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Influence of Edible Potato Production Technologies with the Use of Soil Conditioner on the Nutritional Value of Tubers

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Abstract: The aim of this study was to determine the effect of the application of different organic matter, UGmax soil conditioner and simplifications in potato cultivation on the content of dry matter, starch and sugars in tubers of the medium-early edible cultivar 'Satina' after harvest and after long-term storage. The highest dry matter (173.4 g kg^{-1}) and starch (124.6 g kg^{-1} f. m.) content was obtained with the simultaneous application of a manure with soil conditioner at 100% mineral fertilization. In the case of sugars, the withdrawal of the soil conditioner from the crop proved most beneficial, for total sugars on the stubble intercrop (5.06 g kg^{-1} f. m.) and for reducing sugars (1.99 g kg^{-1} f. m.) in the case of straw treatment. Each protection reduction applied resulted in a significant reduction in starch content. In this regard, the withdrawal of herbicides with the simultaneous application of manure and UGmax proved most beneficial. Long-term storage of tubers caused a significant reduction in their quality in terms of dry matter and starch content (average by −3.6 and −2.3%, respectively) and an increase in total and reducing sugars (average by 11.8 and 9.6%, respectively). The decrease in dry matter and starch content was significantly influenced by the 50% reduction in NPK fertilization applied during the growing season, while the application of soil conditioner with full protection contributed to the increase in reducing sugars after storage at 28.9 pts%. Our research is in line with current trends of used potato cultivation technologies focused mainly on environmental protection, so the results of this study can provide a basis for validation for researchers currently engaged in such evaluation.

Keywords: *Solanum tuberosum* L.; organic matter; fertilization; soil conditioner; chemical protection; sugars; dry matter; starch

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1. Introduction

Along with wheat, corn and rice, the potato is the world's most important food security crop [1,2]. Its good market position is due to the high nutritional value of its tubers, its high consumption, its suitability for processing and its membership in the group of durable, storable vegetables [3–6].

In recent years, the strongest factors influencing food choices have been taste, healthiness and price [7,8]. Today, however, environmental considerations are also important determinants of food choices, especially for certain groups of consumers [8–10]. Consequently, there is great interest in producing food using methods with minimal negative impacts on the environment. This can be achieved by introducing controlled production systems, including organic farming. According to consumers, organic products are healthier, tastier and safer for the environment compared to those produced by conventional agriculture [11,12]. Environmental and consumer protection prompts the search for new opportunities through simplifications in crop production or the use of various agents such as immune stimulants, bacterial vaccines, algae extracts and effective preparations containing microorganisms [10,13–16]. Such substances include the soil conditioner UGmax, which, thanks to the microorganisms and elements contained in its composition, has the effect of processing, composting and humification of natural and organic fertilizers to create humus [17–19].

The production of edible potatoes should be based on natural fertilizers (manure, slurry), organic fertilizers (straw) or the use of catch crops, as well as balanced mineral fertilization [20–22]. Natural and organic fertilizers improve the condition of the soil and increase the use and efficiency of mineral fertilizers as a result of which the quality of the crop increases in terms of nutritional value, health-promoting value and safety [23,24]. In addition, due to the large number of weeds and pathogens present, the potato is a difficult crop to cultivate. An important aspect in potato cultivation is therefore the use of chemical protection during its growth.

For many years, researchers' efforts regarding potato production have focused on increasing yields while overlooking the improvement in tuber quality in terms of nutritional value [13]. For this reason, solutions are being sought to eliminate at least some of the crop protection products [25–28]. The proper selection and correct use of chemicals reduce the negative effects of simplifications introduced in potato cultivation [29–32].

Current challenges facing the potato industry include measures to preserve the quality of tubers during storage, ensuring their marketability and high nutritional value. It should be remembered that the appearance of tubers is the main factor that induces consumers to purchase fresh potatoes. Achieving these goals requires monitoring not only the impact of storage factors (temperature, humidity and storage time) but also the agrotechnical factors used during potato cultivation [33,34].

Taking into account the aforementioned aspects, a study was conducted to determine the effect of reduction in mineral fertilization, the use of diversified organic material, the partial elimination of crop protection products and the application of soil conditioner on the quality characteristics of tubers after harvest and after storage.

2. Materials and Methods

2.1. Material and Field Experiment

The material for this study was a medium–early potato variety (*Solanum tuberosum* L.) 'Satina N'. Three-factor field experiments carried out in 2009/2010, 2010/2011 and 2011/2012 were established at the Faculty Research Station of Agriculture and Biotechnology of the Bydgoszcz University of Science and Technology in Mochełek (53°13′ N, 17°51′ E). The experiments were located on a flat soil made of till classified as good rye complex, class IV b in 3 replications. The experiment was carried out in plots of 35 m^2 with a row spacing of 0.75×0.35 m. The forecrop was cereals.

Two parallel experiments were conducted according to the schemes:

Experiment I:

Factor A—organic matter application (manure—25 t ha^{-1} in autumn; straw—4 t ha^{-1} after post-harvest of cereals in summer; stubble intercrop (peas)—4 t ha^{-1} after post-harvest of cereals in autumn; no additional matter—control); factor B—NPK fertilization (100% and 50%); factor C—soil conditioner application (UGmax application, no UGmax application—control).

Experiment II:

Factor A—chemical protection (full protection, no herbicides, no fungicides and no insecticides); factor B—organic matter application (manure, straw, stubble intercrop and no additional matter—control); factor C—soil conditioner application (UGmax application; no UGmax application—control).

2.2. Treatment Details

Application of NPK mineral fertilizers was carried out in the spring before planting potatoes at doses of 100 kg N ha^{-1} (ammonium nitrate—34%), 100 kg P_2O_5 ha^{-1} (triple superphosphate—46%) and 150 kg K_2O ha^{-1} (potassium sulfate—50%). The soil fertilizer UGmax was applied at three doses: in autumn at a rate of 0.6 L ha^{-1}, in spring at a rate of 0.3 L ha^{-1} and foliarly during vegetation at a rate of 0.3 L ha^{-1}. The UGmax fertilizer includes lactic acid bacteria, photosynthetic bacteria, Azotobacter, Pseudomonas and radicles, as well as elements: potassium (3500 mg L^{-1}), nitrogen (1200 mg L^{-1}), sulfur (100 mg L^{-1}), phosphorus (500 mg L^{-1}), sodium (200 mg L^{-1}), magnesium (100 mg L^{-1}), zinc (20 mg L^{-1}) and manganese (0.3 mg L^{-1}). During cultivation, the following were applied: herbicide—Afalon 50 WP (2 L ha^{-1}); fungicides—Helm-cymi (2 kg ha^{-1}) and Ridomil (2 L ha^{-1}); and insecticide—Nurelle D 550 EC (0.6 L ha^{-1}). For a description of soil properties and meteorological conditions, see Pobereżny et al. [12].

Potatoes were harvested at full maturity. Tuber samples were taken from each experimental plot for analytical tests immediately after harvest (10 kg) and for long-term storage (10 kg) in each year of study. Medium-sized tubers were taken by hand. Potatoes were stored in chambers (Thermolux Chłodnictwo Klimatyzacja, Raszyn, Poland) with a controlled atmosphere for 6 months (October–March). A constant temperature of +4 °C and a relative humidity of 95% recommended for edible potato were maintained throughout the storage period.

2.3. Potato Tuber Quality Characteristics

2.3.1. Procedure for Dry Matter Determination

The dry matter content of potato tubers was determined according to the AACC international methods [35]. The tubers were washed, dried, diced and homogenized in a Retsch 169 ZM 100 Ultra-Centrifuge laboratory blender (Retsch, Haan, Germany) until a homogeneous pulp was obtained. Next, 10 g of pulp was weighed into a Petri dish and then dried using a dryer (WAMED, model SUP-100, Warsaw, Poland) at 60 °C for 24 h. The temperature in the dryer was then raised to 105 °C and dried for another 3 h. After the drying process was completed, the samples were cooled in desiccators to room temperature and weighed. The total dry matter content of the potato tubers was calculated from the weight difference and expressed in g kg^{-1}.

Calculation:

$$\mathrm{DM} = \frac{\mathrm{SWA}}{\mathrm{SWB}} \times 1000$$

DM—dry matter content (g kg^{-1})
SWB—sample weight before drying (g)
SWA—sample weight after drying (g)

2.3.2. Procedure for Starch Determination

Starch was determined according to ICC Standard No. 123 [36]. In total, 10 g of crushed potato tubers was weighed into an Erlenmayer flask. Then, 50 mL of 1.124% HCl solution (Chempur, Piekary Śląskie, Poland) was added to the flask. The whole mixture was heated in a water bath for 25 min to hydrolyze the starch. After heating, the samples were cooled to room temperature. The suspension was then transferred to a 100 mL volumetric flask and 1.5 mL of 14.4% ammonium molybdate solution (Roth, Karlsruhe, Germany) was added. The flask was made up with distilled water, stirred and then the suspension was filtered with filter paper No. 593 1/2 (Schleicher & Schuell, Taufkirchen, Germany). The filtrate was placed in a polarimeter (Krüss, type P 1000, Hamburg, Germany) and the optical rotation of the solution was determined. Starch content was expressed in g kg^{-1} f. m. (fresh mass). The starch content of potato tubers was then calculated according to Biot's formula, assuming that the specific rotation of starch dissolved in HCl is 183.7°.

Calculation:

$$\mathrm{SC} = \frac{513 \times \alpha}{\mathrm{L} \times \mathrm{a}}$$

SC—starch content (g kg^{-1} f. m.)
a—weight of analyzed material (g)
L—length of polarimeter tube (dm)
α—measured rotation in degrees

2.3.3. Procedure for Total Sugar and Reducing Sugar Determination

The content of total and reducing sugars was measured using a spectrophotometric method [37]. A 10 g homogeneous sample of shredded potato was placed in a 250 mL volumetric flask and distilled water was added. The entire sample was shaken for 60 min and then strained through Whatman filter paper (International Limited, Kent, UK). For the determination of reducing sugars, 1 mL of the filtrate was transferred to a tube and 3 mL of DNP (Dinitrophenol (Sigma Aldrich, St. Louis, MO, USA)) was added. The whole tube was shaken on a vortex (Grand-bio, Shepreth Cambridgeshire, UK) and then heated for 6 min in a boiling water bath. Absorption was then measured at 600 nm in 1 × 1 cm thick cuvettes using a SHIMADZU UV-1800 spectrophotometer (Nishinokyo Kuwabara-cho, Nakagyo-ku, Kyoto, Japan).

The content of total sugars was determined by measuring 40 mL of the filtrate into an Erlenmeyer flask and acidified with a concentrated HCl solution (Chempur, Piekary Śląskie, Poland). The content of the flask was heated in a boiling water bath for 30 min. After cooling, the flask content was neutralized with concentrated NaOH solution (POCH S.A., Gliwice, Poland). For the determination of total sugars, 1 mL of the neutralized solution was taken and further followed the procedure for the determination of reducing sugars. The results were given in g kg^{-1} f. m. using the standard curve for glucose solution.

2.3.4. Statistical Analysis

The results were analyzed using Statistica 13.1 software (StatSoft, Tulsa, OK, USA). Values were presented as means with standard deviations. Data were checked for normality of distribution by the Shapiro–Wilk test and homogeneity of variance. The mean values obtained in each group were then subjected to a multivariate analysis of variance ANOVA, at a significance level of 0.05, using Tukey's method. Spearman's rank correlation coefficients were determined at $\alpha = 0.05$ to determine the relationship between the qualitative characteristics studied.

3. Results and Discussion

3.1. Dry Matter

The post-harvest dry matter content in tubers of the tested Satina variety, regardless of factors, averaged 152.0 and 146.9 g kg^{-1} for Experiment I and Experiment II, respectively (Tables 1 and 2). The varying dry matter content of tubers of edible varieties has been reported by Koch et al. [38], Mystkowska [39] and Naeem and Caliskan [40], among others. According to the authors, the dry matter content of tubers, depending on the variety and the cultivation technology, can vary within very large limits from 183 g kg^{-1} in the study of Mystkowska [39] to 350 g kg^{-1} in the study of Naeem and Caliskan [40]. In our study, only the application of manure in Experiment II had a significant effect on the change in dry matter content (Table 2).

The highest dry matter contents of 154.2 and 151.7 g kg^{-1} were obtained after the application of manure and the lowest of 150.0 and 143.4 g kg^{-1} were obtained from the control plot (for Experiment I and II, respectively) (Tables 1 and 2). The positive effect of organic fertilization in the cultivation of edible potato, especially in the context of dry matter content, has been reported by many researchers [5,41,42]. The authors indicate that the increase in dry matter content after the application of organic fertilizers is the result of a better supply of nutrients to plants and the gradual availability of nutrients during the growing season. This is closely related to the type and rate of application of these fertilizers. In addition, it was observed that reducing mineral fertilization to 50%, despite maintaining the N:P:K ratio, resulted in a significant decrease in dry matter content by 7.1% (Table 1).

Manolov et al. [43] and Bărăscu et al. [44] take a different view, as they state that regardless of the variety, the most important thing is to maintain the portion of N:P:K doses so that there is no change in the dry matter content of the tubers. However, according to the authors, any change in the N:P:K proportion results in a reduction in dry matter content [45–48]. However, it is important to remember that a key component of potato production systems affecting the quality is nitrogen management [5,25,45,49–51].

Table 1. Dry matter [g kg^{-1}] and starch content [g kg^{-1} f. m.] in potato tubers after harvest depending on applied organic matter, mineral fertilization and use of biostimulant [Experiment I].

[1] Experiment Factors		Dry Matter			Starch		
		MF (NPK)					
OM	SC	100%	50%	Mean	100%	50%	Mean
CO	control	149.1 ± 2.9	145.2 ± 2.8	147.2 ± 3.2	96.7 ± 2.3	91.3 ± 1.2	94.0 ± 3.3
	with UGmax	153.0 ± 3.4	152.9 ± 2.8	153.0 ± 2.8	103.7 ± 2.4	100.2 ± 2.6	102.0 ± 2.9
Mean		151.0 ± 3.6	149.0 ± 4.8	150.0 ± 4.2	100.2 ± 4.4	95.8 ± 5.2	98.0 ± 5.1
SI	control	153.3 ± 2.9	146.0 ± 4.1	149.7 ± 5.1	100.4 ± 1.6	99.0 ± 3.0	99.7 ± 2.2
	with UGmax	163.2 ± 2.5	150.0 ± 3.3	156.6 ± 7.6	114.2 ± 2.4	109.6 ± 3.2	111.9 ± 3.6
Mean		158.2 ± 5.9	148.0 ± 4.0	153.1 ± 7.2	107.3 ± 7.8	104.3 ± 6.5	105.8 ± 7.0
S	control	150.7 ± 2.9	148.5 ± 3.0	149.6 ± 2.9	98.1 ± 1.9	96.0 ± 0.9	97.0 ± 1.7
	with UGmax	157.6 ± 2.9	145.9 ± 1.2	151.8 ± 6.7	108.5 ± 2.3	111.7 ± 3.0	110.1 ± 3.0
Mean		154.1 ± 4.6	147.2 ± 2.5	150.7 ± 5.1	103.3 ± 6.0	106.3 ± 8.8	104.8 ± 7.2
M	control	157.5 ± 3.1	139.92.3	148.7 ± 9.9	104.1 ± 1.1	97.4 ± 1.9	100.7 ± 3.9
	with UGmax	173.4 ± 1.7	145.9 ± 1.2	159.7 ± 15.1	124.6 ± 3.2	108.8 ± 1.7	116.7 ± 9.0
Mean		165.4 ± 9.0	142.9 ± 3.7	154.2 ± 13.5	114.3 ± 11.5	103.1 ± 6.5	108.7 ± 10.6
Mean	control	152.7 ± 4.1	144.9 ± 4.2	148.8 ± 5.7	99.8 ± 3.3	95.9 ± 3.4	97.9 ± 3.8
	with UGmax	161.8 ± 8.3	148.7 ± 3.7	155.2 ± 9.2	112.7 ± 8.4	107.6 ± 5.1	110.2 ± 7.3
Mean		157.2 ± 7.9	146.8 ± 4.3	152.0 ± 8.2	106.3 ± 9.1	101.7 ± 7.3	104.0 ± 8.5
[2] LSD α = 0.05		A—6.83; B—3.71; C—4.42 A/B—3.85; A/C—3.26; B/C—2.46; A/B/C—2.58			A—6.37; B—4.80; C—3.39 A/B—3.47; A/C—2.57; B/C—n. s.; A/B/C—2.62		

[1] Experiment factors: OM—organic matter [A]; MF—mineral fertilization [B]; SC—soil conditioner [C]. CO—control; SI—stubble intercrop; S—straw; M—manure. [2] LSD—least significant difference; n. s.—not significant.

Table 2. Dry matter [g kg] and starch [g kg^{-1} f. m.] content in potato tubers after harvest depending on the applied chemical protection, organic matter and use of biostimulant [Experiment II].

		Dry Matter					Starch				
[1] Experiment Factors		OM									
ChP	SC	CO	SI	S	M	Mean	CO	SI	S	M	Mean
FP	control	149.1 ± 16.8	153.3 ± 2.9	150.7 ± 2.9	157.5 ± 3.1	152.7 ± 4.1	96.7 ± 10.5	100.4 ± 1.6	98.1 ± 1.9	104.1 ± 1.1	99.8 ± 3.3
	with UGmax	153.0 ± 3.4	163.2 ± 2.5	157.6 ± 2.9	173.4 ± 1.7	161.8 ± 8.3	103.7 ± 2.4	114.2 ± 2.4	108.5 ± 2.3	124.6 ± 3.2	112.7 ± 8.4
Mean		151.0 ± 3.6	158.2 ± 5.9	154.1 ± 4.6	165.4 ± 9.0	157.2 ± 7.9	100.2 ± 4.4	107.3 ± 7.8	103.3 ± 6.0	114.3 ± 11.5	106.3 ± 9.1
NH	control	146.4 ± 3.3	150.3 ± 2.9	147.8 ± 3.0	154.3 ± 3.3	149.7 ± 4.1	96.0 ± 2.0	99.8 ± 1.3	97.4 ± 1.6	103.5 ± 1.2	99.2 ± 3.2
	with UGmax	147.0 ± 3.5	151.5 ± 2.6	148.7 ± 3.1	156.1 ± 2.0	150.8 ± 4.3	100.5 ± 0.9	107.4 ± 1.8	103.5 ± 1.2	114.2 ± 2.9	106.4 ± 5.6
Mean		146.7 ± 3.1	150.9 ± 2.6	148.3 ± 2.8	155.2 ± 2.6	150.3 ± 4.2	98.3 ± 2.8	103.6 ± 4.4	100.4 ± 3.6	108.9 ± 6.2	102.8 ± 5.8
NF	control	132.4 ± 2.4	135 ± 1.4	133.2 ± 1.9	137.5 ± 0.5	134.5 ± 2.5	92.5 ± 1.2	93.51 ± 0.8	92.5 ± 1.4	94.6 ± 2.6	93.3 ± 1.8
	with UGmax	134.9 ± 3.0	140.1 ± 2.6	137.0 ± 2.6	145.2 ± 3.4	139.3 ± 4.8	93.5 ± 3.2	94.6 ± 3.2	93.6 ± 3.2	95.7 ± 3.4	94.3 ± 2.9
Mean		133.6 ± 2.8	137.5 ± 3.3	135.1 ± 2.9	141.4 ± 4.8	136.9 ± 4.6	93.0 ± 2.2	94.1 ± 2.4	93.1 ± 2.3	95.1 ± 2.8	93.8 ± 2.4
NI	control	143.6 ± 3.8	147.4 ± 2.9	145.0 ± 3.2	151.1 ± 3.6	146.8 ± 4.1	95.4 ± 2.7	99.2 ± 1.6	96.8 ± 2.1	103.0 ± 1.4	98.6 ± 3.4
	with UGmax	140.9 ± 3.6	139.8 ± 2.8	139.9 ± 3.2	138.7 ± 2.3	139.8 ± 2.7	97.4 ± 3.0	100.6 ± 1.7	98.5 ± 2.2	103.8 ± 2.6	100.1 ± 3.3
Mean		142.3 ± 3.7	143.6 ± 4.9	142.5 ± 4.0	144.9 ± 7.3	143.3 ± 4.9	96.4 ± 2.8	99.9 ± 1.7	97.7 ± 2.1	103.4 ± 1.9	99.3 ± 3.4
Mean	control	142.9 ± 7.1	146.5 ± 7.6	144.2 ± 7.4	150.1 ± 8.3	145.9 ± 7.9	95.2 ± 2.5	98.2 ± 3.2	96.2 ± 2.7	101.3 ± 4.3	97.7 ± 3.9
	with UGmax	143.9 ± 7.6	148.7 ± 10	145.8 ± 8.8	153.3 ± 13.8	147.9 ± 10.7	98.8 ± 4.5	104.2 ± 7.9	101.0 ± 6.1	109.6 ± 11.7	103.4 ± 8.8
Mean		143.4 ± 7.3	147.6 ± 8.9	145.0 ± 8.0	151.7 ± 11.3	146.9 ± 9.4	97.0 ± 4.0	101.2 ± 6.6	98.6 ± 5.2	105.4 ± 9.6	100.6 ± 7.3
[2] LSD α = 0.05		A—3.20; B—5.16; C—3.81 A/B—4.65; A/C—n. s.; B/C—3.77; A/B/C—2.65					A—3.32; B—3.84; C—2.75 A/B—3.34; A/C—2.85; B/C—3.11; A/B/C—3.02				

[1] Experiment factors: ChP—chemical protection [A]; OM—organic matter [B]; SC—soil conditioner [C]. FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure. [2] LSD—least significant difference; n. s.—not significant.

In addition, it was observed that the dry matter content was influenced by the interaction of the tested organic material and mineral fertilization. In Experiment I (Table 1), at a 100% mineral fertilization rate, a significant increase in dry matter content compared to the control was obtained after the application of manure (9.5%) and stubble intercrop (4.5%). The interaction that has occurred is a result of the high potassium dosage resulting from the combined application of potassium in the form of mineral and organic fertilization [43]. On the other hand, when the NPK rate was reduced to 50%, a significant decrease in dry matter content was obtained only after the application of manure (4.1%) (Table 1). The introduction of manure when NPK is lowered to 50% changes the N:P:K ratio to the greatest extent, resulting in lower dry matter content [45–48].

After the inoculation of soil and plants with soil conditioner, regardless of the factors studied, a significant increase in dry matter content was found, on average by 4.3 and 1.4% for Experiment I and II, respectively, compared to facilities where UGmax was not applied (Tables 1 and 2). The use of a soil conditioner in potato production reduces tuber infestation by pathogens, which contributes to improving the quality of the tubers in terms of nutrients [52–54].

There was also a positive interaction between the soil conditioner and organic matter and a statistically significant increase in dry matter was obtained only with manure (8.5%) in Experiment I (Table 1). A positive correlation was also found between the soil conditioner and manure, as a significant increase in dry matter content of 8.5% was obtained in Experiment 1 (Table 1). This is due to the better utilization of soil minerals after the application of soil biostimulants, which accelerate the decomposition of organic material [54]. In addition, Kazimierczak et al. [5] note the positive effect of the organic farming system on the increase in dry matter content in tubers. On the other hand, in Experiment II, this was found after the application of stubble intercrop in the form of peas and manure (Table 2). The simultaneous application of UGmax and mineral fertilization caused an increase in the dry matter content of potato tubers, while a significant increase was obtained with 100% NPK fertilization (in Experiment I) (Table 1).

There was a statistically significant effect on dry matter content, of the protection applied, regardless of the other experimental factors (Table 2). The application of protection devoid of fungicides and insecticides caused the greatest decrease in dry matter content with averages of 12.9 and 11.1%, respectively (Table 2). This is confirmed by the study of Zarzecka et al. [55], who proved that although there was no significant effect of insecticides on dry matter content, there was a tendency for this component to decrease under their influence compared to the control plot. Other results were obtained in the study by Sayuk et al. [56], who proved that in the variants with fungicide application there is an increase in the dry matter content of tubers by 0.1–0.6%.

Taking into account the interactions of all experimental factors, the highest dry matter content was characterized by potatoes grown in soil containing manure and conditioner. It was noted that in Experiment I, the increase in dry matter was most favorable after the application of 100% NPK and in Experiment II with full protection (Tables 1 and 2). Obtaining such an effect may have been due to a faster release of compounds and an increase in plant resistance to disease under the influence of microorganisms contained in UGmax [17–19].

3.2. Starch

The most important component of dry matter is starch [57–60], as evidenced by the significantly positive correlation coefficients between dry matter and starch in Experiments I and II, equal to r = 0.509 and 0.716 ($p \geq 0.05$), respectively (Table 3). In the studies conducted, the starch content averaged from 100.6 g kg^{-1} f. m. for Experiment II to 104.0 g kg^{-1} f. m. for Experiment I (Tables 1 and 2). The results show that the starch content was low. Many authors point to the influence of variety, agrotechnical and storage conditions on the content of this component, the value of which varies between 11 and 21% [39,61–66]. However, it should be remembered that with proper agrotechnology, varieties with lower starch content can yield starch at a comparable or higher level than lower-yielding varieties, but with a higher starch content [67,68].

Table 3. The correlation coefficients (r) according to the rank order of Spearman between the studied parameters.

Parameters			Starch	Total Sugars	Reducing Sugars
	Experiment	[1] Assessment Date			
Dry matter	I	ah	** 0.509		
		as	** 0.667		
	II	ah	** 0.716	** −0.551	* −0.262
		as	** 0.884	** −0.774	** −0.426
Starch	I	ah		** −0.569	** −0.407
		as		** −0.561	
	II	ah		** 0.587	** −0.449
		as		** −0.768	** −0.364
Total sugars	I	ah			* 0.354
		as			** 0.521
	II	ah			** 0.418
		as			** 0.600

[1] ah—after harvest; as—after storage; significance levels are represented as '*' $p \leq 0.05$; '**' $p \leq 0.01$.

Each of the applied factors in the experiments had a significant effect on the starch content of the tubers of the tested cultivar Satina (Experiments I and II) (Tables 1 and 2). The application of organic material generally had a significant effect on the increase in starch content compared to the control. Only in Experiment II was there no significant effect of applied straw on the content of this parameter. Murawska et al. [69], Koireng et al. [70] and Demidenko et al. [60] showed that potato tubers grown in manure had the highest starch content, as shown in our experiments. In the study of Murawska et al. [69], the average starch content was higher by an average of 3.8%, while in our study, an increase of as much as 14.1% was observed (Tables 1 and 2).

In the study conducted, reducing the NPK fertilization rate by 50% resulted in a significant decrease of 4.4% in the starch content of potato tubers. The decrease in starch content was almost twice that of dry matter. This is due to the fact that most potato traits are genetically determined and subject to high phenotypic variability [71].

El-Zehery [72] reports that limitations on mineral fertilization in potato cultivation should be implemented with the simultaneous application of organic fertilization, which is consistent with the results of our study (Tables 1 and 2). The starch content of the tubers of the tested Satina variety was the highest on both 100 and 50% NPK fertilization with manure (Table 1). It was noted that the starch content on the objects where 50% mineral fertilization and manure were applied was higher compared to the object where 100% NPK fertilization was applied. El-Zehery [72] obtained the highest quality of potato tubers, in terms of starch, after applying organic and biological fertilization with reduced levels of mineral fertilization by 25%. Thus, reducing the dose of mineral fertilization supplemented with organic matter has an effect on limiting the reduction of starch content [72,73].

As for dry matter content, the application of UGmax resulted in an increase in starch content in potato tubers. This is due to the fact that starch content in potato tubers is closely correlated with starch content (r = 0.51, r = 0.72, $p \leq 0.05$ for Experiment I and II, respectively) (Table 3). However, it was noted that the increase was significantly higher for starch, with 12.6 and 5.8% for Experiment I and II, respectively (Tables 1 and 2). El Zehery [72] obtained an increase in starch content equal to 14.6%, using biofertilizer, comparable to our study. The positive effect of using biostimulants on the starch content of potato tubers has been reported by many authors [10,39,74]. Such an effect is due to the microorganisms contained in the soil conditioner [52–54]. On the other hand, a study by

Maciejewski et al. [75] showed no effect of biostimulant application on the starch content of potatoes, which may be due to the application of biostimulants only in foliar form.

The application of the fertilizer UGmax in Experiment I resulted in a significant increase in starch content on average from 12.2% for the object with stubble intercrop to 15.9% for the object with manure in Experiment I (Table 1), and from 1.1% after the withdrawal of fungicides to 7.3% after the withdrawal of herbicides in Experiment II (Table 2). This is due to an increase in plant resistance to diseases and pathogens under the application of biostimulants [76,77].

Each protection reduction applied resulted in significant reductions in starch content compared to the control, which were 3.4, 13.8 and 7.0% after the withdrawal of herbicides, fungicides and insecticides, respectively (Table 2). The withdrawal of certain herbicide and fungicide protective treatments in potato cultivation leads to a decrease in the nutritional value of potato tubers. The withdrawal of fungicides increases the risk of plant infection with dangerous pathogens [78]. On the other hand, the withdrawal of herbicides leads to excessive weed infestation of the crop and an increase in the proportion of fine tubers in the yield and, consequently, a decrease in starch content [79,80].

In our study, the highest starch content of 112.7 g kg^{-1} f. m. was obtained after simultaneous application of a soil conditioner and full protection (Experiment II) (Table 2). Zarzecka et al. [59] showed that the highest starch yield compared to the control plot was obtained after the application of a biostimulant together with plant protection in the form of herbicide. Baranowska [74] also obtained a 16.3% increase in starch content with the simultaneous application of a biostimulant and herbicides. Kaliyeva et al. [81] report that the starch content of tubers is also affected by the use of insecticides in potato cultivation. The authors reported that the starch content of potato tubers in the control variant ranged from 10.1 to 10.3%, while in the variant with insecticide protection the content ranged from 15.0 to 16.4%. The resulting increase over the control ranged from 4.9 to 6.1% [81].

3.3. Total and Reducing Sugars

In the conducted studies, the contents of total and reducing sugars were at the levels of 4.62 and 1.52 g kg^{-1} f. m. for Experiment I and 4.97 and 2.15 g kg^{-1} f. m. for Experiment II, respectively (Tables 4 and 5). Regarding nutritional value, higher sugar contents in tubers are desirable, while specific standards are set for potatoes intended for processing (requirements for tubers: reducing sugars content $< 0.25\%$; total sugars content $< 0.8\%$) [28,62,82].

In the studies conducted, organic matter had a significant effect on the content of total sugars and reducing sugars in Experiments I and II (Tables 4 and 5). The highest content of total sugars was recorded for the control plot and the lowest for the object with manure (5.22 and 3.56 g kg^{-1} f. m. for Experiment I and 5.60 and 4.44 g kg^{-1} f. m. for Experiment II, respectively) (Tables 4 and 5).

Also, in a study by Xing et al. [83], a reduction in the sugar content of potato tubers was obtained. The authors [83] indicate that increasing the soil pH by applying manure can reduce the sugar content, since a more acidic soil improves the quality of potatoes. Similar trends occurred for reducing sugars in Experiment II (Table 5). These contents were 2.38 and 1.79 g kg^{-1} f. m. for the control and manure objects, respectively (Table 5). A different relationship was observed for Experiment I, where the highest content of reducing sugars was found for the control plot and the lowest for the object for which straw was used, 1.81 and 1.28 g kg^{-1} f. m., respectively.

In our study, reducing mineral fertilization to 50% resulted in a significant decrease in the content of reducing sugars only. The decrease in the content of reducing sugars was 0.54 g kg^{-1} f. m. (Table 4). As reported by Mona et al. [84], AbdEl-Nabi et al. [85] and Jatav et al. [86], the content of reducing sugars was significantly lower on sites where reduced mineral fertilization was applied. Similar results were obtained by El-Ghamriny and Saeed [87] for other plants. This may be due to a decrease in the intensity of polysaccharide hydrolysis processes, the conversion of organic acids into soluble sugars and a decrease in the solubilization of insoluble starch under reduced mineral fertilization [47].

Table 4. Total [g kg^{-1} f. m.] and reducing content [g kg^{-1} f. m.] in potato tubers after harvest depending on applied organic matter, mineral fertilization and use of biostimulant [Experiment I].

[1] Experiment Factors		Total Sugars			Reducing Sugars		
		MF (NPK)					
OM	SC	100%	50%	Mean	100%	50%	Mean
CO	control	5.77 ± 0.47	5.19 ± 0.44	5.48 ± 0.51	2.88 ± 0.15	2.07 ± 0.06	2.48 ± 0.47
	with UGmax	5.13 ± 0.06	4.77 ± 0.50	4.95 ± 0.38	1.31 ± 0.02	0.98 ± 0.10	1.15 ± 0.68
Mean		4.73 ± 0.46	4.98 ± 0.48	4.86 ± 0.51	1.63 ± 1.09	1.04 ± 0.57	1.34 ± 0.88
SI	control	5.06 ± 0.12	5.19 ± 0.44	5.13 ± 0.29	2.10 ± 0.10	1.28 ± 0.47	1.69 ± 0.64
	with UGmax	4.39 ± 0.06	4.77 ± 0.50	4.58 ± 0.37	1.16 ± 0.30	1.01 ± 0.06	1.09 ± 0.45
Mean		4.73 ± 0.36	4.98 ± 0.48	4.86 ± 0.42	1.63 ± 0.67	1.04 ± 0.30	1.34 ± 0.58
S	control	4.92 ± 0.25	4.61 ± 0.42	4.76 ± 0.35	1.99 ± 0.10	1.29 ± 0.06	1.64 ± 0.41
	with UGmax	4.26 ± 0.06	4.21 ± 0.01	4.23 ± 0.05	1.75 ± 0.12	1.11 ± 0.20	1.43 ± 0.39
Mean		4.92 ± 0.40	4.61 ± 0.35	4.76 ± 0.37	1.99 ± 0.16	1.29 ± 0.16	1.64 ± 0.40
M	control	4.35 ± 0.59	4.210.17	4.28 ± 0.40	1.83 ± 0.06	1.48 ± 0.26	1.65 ± 0.25
	with UGmax	3.65 ± 0.12	3.48 ± 0.10	3.56 ± 0.13	1.32 ± 0.19	0.77 ± 0.01	1.05 ± 0.36
Mean		4.00 ± 0.54	3.84 ± 0.40	3.92 ± 0.46	1.58 ± 0.34	1.12 ± 0.42	1.35 ± 0.43
Mean	control	5.02 ± 0.62	4.80 ± 0.55	4.91 ± 0.51	2.20 ± 0.42	1.53 ± 0.44	1.86 ± 0.47
	with UGmax	4.36 ± 0.55	4.31 ± 0.62	4.33 ± 0.38	1.39 ± 0.60	0.97 ± 0.15	1.18 ± 0.20
Mean		4.69 ± 0.67	4.55 ± 0.63	4.62 ± 0.64	1.79 ± 0.25	1.25 ± 0.20	1.52 ± 0.61
[2] LSD α = 0.05		A—0.369; B—n. s.; C—0.339 A/B—n. s.; A/C—n. s.; B/C—n. s.; A/B/C—n. s.			A—0.499; B—0.320; C—0.307 A/B—n. s.; A/C—0.355; B/C—n. s.; A/B/C—n. s.		

[1] Experiment factors: OM—organic matter [A]; MF—mineral fertilization [B]; SC—soil conditioner [C]. CO—control; SI—stubble intercrop; S—straw; M—manure. [2] LSD—least significant difference; n. s.—not significant.

Table 5. Total [g kg^{-1} f. m.] and reducing content [g kg^{-1} f. m.] content in potato tubers after harvest depending on the applied chemical protection, organic matter and use of biostimulant [Experiment II].

[1] Experiment Factors		Total Sugars					Reducing Sugars				
		OM									
ChP	SC	CO	SI	S	M	Mean	CO	SI	S	M	Mean
FP	control	5.77 ± 0.49	5.06 ± 0.14	4.91 ± 0.24	4.35 ± 0.62	5.02 ± 0.64	2.88 ± 0.04	2.10 ± 0.06	1.99 ± 0.09	1.83 ± 0.06	2.20 ± 0.43
	with UGmax	5.13 ± 0.03	4.39 ± 0.07	4.26 ± 0.04	3.65 ± 0.13	4.36 ± 0.55	1.31 ± 0.06	1.16 ± 0.08	1.75 ± 0.11	1.32 ± 0.11	1.39 ± 0.66
Mean		5.45 ± 0.47	4.73 ± 0.38	4.59 ± 0.39	4.00 ± 0.56	4.69 ± 0.68	2.10 ± 0.18	1.63 ± 0.67	1.37 ± 0.16	1.58 ± 0.59	1.67 ± 0.71
NH	control	5.78 ± 0.42	4.76 ± 0.20	4.77 ± 0.22	4.61 ± 0.19	4.98 ± 0.54	3.13 ± 0.13	2.92 ± 0.14	2.53 ± 0.02	2.19 ± 0.01	2.69 ± 0.39
	with UGmax	5.32 ± 0.49	5.02 ± 0.19	4.67 ± 0.34	3.84 ± 0.34	4.71 ± 0.65	1.69 ± 0.06	1.62 ± 0.23	1.66 ± 0.17	1.27 ± 0.22	1.56 ± 0.30
Mean		5.55 ± 0.48	4.89 ± 0.23	4.72 ± 0.26	4.23 ± 0.49	4.84 ± 0.60	2.41 ± 1.08	2.27 ± 0.67	2.09 ± 0.16	1.73 ± 0.59	2.12 ± 0.67
NF	control	6.04 ± 0.72	5.66 ± 0.15	5.35 ± 0.37	5.27 ± 0.29	5.58 ± 0.49	2.74 ± 0.10	3.40 ± 0.21	2.57 ± 0.35	2.21 ± 0.23	2.73 ± 0.55
	with UGmax	5.49 ± 0.46	5.18 ± 0.36	4.84 ± 0.37	4.87 ± 0.56	5.09 ± 0.47	1.85 ± 0.25	1.98 ± 0.13	1.42 ± 0.25	1.44 ± 0.17	1.67 ± 0.39
Mean		5.78 ± 0.62	5.42 ± 0.31	5.10 ± 0.41	5.07 ± 0.46	5.34 ± 0.52	2.29 ± 0.52	2.69 ± 0.94	1.99 ± 0.69	1.83 ± 0.46	2.20 ± 0.71
NI	control	5.78 ± 0.35	4.45 ± 0.27	4.62 ± 0.20	4.87 ± 0.26	4.93 ± 0.59	3.39 ± 0.27	3.73 ± 0.33	3.06 ± 0.12	2.54 ± 0.08	3.18 ± 0.50
	with UGmax	5.51 ± 0.99	5.65 ± 0.44	5.08 ± 0.70	4.03 ± 0.71	5.07 ± 0.91	2.06 ± 0.47	2.09 ± 0.30	1.58 ± 0.37	1.55 ± 0.25	1.82 ± 0.41
Mean		5.65 ± 0.68	5.05 ± 0.73	4.85 ± 0.53	4.45 ± 0.67	5.00 ± 0.75	2.72 ± 0.80	2.91 ± 0.95	2.32 ± 0.85	2.04 ± 0.57	2.50 ± 0.83
Mean	control	5.84 ± 0.46	4.98 ± 0.45	4.91 ± 0.34	4.78 ± 0.48	5.13 ± 0.60	3.04 ± 0.30	3.04 ± 0.71	2.54 ± 0.43	2.19 ± 0.29	2.70 ± 0.57
	with UGmax	5.36 ± 0.53	5.06 ± 0.54	4.71 ± 0.48	4.10 ± 0.64	4.81 ± 0.71	1.73 ± 0.60	1.71 ± 0.56	1.60 ± 0.25	1.40 ± 0.37	1.61 ± 0.48
Mean		5.60 ± 0.54	5.02 ± 0.49	4.81 ± 0.42	4.44 ± 0.65	4.97 ± 0.67	2.38 ± 0.81	2.38 ± 0.92	2.07 ± 0.59	1.79 ± 0.55	2.15 ± 0.77
[2] LSD α = 0.05		A—0.369; B—0.306; C—0.267 A/B—n. s.; A/C—0.294; B/C—0.362; A/B/C—n. s.					A—0.420; B—0.422; C—0.215 A/B—n. s.; A/C—n. s.; B/C—n. s; A/B/C—n. s.				

[1] Experiment factors: ChP—chemical protection [A]; OM—organic matter [B]; SC—soil conditioner [C]. FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure. [2] LSD—least significant difference; n. s.—not significant.

The application of UGmax had a significant effect on reducing the content of total and reducing sugars (Tables 4 and 5). Thus, it is necessary to use a soil conditioner in the cultivation of potatoes for the production of refined products. The average decreases in total sugars for Experiment I and II were 13.4 and 6.7% and for reducing sugars these were 57.6 and 67.8%, respectively (Tables 4 and 5). This is confirmed by the results obtained by Haider et al. [88]. On the other hand, in the studies by Maciejewski et al. [75], Zarzecka and Gugała [89] and Głosek-Sobieraj et al. [27], the results on the effect of biostimulants on the content of sugars in potato tubers are not so clear. Maciejewski et al. [75], after the foliar application of biostimulants Asahi SL and Atonik Sl, obtained both an increase and decrease in the content of reducing sugars in tubers of different varieties, but these differences were not statistically proven. Trawczyński [90] used one biostimulant and found no significant effect of its action on the content of reducing sugars in potatoes during the years of the study. On the other hand, Zarzecka and Gugala [89] obtained a significant increase in the content of reducing sugars for the Gawin and Honorata varieties, while the authors found no effect of the tested biostimulants on the Bartek variety. Głosek-Sobieraj et al. [27] used four different biostimulants and five varieties and obtained a decrease in the content of reducing sugars for two varieties. However, Karak et al. [91] used six different biostimulants and observed an unambiguous increase in total and reducing sugars. It should be noted, however, that this study involved only one variety. The results discussed here indicate that the sugar content of potatoes is influenced by many factors: variety, environmental conditions, type of formulation, application rate and frequency of application [28]. Ezzat et al. [92] and Arafa and Hussien [93] indicate that the effect of soil conditioners also depends on the dose and type of mineral fertilization. In addition, the foliar application of biostimulants affects plant metabolism and improves plant growth within the leaves, which increases the carbohydrate content of these organs. Due to transport, these compounds enter the tuber from where they are partially released into the rhizosphere. Thus, soil microorganisms release various organic substances and increase the availability of nutrients for potato tubers [92,94].

In our study, in Experiment I, there was a significant interaction effect of organic matter and soil fertilizer on the content of reducing sugars (Table 4). The highest content of reducing sugars was characterized by tubers from the object where organic matter and soil conditioner were not applied, and the lowest by tubers grown using manure with soil conditioner. This is in line with the results of Głosek-Sobieraj et al. [27] and AbdEl-Nabi et al. [85], who also obtained a decrease in sugars after applying soil conditioner and organic matter. In contrast, in Experiment II, the content of total sugars was significantly affected by the simultaneous application of chemical protection with soil fertilizer and organic matter with UGmax (Table 5). Tubers grown without fungicides and without soil conditioner had the highest total sugar content (5.58 g kg^{-1} f. m.). On the other hand, the lowest content of total sugars was characterized by tubers after the combined application of manure and soil conditioner (4.10 g kg^{-1} f. m.). Starch, sucrose and simple sugars play an important role in the formation of potato tubers and the mechanism of starch metabolism is the dominant pathway. Sucrose is the main form of carbohydrate transport and in potato tubers it is subject to degradation to reducing sugars, which are the substrate for starch metabolism [95]. This is confirmed by the negative significant correlation coefficients, obtained in our study, between starch content and total sugars and reducing sugars of r = −0.569 and r = −0.407 ($p \leq 0.05$) for Experiment I and r = −0.587 r = −0.449 ($p \leq 0.05$) for Experiment II, respectively (Table 3).

This study found that, regardless of the pesticide withdrawn, there was generally a significant increase in total sugars and reducing sugars in tubers by an average of 7.3 and 26.4%, respectively, compared to the content obtained in tubers from a facility where full pesticide protection was applied (Table 5). The greatest increase in total sugars was obtained by withdrawing fungicides and in reducing sugars by withdrawing insecticides (Table 5). Such results were caused by the stress induced by improper plant protection against pathogens. Kumar et al. [96] note that sugar content is influenced by abiotic factors. In addition, the authors state that each genotype requires proper cultivation technology, and stress, regardless of the type, increases sugar accumulation. On the other hand, Zarzecka et al. [97] and Baranowska and Mystkowska [98] report that the content of sugars in potato tubers depends on the type of pesticide used. Biotic stresses caused by improper chemical protection intensify the defense response of plants by producing a greater amount of secondary metabolites, the production of which is associated with a change in the sugar balance by plants [99,100].

3.4. Storage

In order to preserve the quality of the tubers and increase their availability throughout the year, long-term storage is necessary. In the tests conducted after 6 months of storage, the dry matter content of the tubers decreased at comparable levels for Experiment I and II, by 3.2 and 3.6%, respectively (Figures 1 and 2). A decrease in starch content, whose content is closely related to dry matter content, was also obtained in tubers after long-term storage [101] (Figures 3 and 4). This is confirmed by the highly significant correlation coefficients between dry matter and starch content obtained in our study, amounting to r = 0.667 ($p \leq 0.05$) for Experiment I and r = 0.884 ($p \leq 0.05$) for Experiment II, respectively (Table 3). It should be noted that the decrease in starch content was almost twice as high in Experiment I compared to Experiment II (Tables 3 and 4). Pandey et al. [102] and Siddiqui et al. [103] report that the starch content of potatoes decreases during storage due to the conversion of starch to sugar and its use in respiration. Ozturk and Polat [3] report a decrease and increase in dry matter and starch content in potato tubers after storage (6 months). The authors, storing seven varieties under controlled conditions, obtained a decrease in dry matter content of 1.5% on average and an increase in starch content of 3% on average. At the same time, in the case of two varieties, they recorded an increase in dry matter content by an average of 8.2%, while starch content increased by as much as 17.4%. The authors clearly indicate that potato genotype has the greatest impact on losses in dry matter and starch content. Potato varieties differ in the thickness of the periderm and the amount of deposited suberin, which is a natural barrier to water transport and so different varieties carry out vital processes with different intensities under the same conditions. On the other hand, Sahin et al. [104] and Pobereżny and Wszelaczyńska [105] point out that losses of dry matter and starch content are highly dependent on storage time. The authors report that extending the storage period increases losses.

In addition, it was shown that the effect of factors applied during the potato growing season on the dry matter and starch content of tubers after storage was the same as after harvest (Tables 1 and 2, Figures 1–4).

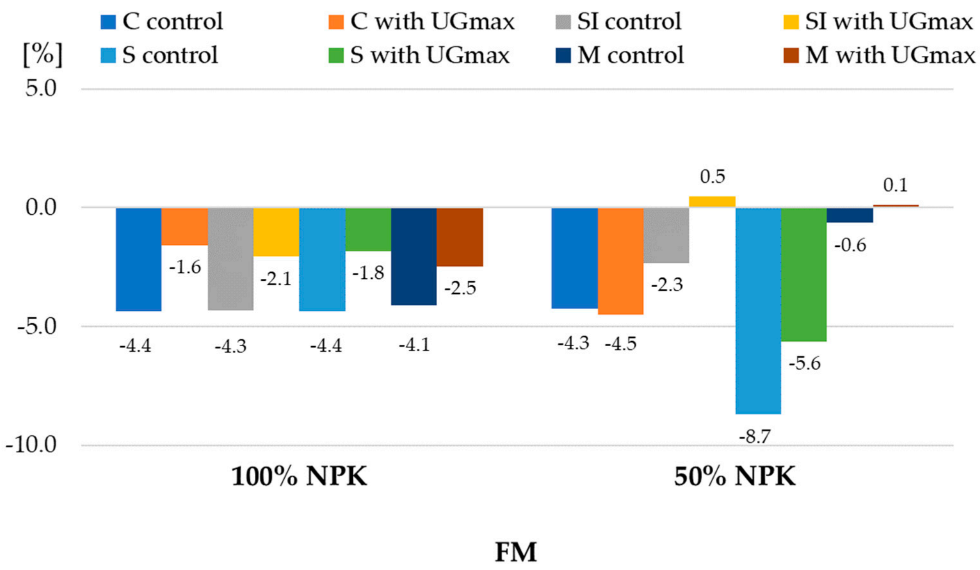

Figure 1. Percentage changes in dry matter content depending on the applied organic matter, mineral fertilization and use of biostimulant after storage. OM—organic matter; C—control; SI—stubble intercrop; S—straw; M—manure.

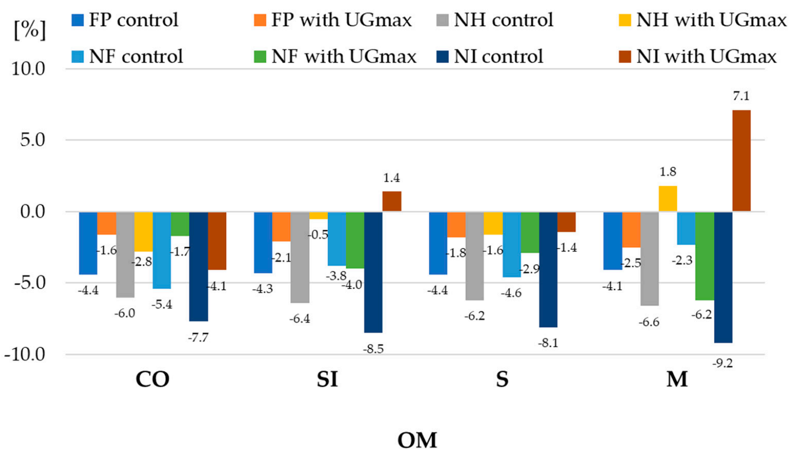

Figure 2. Percentage changes in dry matter content depending on the use of chemical protection, organic matter and biostimulant after storage. OM—organic matter; FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure.

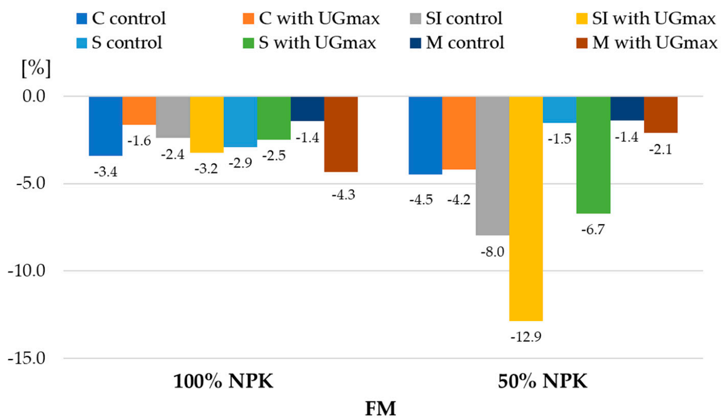

Figure 3. Percentage changes in starch content depending on the applied organic matter, mineral fertilization and use of biostimulant after storage. OM—organic matter; C—control; SI—stubble intercrop; S—straw; M—manure.

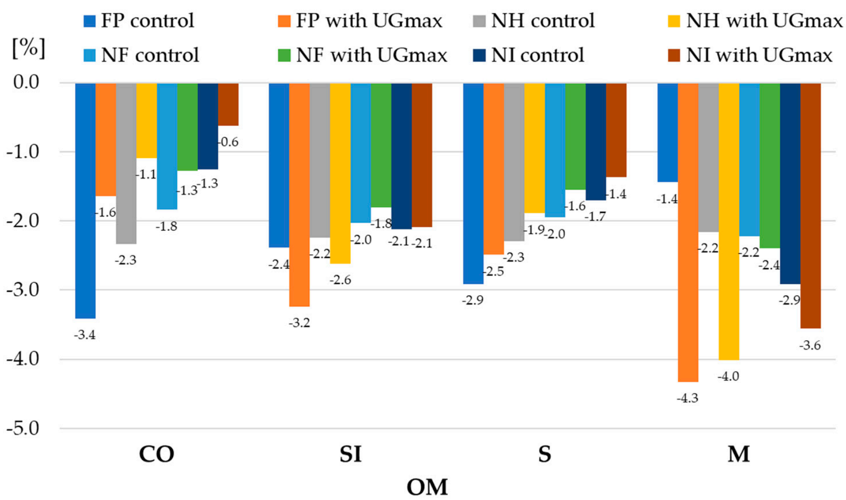

Figure 4. Percentage changes in starch content depending on the use of chemical protection, organic matter and biostimulant after storage. OM—organic matter; FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure.

After six months storage, there was an increase in total sugars and reducing sugars in the tubers. For Experiment I, the increase in total sugars was 8.2% and for reducing sugars it was 27.6% (Figures 5 and 6). In contrast, for Experiment II, an increase of 11.8% in total sugars and 8.6% in reducing sugars was achieved (Figures 7 and 8). According to many authors, the accumulation of sugars during six months storage is mainly due to genetic conditions [101,106,107], so the storage period should be determined taking into account the varietal characteristics of the potato [108]. A similar view is presented by Alamar et al. [34] and Wszelaczyńska et al. [109]. In the study of Wszelaczyńska et al. [109], a higher increase in sugar content (54.3%) was obtained after 6 months of storage for the Denar variety compared to the Gardena variety (43.6%). Stress factors such as moisture deficiency or temperature changes during storage are also important determinants of sugar content in tubers [66]. As indicated by Amjad et al. [106] and Zhang and Zhen-Xiang [107], low temperatures of 2–4 °C can contribute to the accumulation of reducing sugars due to the so-called cold-induced sweetening. The sweetening process is a natural process that occurs as a result of tuber aging. It is irreversible and involves cellular breakdown. After cellular breakdown, structural and non-structural carbohydrates are depolymerized by hydrolytic enzymes [34]. Therefore, maintaining appropriate storage conditions, including temperature, can contribute to reducing the weight loss and sweetening of potatoes.

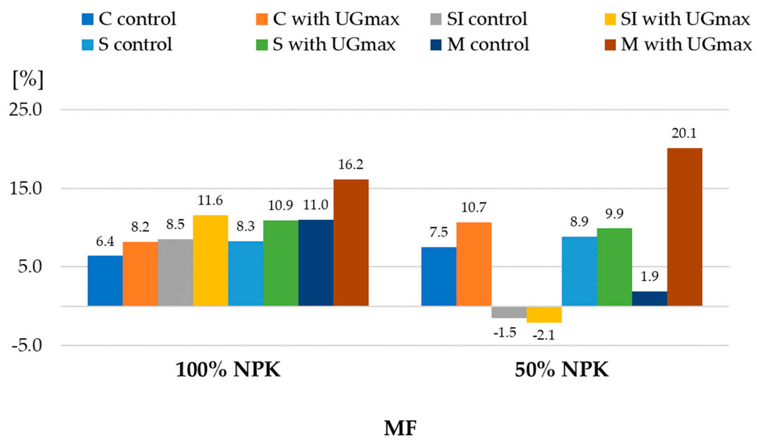

Figure 5. Percentage changes in total sugar content depending on the applied organic matter, mineral fertilization and use of biostimulant after storage. OM—organic matter; C—control; SI—stubble intercrop; S—straw; M—manure.

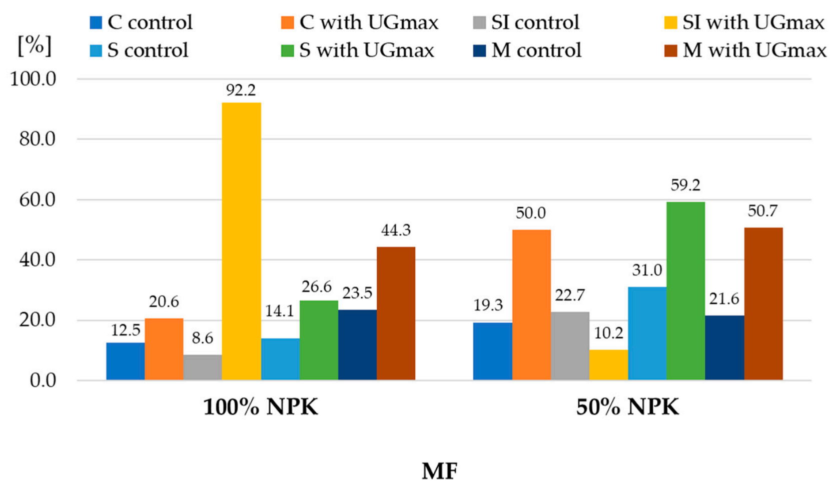

Figure 6. Percentage changes in reducing sugar content depending on the applied organic matter, mineral fertilization and use of biostimulant after storage. OM—organic matter; C—control; SI—stubble intercrop; S—straw; M—manure.

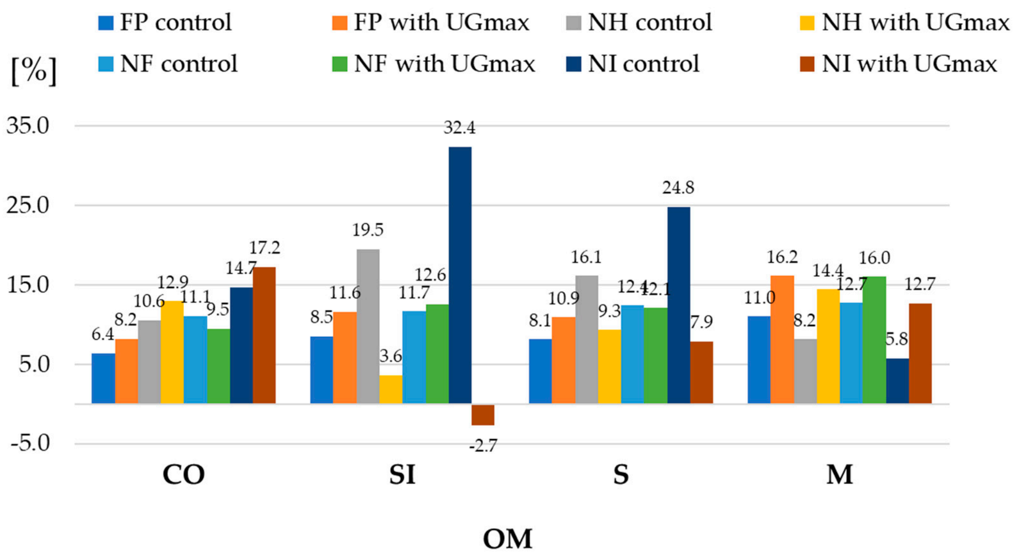

Figure 7. Percentage changes in total sugar content depending on the use of chemical protection, organic matter and biostimulant after storage. OM—organic matter; FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure.

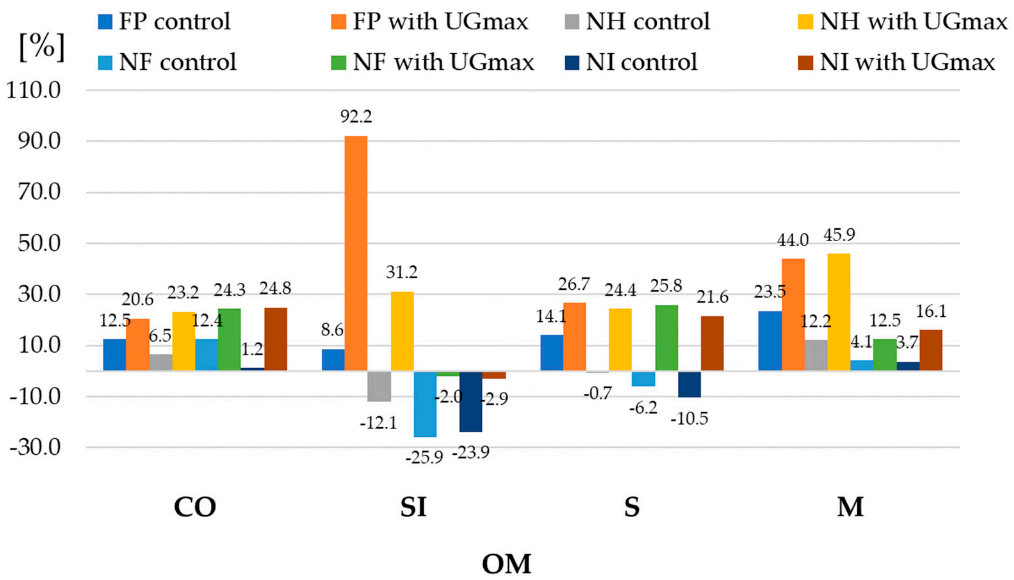

Figure 8. Percentage changes in reducing sugar content depending on the use of chemical protection, organic matter and biostimulant after storage. OM—organic matter; FP—full protection; NH—no herbicides; NF—no fungicides; NI—no insecticides; CO—control; SI—stubble intercrop; S—straw; M—manure.

Considering the field factors applied during potato cultivation, it was found that in Experiment II, the effect of these factors on the content of total sugars and reducing sugars in tubers after storage was the same as after harvest (Table 5, Figures 7 and 8). In contrast, in Experiment I, it was shown that the field factors had the same effect only on the content of total sugars after storage (Table 4, Figure 5).

The highest increase in total sugars and reducing sugars in tubers after storage in Experiment I was obtained in potatoes after cultivation on manure and straw along with soil conditioner (Figures 5 and 6). In contrast, reducing NPK fertilization to 50% resulted in the highest increase in reducing sugars (Figure 8).

In Experiment II, the withdrawal of insecticides and fungicides resulted in the largest increase in total sugars and, at the same time, the smallest increase in reducing sugars (Figures 7 and 8). In contrast, the application of UGmax, similarly to that in Experiment I, caused an increase in the content of reducing sugars (by 24.4% on average). It should be noted, however, that after potato cultivation without the application of soil conditioner, a slight decrease in the content of reducing sugars was obtained (−0.8%) after storage (Figure 8).

4. Conclusions

The highest dry matter and starch content in Satina potato tubers was obtained after applying 100% NPK, manure and soil conditioner. Studies have shown that after the introduction of a mineral fertilization limitation of up to 50% (50 kg N, 50 kg P_2O_5 and 75 kg K_2O kg ha^{-1}) in the cultivation of edible potatoes, the highest dry matter and starch contents in tubers can be obtained after the simultaneous application of soil conditioner with stubble intercrop in the form of fodder peas. On the other hand, with the introduction of crop protection limitations, the best results were obtained after the withdrawal of herbicides with the simultaneous application of manure and UGmax. In addition, in the case of total sugars, the use of stubble intercrop without fertilizer proved to be the most beneficial and, in the case of reducing sugars, also the use of straw without fertilizer.

Long-term storage under constant conditions resulted in a decrease in dry matter and starch content. Limiting mineral fertilization in the crop to 50% resulted in increased dry matter and starch losses after storage. Regardless of the field factors used, long-term storage generally resulted in an increase in total sugars and reducing sugars in the tubers. In contrast, the lack of fertilizer application while reducing insecticides and fungicides, however, contributed to a decrease in the content of reducing sugars after storage. The research conducted was, and still is, very timely and necessary, as there are not enough reports on the effect of so many field factors applied simultaneously on tuber quality. This is especially true as the quality of tubers after storage depending on so many factors.

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