundi et al. 2023).

From all of the above, it is evident that potatoes are one of the most important crops, primarily because of their importance in nutrition, but also as raw material for processing. Due to the early harvest, early potatoes have great agrotechnical importance because they can be the first crop in intensive crop rotation, and this represents a better use of the agricultural land.

The imperative in early potato production is to achieve a high and stable yield of good quality. Also, one of the goals is to arrive on the market as early as possible and achieve maximum profit. Producers strive to achieve earlier and safer production by applying certain specific covering treatments, such as mulching and plant covering, to make higher profits.

Mulching and covering plants belong to the group of fundamental techniques in agriculture. Mulching is a widespread technique of applying organic or inorganic materials to the soil surrounding plants.

Organic mulches include straw, manure, wood chips, compost, and hay. These organic substances improve soil physical properties, water and nutrient retention, regulate temperature, and prevent soil erosion (Jabran 2019). Inorganic mulches use plastic materials such as polyvinyl chloride (PVC) or polyethylene films. This agricultural technique serves as an obstacle to the growth of weeds (Yimer 2020).

Plant covers include physical materials, such as frost cloth, shade cloth, or row covers, to protect plants from specific environmental conditions. For example, frost fabric protects plants during cold periods by retaining heat and mitigating frost damage. Similarly, shade cloth protects plants during extremely high temperatures. Row covers, which function as a physical barrier, protect plants from pests and extreme weather conditions while allowing sunlight and water to reach the plants.

Recent research showed that plastic mulching improves yield in rice production (Gao et al. 2023), crop production in China (Xiao et al. 2023), maize production (Chen et al. 2023), and in the wheat-summer maize rotation (Li et al. 2022). Furthermore, previous research concluded that the chemical composition of potato tubers is affected by mulching (Wadas et al. 2006; Wadas 2012; Rębarz et al. 2015; Schönhals et al. 2016; min Liang et al. 2018; Hou et al. 2019, Li et al. 2019; Sekhon et al. 2020). Microplastic contamination in agroecosystems is a growing concern for environmentalists, as it can negatively impact our health, climate change, and ecosystems. Agricultural practices, such as plastic mulching, are a significant source of microplastic in agroecosystems (Khalid et al. 2023; Xiong et al. 2023). To address this issue, farmers need to adopt sustainable practices, such as the use of bioplastic substances for mulching (Somanathan et al. 2022).

Potatoes have a unique combination of carbohydrates, vitamins, minerals, and other nutrients. Understanding this nutrient combination is highly important, as it provides valuable insights into their nutritional value and potential health benefits. Considering the great economic importance and nutritional value of early potatoes, this research aimed to determine the exact impact of different covering treatments (biodegradable mulching, agrotextile, low tunnel) on the quality of early potato tubers.

Materials and Methods

Description of the Locality

A 3-year field experiment was conducted in Begeč (45°14′35″N; 19°36′31″E), located in South Bačka District, AP Vojvodina, Serbia, to evaluate the impact of specific covering treatments on the quality of early potatoes. The soil in this area consists of alluvial deposits with a carbonate chernozem type. Prior to commencing the experiment, a soil analysis was performed on samples collected from a 30 cm depth before potato cultivation began (Table 1).

Planting was carried out on March 17, 2019, and March 23, 2020; in the third year, 2021, planting was on March 21. A part of the elementary plot of 10 m^2 was left to determine the yield per hectare. The yield of early potatoes was determined, in tons per hectare, after the last sampling.

The climate data for the three experimental years are presented in Fig. 1 (precipitation) and Fig. 2 (temperature). Based on the total amount of precipitation, and comparing it with multi-year values, it can be concluded that the examined

Table 1 The results of the soil analysis

Depth	pH, KCl	pH, H_2O	$CaCO_3$ (%)	Humus (%)	Total N (%)	Al P_2O_5 (mg/100 g)	Al K_2O (mg/100 g)
0–30 cm	7.14	7.87	3.26	2.34	0.234	20.6	31.5

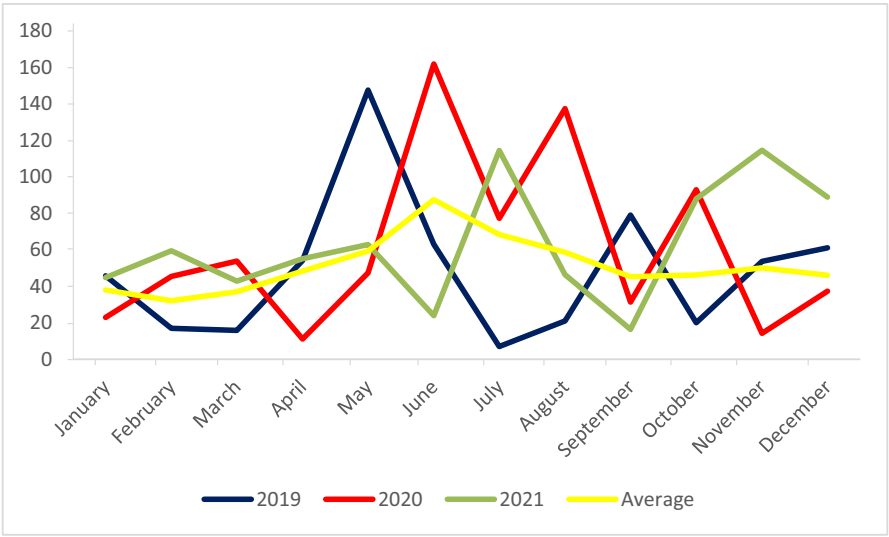

Fig. 1 Precipitation data (in mm) during the 3-year experiment (2019, 2020, 2021) and average values

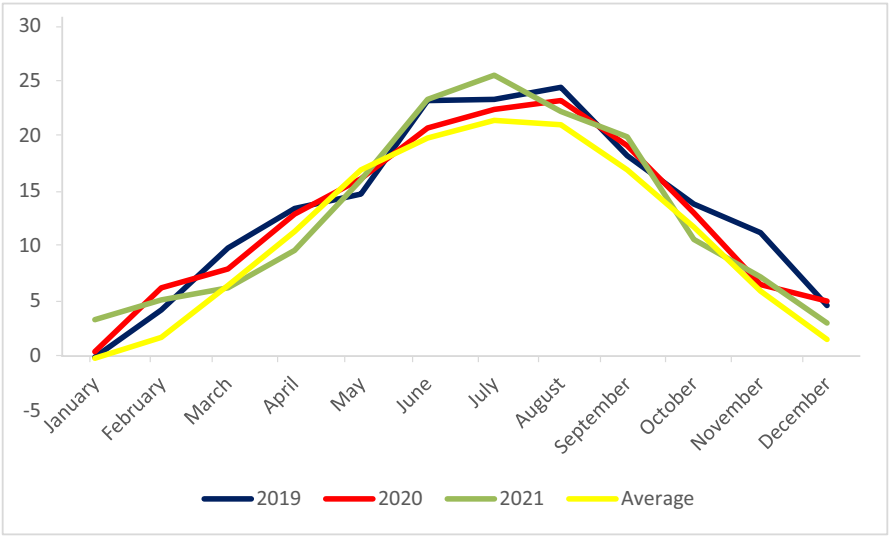

Fig. 2 Temperature data (in °C) during the 3-year experiment (2019, 2020, 2021) and average values

years were wet and relatively suitable for potato production. By comparing temperature data with the multi-year average temperature, it can be concluded that, in all three experimental years, the temperature conditions were at the level of average values.

Experimental Design and Treatments

Two early potato cultivars were used in the research: Cleopatra and Riviera. Cleopatra (HZPC-The Netherlands) is one of the most notable early cultivars (85–90 days). This cultivar is of medium height, medium branched, and well-covered with leaves. It has fast growth, good soil coverage, and forms 8–9 large, oval tubers with red skin and light yellow flesh color. Riviera (Agrico-Holland) is an early variety (80–85 days). It has good initial growth, so it covers land well. It forms 8–9 oval-round, large tubers with yellow skin and light yellow flesh color (Broćić and Stefanović 2012).

The experiment was set up according to a split-plot design, in five replications. Varieties (factor a_1—Cleopatra and a_2—Riviera) were located in the main plots, and production methods were analyzed within them (b_1—control variant; b_2—mulching (F), b_3—agrotextile (A); b_4—low tunnel (T); b_5—mulching and agrotextile (FA); b_6—mulching and low tunnel (FT); b_7—agrotextile and low tunnel (AT); and b_8—mulching, agrotextile, and low tunnel (FAT)).

Mulching, covering the plants with agrotextile, and setting up low tunnels, were done immediately after planting the tubers. The mulching was done by machine (polyethylene film with a thickness of 0.012 mm and a width of 120 cm), while covering the plants with agrotextile ("Agryl" mass 17 g/m^2), and setting low tunnels (polyethylene film with a width of 1.5 m and a thickness of 0.05 mm) were done manually.

Applied Agricultural Technology

The standard technology of intensive production of early potatoes was implemented during the 3 years. All agronomic techniques were performed within optimal deadlines as per a timely schedule. Prior to potato cultivation, carrots were the pre-crop for all years under evaluation. Soil chemical analysis was conducted annually, and fertilization was carried out with 300 kg/ha of NPK formulation 5:14:28 for the basic treatment and 150 kg/ha of AN before planting.

Planting was mechanized using one tuber per hill with ridge formation in March's third decade for the second and third year and in the second decade of March in the first year. The inter-row distance during planting was 65 cm, and the distance between plants in a row was 30 cm. Standard agronomic techniques were applied during the growing season.

Analytical Methods

Samples for determining the chemical composition of tubers were taken 85 days after planting. The analysis was done in the average sample per repetition and treatment, for each studied cultivar. The following characteristics were analyzed: dry matter content (%), starch content (%), total sugar content (%), reducing

sugar content (%), sucrose content (%), nitrate content (%), vitamin C content (mg/100 g), cellulose content (%), and ash content (%).

The oven drying method (AOAC 2006) was used to determine the dry matter content. Similarly, ash content was determined by ashing the residue of moisture determination for 24 h at 550 °C (AOAC 2006).

During the analysis of the potato samples, AOAC Method 969.39 and AACC Method 76–13.01 were employed to examine the starch content. Furthermore, AOAC 920.181 and AOAC 923.09 were utilized for the determination of total sugars and reducing sugars, respectively. In addition, AOAC Method 980.13 was employed to determine the sucrose content, while AOAC 984.13 was utilized for the determination of nitrate levels in the potato samples. The vitamin C content of the potatoes was determined using the AOAC 967.21 method. Lastly, the cellulose content of the potato samples was determined using AOAC 962.09. Total protein, total lipids, and dietary fiber were determined using AOAC (2012).

Statistical Analysis

The data were analyzed using the statistical software GenStat Release 9.1, available from the Rothamsted Experimental Station. The analysis of variance was conducted based on average mean values, utilizing the split-plot model. Mean values were compared using the LSD test at significance levels of 0.05 and 0.01.

A multivariate analysis of variance (MANOVA) was performed at a significance level $p < 0.001$, using SPSS software, version 21.0 (IBM Corporation, New York, USA).

Results

The quality parameters of the tubers are reflected in its chemical composition, such as the content of dry matter, starch, total and reducing sugars, sucrose, nitrates, protein, minerals, vitamins, etc.

Potato Yield

Over the 3-year investigation, the average yield was 37.51 t/ha (Table 2). Across all treatments, the Riviera variety reached a slightly higher yield (by 750 kg/ha) than cv. Cleopatra. Nevertheless, the observed difference in comparison to the Cleopatra variety was not statistically significant.

On average, for both varieties, the recorded yield within the control treatment was 32.14 t/ha, and it was statistically significantly lower than within all the other tested treatments.

The yield of tubers in the control was lower by 12–25% compared to treatments with cover. The highest yield was recorded with the AT treatment (40.07 t/ha), and this value was statistically significantly higher ($p < 0.01$) than with treatments F and FA.

Significantly higher yield, at level 0.01, compared to variant F, was also recorded at treatments A and T. Differences between other tested treatments were not statistically significant.

Table 2 Average potato yield (t/ha) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	31.82^{b}	35.08^{ab}	39.71^{a}	38.09^{a}	36,03^{ab}	37.51^{a}	39.83^{a}	38.95^{a}	37.13
Riviera	32.46^{b}	36.89^{ab}	39.07^{a}	40.10^{a}	37.28^{a}	37.95^{a}	40.31^{a}	39.01^{a}	37.88
Average (B)	32.14^{d}	35.98^{c}	39.39^{ab}	39.10^{ab}	36.66^{bc}	37.73^{abc}	40.07^{a}	38.98^{abc}	37.51
		A		B		B × A		A × B	
LSD $_{0.05}$		1.84		2.36		3.55		3.28	
LSD $_{0.01}$		3.11		3.08		4.80		4.39	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Tuber Dry Matter Content

The average content of dry matter in early potato tubers for a 3-year research period was 16.94% (Table 3). The cultivar Cleopatra (17.47%) reached a slightly higher content of dry matter than the Riviera cultivar (16.42%), in the same period, but this difference was not statistically significant.

Compared to the control treatment (15.41%), the average dry matter content of both potato cultivars was significantly higher across all treatments. The Cleopatra cultivar consistently exhibited higher dry matter content across all treatments than the Riviera cultivar, with the difference being significant only between control and AT treatment. The highest dry matter content was recorded in treatment AT (18.15%).

Table 3 Average dry matter content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	16.04^{b}	17.49^{ab}	17.12^{ab}	17.61^{ab}	17.58^{ab}	17.90^{ab}	18.15^{a}	17.84^{ab}	17.47
Riviera	14.79 ^{b}	16.04^{ab}	16.55^{ab}	16.51^{ab}	16.66^{ab}	16.99^{a}	16.90^{a}	16.93^{a}	16.42
Average (B)	15.41^{b}	16.77^{a}	16.84^{a}	17.06^{a}	17.12^{a}	17.45^{a}	17.52^{a}	17.38^{a}	16.94
		A		B		B × A		A × B	
LSD $_{0.05}$		0.75		1.03		1.44		1.44	
LSD $_{0.01}$		1.25		1.33		1.92		1.90	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

The Riviera cultivar had the lowest dry matter content among all treatments in the control (14.79%), with the difference being highly significant ($p < 0.01$) compared to FT, AT, and FAT treatments. The dry matter content was consistent across all treatments.

Starch, Total Sugars, Reducing Sugars, Sucrose, Cellulose, Ash, Nitrate, Vitamin C

Starch

Over the 3-year experiment, the average starch content was recorded as 15.17% (Table 4). The cultivar Cleopatra exhibited significantly higher starch content on average than the Riviera cultivar. For both varieties, the lowest average starch content (13.72%) was observed in the control treatment, while all other treatments resulted in significantly higher starch content (ranging from 15.09 to 15.79%).

Regarding the Cleopatra cultivar, the application of the AT treatment resulted in the highest starch content (16.35%), while the control variety exhibited the lowest starch content (14.66%). Similarly, the Riviera variety had the lowest starch content in the control treatment (12.77%), with all other tested treatments achieving statistically significantly higher starch content (ranging from 14.69% to 15.23%), except the A treatment ($p < 0.01$).

Total Sugars

The total sugar content of tubers (Table 5) for the Cleopatra cultivar was slightly higher than that of the Riviera cultivar, although this difference was not statistically significant.

On average, both cultivars exhibited the highest total sugar content (0.6623%) in the control treatment, with the difference being highly significant compared to all other examined treatments. Treatment F (0.5763%) resulted in a higher percentage of total sugars, with the difference being highly significant at both levels, compared to other treatments, except with the FAT treatment.

Table 4 Average starch content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	14.66[a]	15.30 [a]	15.70[a]	15.74[a]	15.42[a]	15.76[a]	16.35[a]	15.75[a]	15.59
Riviera	12.77[b]	14.89[a]	14.69[ab]	15.14[a]	14.80[a]	15.39[a]	15.23[a]	15.07[a]	14.75
Average (B)	13.72[b]	15.09[a]	15.20[a]	15.44[a]	15.11[a]	15.57[a]	15.79[a]	15.41[a]	15.17
		A		B		B × A		A × B	
$LSD_{0.05}$		0.66		1.01		1.46		1.44	
$LSD_{0.01}$		1.11		1.35		2.02		1.96	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Table 5 Average total sugars content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0.6673^{a}	0.6100^{ab}	0.4927^{c}	0.4853^{c}	0.5420^{bc}	0.5393^{bc}	0.5013^{c}	0.5273^{c}	0.5457
Riviera	0.6573^{a}	0.5427^{b}	0.4940^{b}	0.5153^{b}	0.4880^{b}	0.4933^{b}	0.5000^{b}	0.5560^{b}	0.5308
Average (B)	0.6623^{a}	0.5763^{b}	0.4933^{c}	0.5003^{c}	0.5150^{c}	0.5163^{c}	0.5007^{c}	0.5417^{bc}	0.5383
		A		B		B × A		A × B	
$LSD_{0.05}$		0.0257		0.0429		0.0611		0.0605	
$LSD_{0.01}$		0.0423		0.0573		0.0817		0.0807	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Reducing Sugars

The average reducing sugar content was 0.2854% (Table 6). On the 3-year average, the Riviera cultivar had a statistically significantly lower percentage of reducing sugars (0.2595%) compared to the Cleopatra cultivar (0.3113%).

On average, both cultivars on all tested treatments had a highly significantly lower content of reducing sugars ($p < 0.01$) compared to the control variety (0.4300%). In addition to the control, treatment F (0.3017%) achieved a very significantly higher content compared to the treatments A, T, FA, FT, AT, and FAT, while the treatment FA was statistically highly significantly higher compared to the treatments A, T, and AT. Treatment FT had a statistically significantly higher percentage of reducing sugars compared to treatments T and AT.

Compared to the Riviera cultivar, the Cleopatra cultivar achieved a higher content within all treatments, and the differences were very significant in the F, FA, FT, AT, and FAT treatments.

Table 6 Total reducing sugars content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0.4307^{a}	0.3793^{b}	0.2600^{e}	0.2373^{e}	0.2967^{cd}	0.3133^{c}	0.2693^{de}	0.3033^{cd}	0.3113
Riviera	0.4293^{a}	0.2240^{b}	0.2413^{b}	0.2253^{b}	0.2560^{b}	0.2347^{b}	0.2273^{b}	0.2380^{b}	0.2595
Average (B)	0.4300^{a}	0.3017^{b}	0.2507^{def}	0.2313^{f}	0.2763^{c}	0.2740^{cd}	0.2483^{ef}	0.2707^{cde}	0.2854
		A		B		B × A		A × B	
$LSD_{0.05}$		0.0149		0.0184		0.0277		0.0265	
$LSD_{0.01}$		0.0244		0.0245		0.0366		0.0345	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Table 7 Average sucrose content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0.2260^{a}	0.2193^{a}	0.2213^{a}	0.2367^{a}	0.2333^{a}	0.2153^{a}	0.2200^{a}	0.2140^{a}	0.2233
Riviera	0.2167^{b}	0.3033^{a}	0.2393^{ab}	0.2760^{ab}	0.2207^{b}	0.2460^{ab}	0.2573^{ab}	0.3033^{a}	0.2578
Average (B)	0.2213^{a}	0.2613^{a}	0.2303^{a}	0.2563^{a}	0.2270^{a}	0.2307^{a}	0.2387^{a}	0.2587^{a}	0.2405
		A		B		B × A		A × B	
$LSD_{0.05}$		0.0258		0.0428		0.0598		0.0599	
$LSD_{0.01}$		0.0429		0.0568		0.0781		0.0793	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Sucrose

The average sucrose content was consistent across both cultivars, with a range from 0.2213% in the control treatment to 0.2613% in the F treatment (Table 7). As such, there was no statistically significant difference observed between the treatments for sucrose content.

Cellulose

The average cellulose content of early potato tubers was determined to be 0.4536% (Table 8). The Cleopatra cultivar exhibited a significantly higher percentage ($p<0.01$) of cellulose compared to the Riviera cultivar. On average, both cultivars demonstrated a significantly higher percentage ($p<0.01$) of cellulose in all tested treatments compared to the control treatment.

The highest cellulose content was observed in treatment T (0.5027%), which was highly significantly higher than treatment A, and significantly higher than treatments

Table 8 Average cellulose content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0.3667^{b}	0.5133^{a}	0.5053^{a}	0.4793^{a}	0.5133^{a}	0.4887^{a}	0.5287^{a}	0.5193^{a}	0.4893
Riviera	0.2673^{d}	0.4647^{ab}	0.3733^{c}	0.5260^{a}	0.4187^{bc}	0.4780^{ab}	0.4220^{bc}	0.3933^{c}	0.4179
Average (B)	0.3170^{c}	0.4890^{a}	0.4393^{b}	0.5027^{a}	0.4660^{ab}	0.4833^{ab}	0.4753^{ab}	0.4563^{ab}	0.4536
		A		B		B × A		A × B	
$LSD_{0.05}$		0.0180		0.0357		0.0495		0.0511	
$LSD_{0.01}$		0.0299		0.0479		0.0690		0.0661	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

FAT and FA. Treatment F exhibited a very significant improvement in cellulose content compared to treatment A.

For the Cleopatra cultivar, all treatments exhibited a relatively uniform percentage of cellulose (0.4793–0.5287%), except for the control treatment (0.3667%), which was very significantly lower than all other treatments.

The highest cellulose content for the Riviera cultivar (0.5260%) was observed in treatment T, with the difference being highly significantly higher than treatments A, FAT, FA, AT, and control.

Ash

The ash content of the examined potato cultivars (Table 9) was found to be uniform, with no statistically significant difference observed at level 0.05. However, significant differences were noted between cultivars in treatments T and AT, while a highly significant difference was observed in the treatment FAT when comparing the ash content over three years.

Within the Cleopatra cultivar, the highest percentage of ash was recorded in treatments FA (1.1740%) and FAT (1.1727%). The lowest ash content was observed in the control treatment (0.8693%), which was very significantly lower than treatments FA, FAT, T, FT, AT, and F.

In the Riviera cultivar, the control had the lowest ash content in the tubers (0.9507%). Treatments AT (1.2560%) and FA (1.2307%) had the highest percentage of ash and were statistically significantly higher than the control and treatments T, FAT, A, and FT.

Nitrate

The average nitrate content in early potato tubers was 176.69 mg/kg (Table 10). On average, the nitrate content of the Cleopatra cultivar (179.01 mg/kg) was higher than the Riviera cultivar (174.36 mg/kg). However, this difference was not statistically significant.

Table 9 Average ash content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0.8693^{c}	1.0827^{ab}	0.9780^{bc}	1.1327^{ab}	1.1740^{a}	1.1200^{ab}	1.1087^{ab}	1.1727^{a}	1.0798
Riviera	0.9507^{c}	1.1547^{ab}	1.0287^{bc}	0.9887^{c}	1.2307^{a}	1.0353^{bc}	1.2560^{a}	1.0067^{bc}	1.0814
Average (B)	0.9100^{e}	1.1187^{abc}	1.0033^{de}	1.0607^{cd}	1.2023^{a}	1.0777^{bcd}	1.1823^{ab}	1.0897^{abcd}	1.0806
		A		B		B × A		A × B	
$LSD_{0.05}$		0.0406		0.0860		0.1201		0.1221	
$LSD_{0.01}$		0.0674		0.1151		0.1608		0.1632	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Table 10 Average nitrate content (mg/kg) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	205.20^{a}	184.57^{ab}	185.57^{ab}	173.00^{b}	173.97^{b}	169.70^{b}	171.00^{b}	169.20^{b}	179.01
Riviera	194.93^{a}	179.43^{ab}	181.37^{ab}	169.37^{b}	179.70^{ab}	161.07^{b}	167.40^{b}	161.60^{b}	174.36
Average (B)	200.07^{a}	181.95^{b}	183.47^{b}	171.18^{bc}	176.83^{bc}	165.38^{c}	169.20^{bc}	165.40^{c}	176.69
		A		B		B × A		A × B	
LSD $_{0.05}$		9.31		12.16		17.55		17.14	
LSD $_{0.01}$		15.51		16.15		23.45		22.87	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

The highest average nitrate content in both potato varieties was observed in the control treatment, measuring 200.07 mg/kg. This difference was statistically highly significant ($p < 0.01$) in comparison to all other tested treatments.

Conversely, the lowest nitrate content was recorded in the FT (165.38 mg/kg) and FAT (165.40 mg/kg) treatments, which were highly significantly lower ($p < 0.01$) than variants A and F, and significantly lower ($p < 0.05$) than the FA treatment. A statistically significant difference was also observed between treatments AT and T, in comparison to variants A and F.

The Cleopatra cultivar exhibited higher nitrates content across all treatments compared to the Riviera cultivar, except for treatment FA, although this difference was not statistically significant.

Vitamin C

The average content of vitamin C in early potato tubers was 17.57 mg/100 g (Table 11). In the 3-year average, for all treatments, the Cleopatra cultivar had

Table 11 Average vitamin C content (mg/100g) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	17.29^{a}	17.69^{a}	17.77^{a}	18.25^{a}	18.97^{a}	18.56^{a}	18.56^{a}	18.56^{a}	18.21
Riviera	15.61^{a}	16.73^{a}	17.03^{a}	16.96^{a}	17.40^{a}	17.30^{a}	17.33^{a}	17.10^{a}	16.93
Average (B)	16.45^{b}	17.21^{ab}	17.40^{ab}	17.61^{ab}	18.19^{a}	17.93^{ab}	17.94^{ab}	17.83^{ab}	17.57
		A		B		B × A		A × B	
LSD $_{0.05}$		0.93		1.15		1.61		1.62	
LSD $_{0.01}$		1.47		1.53		2.22		2.10	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

higher vitamin C content by 7%, and this difference compared to the Riviera cultivar was significantly higher ($p < 0.05$).

In the 3-year average for both varieties, the lowest content was obtained on the control (16.45 mg/100 g), i.e. treatments AT, FT, FAT, and T achieved significantly higher ($p < 0.05$), and variant FA (18.19 mg/100 g) very significantly higher content ($p < 0.01$) of vitamin C compared to the control.

Protein, Lipid, Dietary Fiber

Protein

The average protein content in the early potato tubers was 1.888% (Table 12). Cleopatra cultivar had the highest protein content within the AT treatment (1.927%) and the lowest within the control (1.864%). This value was highly statistically significantly lower ($p < 0.01$) than values within treatments. There was no highly statistically significant difference between protein content within treatments.

In contrast, the Riviera cultivar had the highest value of protein content within the control treatment (1903%) and the lowest within the AT treatment. There was no highly statistically significant difference between protein content within treatments and control, observed at level 0.05.

Lipid

The lipid content of the examined potato cultivars (Table 13) was found to be uniform, with no statistically significant difference observed at both levels within both cultivars. The Cleopatra cultivar had a higher average value, which was statistically highly significantly higher ($p < 0.01$) than the average value of the Riviera cultivar.

Table 12 Average protein content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	1,864[a]	1,914[a]	1,877[a]	1,875[a]	1,876[a]	1,925[a]	1,927[a]	1,888[a]	1,893
Riviera	1,903[a]	1,893[a]	1,897[a]	1,880[a]	1,877[a]	1,873[a]	1,871[a]	1,874[a]	1,884
Average (B)	1,883[a]	1,904[a]	1,887[a]	1,878[a]	1,877[a]	1,899[a]	1,899[a]	1,881[a]	1,888
		A		B		B × A		A × B	
LSD $_{0.05}$		0,027		0,044		0,062		0,068	
LSD $_{0.01}$		0,044		0,059		0,083		0,098	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Table 13 Average lipid content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0,897[a]	0,877[a]	0,908[a]	0,899[a]	0,877[a]	0,882[a]	0,903[a]	0,901[a]	0,893
Riviera	0,472[a]	0,454[a]	0,465[a]	0,473[a]	0,455[a]	0,473[a]	0,458[a]	0,451[a]	0,463
Average (B)	0,685[a]	0,665[a]	0,686[a]	0,686[a]	0,666[a]	0,678[a]	0,681[a]	0,676[a]	0,678
		A		B		B × A		A × B	
LSD $_{0.05}$		0,011		0,024		0,033		0,035	
LSD $_{0.01}$		0,019		0,031		0,045		0,049	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Dietary Fiber

The average value of dietary fiber was 0.556% (Table 14). As was the case for the lipid content, the dietary fiber content was found to be uniform, with no statistically significant difference observed at both levels within both cultivars. The Cleopatra cultivar had a higher average value, which was statistically significantly higher ($p < 0.01$) than the average value of the Riviera cultivar.

MANOVA

The results of MANOVA analysis regarding the Cleopatra cultivar (Table 15), and Riviera cultivar (Table 16) indicated that the influence of treatment and climatic factors, as well as the interaction between treatment and climatic factors, were highly significant at level $p < 0.001$.

Table 14 Average dietary fiber content (%) in studied cultivars (Cleopatra and Riviera) under different methods of covering

Variety (A)	Treatment (B)								Average (A)
	Control	F	A	T	FA	FT	AT	FAT	
Cleopatra	0,664[a]	0,676[a]	0,679[a]	0,666[a]	0,665[a]	0,687[a]	0,669[a]	0,672[a]	0,672
Riviera	0,439[a]	0,449[a]	0,437[a]	0,436[a]	0,449[a]	0,441[a]	0,435[a]	0,436[a]	0,440
Average (B)	0,551[a]	0,562[a]	0,558[a]	0,551[a]	0,557[a]	0,564[a]	0,552[a]	0,554[a]	0,556
		A		B		B × A		A × B	
LSD $_{0.05}$		0,017		0,019		0,027		0,033	
LSD $_{0.01}$		0,028		0,026		0,037		0,050	

F, mulching; *A*, agrotextile; *T*, low tunnel; *FA*, mulching and agrotextile; *FT*, mulching and low tunnel; *AT*, agrotextile and low tunnel; *FAT*, mulching, agrotextile, and low tunnel

Different letters in a row show statistically significant differences ($p < 0.01$)

Table 15 MANOVA table reporting the results of a multivariate comparison evaluating the influence of treatment and climatic factors, as well as the interaction of treatment and climatic factors on the studied traits of early potatoes of Riviera cultivar

	Df	Wilks' lambda	*f* value	*p* value
Treatment	91	0.005	7875	< 0.001
Year	26	0.013	49,935	< 0.001
Treatment×Year	182	0.012	2659	< 0.001

Table 16 MANOVA table reporting the results of a multivariate comparison evaluating the influence of treatment and climatic factors, as well as the interaction of treatment and climatic factors on the studied traits of early potatoes of Cleopatra cultivar

	Df	Wilks' lambda	*f* value	*p* value
Treatment	91	0.003	8897	< 0.001
Year	26	0.003	117,335	< 0.001
Treatment×Year	182	0.018	2388	< 0.001

Discussion

The chemical composition of potatoes varies depending on many agroecological and production factors—soil, fertilization, climatic conditions, predominantly temperature, quantity and distribution of precipitation, sunlight, relative humidity, etc. as well as from the genetic characteristics of the cultivar and conditions during storage (Galdón et al. 2012; Ierna and Mauromicale 2022; Li et al. 2023).

The results obtained in this study indicate that applied covering treatments influenced the chemical composition, thus the nutritional quality of early potatoes.

Our results indicated that all applied treatments achieved a higher yield. The highest yield was reached using a combination of agrotextile and low tunnel (40.07 t/ha), but also with a single use of agrotextile (39.39 t/ha) and low tunnel (39.10 t/ha). These results are in accordance with previously published data (Mahmood et al. 2002; Hou et al. 2010), which highlight the positive effect of mulching on potato yield. Singh and Ahmad (2008) recorded the highest yield in the variant mulched with black polyethylene film (35.2 t/ha), while the lowest yield was recorded within the control treatment (26.6 t/ha). In their research, Ibarra-Jimenez et al. (2011) obtained a significantly higher yield of potatoes with mulching with plastic foils than on bare soil.

The average percentage of dry matter was 16.94%, which is a low content compared to earlier research on other early potato cultivars (Galdón et al. 2012; Zhou et al. 2017). Potato cultivars, such as Cleopatra and Riviera, mature early and usually have higher moisture and lower dry matter content than other potato cultivars (Nayak et al. 2014; Pinhero et al. 2016).

The content of dry matter in the tubers of the Cleopatra cultivar was higher in the 3-year average by 1.05% compared to the content in the Riviera cultivar, which

is consistent with earlier reports that dry matter content is a characteristic feature of the cultivar (Chung et al. 2014; Sim et al. 2023).

Our results indicated that all examined covering treatments had a significant effect on the dry matter content in early potato tubers. The highest dry matter content was achieved with the AT treatment (17.52%), which also reached the highest yield (40.31 t/ha). All treatments resulted in a higher dry matter content in the tubers (by an average of 1.75%) compared to the control variant, which was also concluded in earlier research (Rębarz et al. 2015; min Liang et al. 2018; Sekhon et al. 2020).

Furthermore, Jablonska-Ceglarek and Wadas (2005) determined that by covering early potatoes, the content of dry matter increased by 0.81%, while Wadas et al. (2003) and Wadas et al. (2004) recorded an increase in the dry matter by 1.17% and 1.29%, respectively.

Starch is the main component in potato tubers. Galdón et al. (2012) stated that starch makes up 60–80% of dry matter in potato tubers. The results of this research indicated that the average starch content in early potato tubers was 15.17%. The obtained research results are in line with the results of other authors. Their findings indicated that the starch content in potato tubers of Central European cultivars ranged from 10 to 17% (Schönhals et al. 2016; Li et al. 2019). The Cleopatra cultivar had higher starch content in all three examined years than the Riviera cultivar. These results are consistent with earlier findings that starch content is a cultivar characteristic (Galdón et al. 2012; Leonel et al. 2017a, b; Zhao et al. 2018).

Furthermore, the research results indicated that the applied covering treatments had a significant positive impact on the starch content in early potato tubers, i.e., the tubers from all tested treatments had a higher starch percentage than the control variant.

In our study, as in studies by Hou et al. (2019), Rębarz et al. (2015), and Wadas et al. (2006), higher starch contents were found in tubers grown with mulching with polyethylene foil and direct coverage of plants with agrotextile compared to tubers grown without cover.

The average sugar content was 0.5383%. The obtained results, looking at the 3-year average, indicated that the highest content of total sugars was in the control variant (0.6623%). The starch content in potato tubers was positively associated with the content of dry matter, while it was negatively associated with sugars (Hou et al. 2019).

The average content of sucrose in our study varied from 0.2167 to 0.3033%. These results are in line with some data reported in the literature. Galdón et al. (2010) reported a mean sucrose content of 3.87 ± 2.62 g kg^{-1}. Furthermore, Amrein et al. (2003) studied 74 potato samples from 17 different cultivars and discovered sucrose contents ranging from 1.72 to 6.40 g kg^{-1}.

The difference in the sucrose content of the potato tubers in the studied cultivars coincides with earlier claims that the sucrose content is a cultivar characteristic (Chung et al. 2013; Gikundi et al. 2023).

The obtained results indicated that mulching and direct covering of potatoes with and without a supporting structure, as well as the combination of these three covering treatments, affected the cellulose content in potato tubers. The lowest cellulose

content was recorded on the control treatment (0.3170%). All other applied treatments showed highly significantly higher cellulose content in the tubers.

The average ash content in early potato tubers was 1.0806%. A statistically significant difference between the examined cultivars was recorded. Hence, the results showed that the ash content was a cultivar characteristic. The same statement was emphasized by Abbas et al. (2011).

The highest ash content was observed within the FA treatment (1.2023%). The percentage of ash within the other treatments ranged from 1.0033 to 1.1823%, while it was the lowest within the control treatment (0.9100%). Accordingly, the applied treatments affected the ash content in early potato tubers.

According to Ierna (2009), there is a growing worldwide demand for early potatoes that are harvested at varying stages of maturity. The same author further emphasizes the necessity and importance of determining the content of nitrates in early potato tubers and assessing the risk of their consumption.

Burlingame et al. (2009) indicated that, although potatoes do not belong to the group of vegetables that contain a high concentration of nitrates, due to their almost daily use in the diet, they significantly contribute to the daily amount of nitrates taken into the body. For this reason, Ierna (2009) conducted research in 2005 and 2006 in Sicily and studied the influence of the variety and time of extraction tubers on nitrate content. Among other things, it was established that regardless of the variety and time extraction of potato tubers, the nitrate content was negatively correlated with the mass of the tuber as well as with dry matter content.

The nitrate accumulation in potato tubers poses a threat to food safety; therefore, discovering a new approach to lower this accumulation to the adequate limit is an important matter (Elrys et al. 2021). Several countries in the EU have suggested that potato tubers should have less than 200 mg NO_3^- by 1 kg of fresh weight (Abdo et al. 2020). The average content of nitrates in our experiment was 180.02 mg/kg, which is in accordance with the previously mentioned suggestions.

Our experiment results indicated that the applied covering treatments significantly influenced the nitrate content in the tubers. On average, all tested varieties had lower nitrate content in tubers compared to the control variety. Lachman et al. (2003) concluded that covering new potatoes causes a reduction in nitrate accumulation by the tubers.

In addition to being a source of quality proteins and energy, potatoes are also a valuable source of vitamins and minerals (calcium, potassium, phosphorus). Regardless, the importance of potatoes in our diet, particularly as a source of vitamin C, is often underestimated or ignored (Galdón et al. 2012).

Raigond et al. (2023) claimed that potatoes are the primary source of ascorbic acid in the diet in developed countries, despite the modest content (19.7 mg/100 g of fresh material), due to a large amount of daily consumption. In our experiment, the mean vitamin C content was 17.57 mg/100 g, which was consistent with earlier research (Galdón et al. 2012; Weichselbaum 2010), and with USDA Standard Reference Legacy, 170,032.

The Cleopatra cultivar tubers had a higher vitamin C content, statistically significantly higher at level $p < 0.05$, than the tubers of the Riviera cultivar, which

corresponds to the statement that the vitamin C content is a cultivar characteristic (Hamouz et al. 2006).

The results of our experiment indicated that the applied covering treatments had a significant influence on the vitamin C content in potato tubers. An increase in vitamin C was observed in all applied treatments compared to the control treatment. On average, the highest content was achieved within the variant FA (18.19 mg/100 g) and AT (17.94 mg/100 g).

These results coincide with the results reported by Wadas (2012) that the vitamin C content in early potato tubers increased from 15.77 to 22.14% in treatments with agrotextiles.

Research conducted in saline soil of India indicated better-quality potato tubers, in terms of carbohydrate, protein, fiber, dry matter, and fat content, without tillage and with mulching with paddy straw (Sarangi et al. 2021).

Other researchers that have experimented with plastic mulching suggested avoiding this agrotechnical measure because it negatively affects starch and vitamin C content, and therefore, the mulch should be removed at a convenient time (Hou et al. 2010; Wang et al. 2011).

In our research, the average protein content was in the range of 1.883 to 1.904%. Our results are in accordance with the results of previous studies (Bárta, et al. 2012; Bártova et al. 2012). The average lipids content ranged from 0.665 to 0.0686%, and the average dietary fiber ranged from 0.551 to 0.564; these results are in line with Leonel et al. (2017a, b).

Conclusion

In summary, the application of mulching, agrotextiles, and low tunnels in the production of early potatoes significantly impacted the quality and chemical composition of the tubers. The studied covering treatments resulted in a substantial increase in the dry matter content of the tubers. The highest dry matter content was within the agrotextile + low tunnel treatment (17.52%). Similarly, the agrotextile + low tunnel treatment resulted in the highest average starch content over 3 years. The content of reducing sugars varied between 0.2313 and 0.4300%, with the highest content within the control treatment.

The investigated covering treatments also significantly affected the reduction of nitrate content in early potato tubers, with the control treatment of the highest average nitrate content of 200.07 mg/kg over 3 years. Conversely, the highest vitamin C content was discovered within the mulching + agrotextile treatment (18.19 mg/100 g), while the control treatment had the lowest content (16.45 mg/100 g). All investigated treatments resulted in a higher cellulose and ash content than the control treatment.

Overall, the obtained research results suggest that the combined use of mulching, agrotextiles, and low tunnels can lead to better-quality potatoes, providing opportunities for the wide application of these specific covering treatments in early potato production.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11540-024-09747-8.

Funding This research was supported by Project:"Use of Trichoderma spp. in sustainable agriculture" (142–451-3172/2022–01/01) financed by the Provincial Secretary for Higher Education and Scientific Research, Autonomous Province of Vojvodina.

Declarations

Conflict of Interest The author declares no competing interests.

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