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Optimization of Potato Cultivation Through the Use of Biostimulator Supporter

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Abstract: Seed potato treatment is vital for plant protection, yield enhancement, and product quality. In the conducted research, the plant biostimulator Supporter was applied to evaluate its impact on potato yields and its structure. Supporter contains both synthetic and SL amino acids, which promote plant growth by enhancing nutrient utilization and fostering the development of a more effective root system. Such a formulation allows to maintain better resistance to environmental stresses, which may include drought or nutrient deficiency, among others. The field study was conducted in 2015–2017 in four towns located in different regions of Poland (Barankowo, Głubczyce, Kędrzyno, and Ryn) using a randomized complete block design with a split-plot design. Varieties ('Innovator', 'Lilly', 'Lady Claire', and 'Verdi') were tested. The experiment compared the cultivation technology using Supporter biostimulator with which seed potatoes were treated compared to conventional cultivation (control object) by soaking the tubers in distilled water before planting. The total yield of potato tubers after Supporter application was higher by 13.3%, while the commercial yield increased by 21.1% compared to the traditional cultivation method. The most productive, regardless of cultivation technology and years of research, in terms of total tuber yield was the 'Lilly' variety with an average yield of 47.95 $t \cdot ha^{-1}$, while the least productive variety was the 'Innovator' variety with an average yield of 29.93 $t \cdot ha^{-1}$. The 'Lady Claire' variety had the highest commercial tuber yield, while the 'Innovator' variety had the lowest.

Keywords: cultivars; localizations; plant biostimulators; potato yield; seed potato treatment; tuber structure

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1. Introduction

Potato is the third most important food crop after rice and wheat in respect of human consumption [1]. According to the latest updates to the FAOSTAT database from FAO, global potato production reached approximately 375 million tons in 2022. The leading producers were China, producing 95.5 million tons, and India, producing 56 million tons. Other significant producers are Russia (18.9 million tons), Ukraine (20.9 million tons), and Germany (10.6 million tons) [1]. The potato plays a key role in the world's food supply, with around 80% of the crop area located in Europe and Asia. Since 2005, the area under potatoes in Asia has increased slightly by 1.4%, while yields have increased from 136.6 to 178.6 million tons, with China and India being the largest producers. In Europe, the area under potatoes has decreased by 32.6%, but yields have improved by 31.5%, despite a reduction in the total yield. Ukraine and Russia are the leading producers in Europe. Seed material is a fundamental element in plant production. Its high quality is one of the key factors in achieving high and good-quality potato yields [2]. The seed potato production worldwide is crucial to ensuring an adequate supply of potatoes in local and global markets. Seed potatoes, as planting material, are important for the quality of the crop, which affects production efficiency. In Europe, the seed potato production is diversified, with the largest producers being the Netherlands, which is one of the leading producers of seed potatoes in Europe and worldwide. In 2020, the Netherlands supplied around 30% of European seed potatoes, and its exports to countries outside Europe were growing significantly [1,2]. Therefore, its preparation, including enhancement before planting, is crucial. Traditional methods of preparing seed material include techniques such as sorting and fractionation of tubers [3], stimulation or chitting [4], treating them against diseases and pests [5,6], and various chemical and physical treatments. The aim of enhancing the material is to improve its energy and germination vigor and to reduce variability in physical, physiological, and morphological traits [7]. Thanks to these fairly complex technologies, better plant growth and development are noticeable even in the next generation [8].

Chemical seed treatment of potato tubers involves subjecting them to the action of chemical agents, called seed treatments, in the form of dust or by soaking them in a solution of these agents [9]. Dry dusting of tubers is the oldest and cheapest method of tuber protection, involving applying a chemical substance in powder form to the surface of seed potatoes. This is most commonly performed in stationary devices, where the appropriate dose of the substance is sprinkled onto a measured portion of seed potatoes and then thoroughly mixed. However, a drawback of this method is its low effectiveness due to poor coverage of the potato surface with the treatment. Wet seed treatment in the form of foam is a safer method that limits the amount of treatment used but requires the presence of a specialized seed treater located on a planter [10]. The foam substance is dosed into the hopper, where each seed potato is covered with a layer of foamy treatment. An advantage of this method is the minimal amount of active substance used. Additionally, its good adhesion prevents active substance loss, and the surrounding environment is not exposed to contact with it [11]. Another important parameter in this application method is the amount of treatment applied to the potato surface; too little may not provide sufficient potato protection, while too much may delay or even prevent emergence.

As seed treatments, plant biostimulators or growth bioregulators can be used. Biostimulators are substances that improve plant growth or plant quality by enhancing (a) nutrient use efficiency, (b) tolerance to abiotic stresses, (c) qualitative traits, or (d) nutrient availability in the soil or rhizosphere. They are regulated by the European Union regulation on fertilizing substances [12–18]. According to this regulation, the effects declared by the manufacturer must be relevant for the plants listed on the label. Meanwhile, the 2023 Report [19] provides a global perspective, highlighting regulatory developments not only in the EU but also in other major agricultural markets such as the US and Brazil. This shows that regulations may differ from region to region but share common goals, making the topic relevant to a wider audience. Additional suggestions include international guidelines and opportunities to join and refer to global organizations such as the Food and Agriculture Organization of the United Nations (FAO) or the OECD, which provide overarching guidelines. Sustainable Agriculture: makes biostimulators critical for sustainable agriculture, which has global resonance due to growing environmental concerns. Biostimulator regulations in emerging markets such as India, China, or some regions in Africa are also making progress in agricultural innovation, with various countries having farmers interested in global agricultural practices [13–17].

One of the biostimulators recommended for treating potato seed tubers is Supporter. This biostimulator is an agricultural substance designed to support plant growth and development and increase their resistance to environmental stresses [17]. It typically contains a mixture of active ingredients such as amino acids, vitamins, micronutrients, and metabolism-stimulating substances. The advantages of this biostimulator include enhancing plant resistance to diseases, pests, and environmental stress, thereby contributing to better yields. Regular use of the biostimulator can improve crop quality by increasing nutrient content and substances affecting aroma and taste [17,18]. Another advantage is the increased tolerance to extreme conditions. Plants treated with biostimulator may be more resistant to adverse environmental conditions such as drought, high temperatures, or soil salinity. Additionally, its liquid form facilitates application through spraying or watering. Therefore, the aim of the research was to evaluate the impact of the biostimulator Supporter on the overall yield and commercial yield of potato tubers and their structure. This can be justified from several perspectives, such as:

The need to increase the efficiency of plant production, as modern agriculture imposes increasingly high demands on productivity and production quality. Research into new technologies, such as the use of plant biostimulators, aims to find ways to improve crop cultivation efficiency and increase yields.

Sustainable agricultural development: Biostimulators, such as Supporter, may contribute to more sustainable agricultural development by reducing the use of chemical substances potentially harmful to the environment and decreasing dependence on chemical pesticides and fertilizers.

Improving plant resistance: Research on the effect of Supporter preparation on plant growth and development can provide information on its ability to increase plant resistance to environmental stresses such as drought, diseases, or pests.

In recent years, there has been increased interest in research on plant biostimulators, but studies on the Supporter substance are seldom undertaken. Therefore, the conducted research aims to fill this gap in knowledge about biostimulators.

Therefore, an alternative research hypothesis was proposed in relation to the null hypothesis:

Hypothesis 1: *Effect on Yield*

Null Hypothesis (H0): *The use of the biostimulator Supporter has no significant effect on the total yield of potato tubers.*

Alternative Hypothesis (H1): *The use of the biostimulator Supporter significantly increases the total yield of potato tubers.*

Hypothesis 2: *Effect on Commercial Tubers and Stress Tolerance*

Null Hypothesis (H0): *The use of the biostimulator Supporter has no significant effect on the proportion of commercial tubers in the yield or plant tolerance to environmental stress.*

Alternative Hypothesis (H1): *The use of the biostimulator Supporter significantly increases the proportion of commercial tubers in the yield and improves plant tolerance to environmental stress.*

By splitting the hypotheses, each outcome (total yield and tuber quality/stress tolerance) is tested independently, eliminating the possibility of partial truth in both hypotheses.

2. Material and Methods

Field studies were conducted between 2015 and 2017 in four locations in Poland (Figure 1).

- Barankowo (Greater Poland Voivodeship)—coordinates: 53°18′35″ N, 16°58′19″ E.
- Głubczyce (Opole Voivodeship)—coordinates: 50°12′0″ N, 17°50′3″ E.
- Kędrzyno (West Pomeranian Voivodeship)—coordinates: 54°3′55″ N, 15°27′1″ E.
- Ryn (Warmian–Masurian Voivodeship)—coordinates: 53°56′57″ N, 21°30′54.17″ E.

Figure 1. Research location in Poland. Source: own.

2.1. Field Research

In this study, three factors were analyzed: cultivation technologies: (a) using the biostimulator Supporter as a seed treatment before planting potatoes, and (b) traditional cultivation, with soaking the tubers in distilled water before planting, as the control treatment; potato varieties ('Innovator', 'Lilly', 'Lady Claire', and 'Verdi'); and locations (Barankowo, Głubczyce, Kędrzyno, and Ryn). The experiment was set up using a randomized complete block design with three replications. Tubers were grouted with Supporter mortar using a wet method immediately before planting using a potato treater (Figure 2), applying Supporter at a rate of 300 mL per hectare along with additional water to the basic mixture. Treatment with the Supporter substance was carried out using a planter equipped with a treater.

Figure 2. Planter with mounted dressing device; source: own.

2.2. Potato Cultivation and Protection

The preceding crop for potatoes in all locations and years of this study was spring barley. Both organic and mineral fertilization for potatoes were at the same level (Biennial compost {straw + red clover + hay}—35 t·ha^{-1}, and 90 kg N·ha^{-1}, 90 kg P·ha^{-1}, 135 kg K·ha^{-1}). The average mineral composition of the compost used in the research was as follows: 520 g of dry matter, 55.6 g of ash, 19.6 g of total nitrogen (N), 0.98 g of mineral nitrogen (N), 3.2 g of phosphorus (P), 32.2 g of potassium (K), 4.9 g of magnesium (Mg), and 0.7 g of sodium (Na) per kg of dry matter of compost. Additionally, the compost contained: 0.45 mg of copper (Cu), 1.4 mg of cadmium (Cd), 15.6 mg of chromium (Cr), 7.10 mg of nickel (Ni), 36.2 mg of zinc (Zn), 36.9 mg of manganese (Mn), and 64.3 mg of iron (Fe) per kg of dry matter of compost.

Mineral fertilization was applied in spring in the form of polyphosphate with the following composition: 6-20-30 (NPK), (S7), and the remaining nitrogen (N) was applied in the form of urea (46%). To reduce weed infestation in potato plantations, herbicides listed in the current list of plant protection substances according to the Institute of Plant Protection—National Research Institute (IPP—NRI) [19] were used. For controlling broadleaf weeds, an herbicide based on the active substance linuron—a compound from the urea derivatives group—450 g.dm^{-1} was used. The treatment for controlling broadleaf weeds was carried out directly after planting, just before potato plant emergence, after prior field preparation and harrowing, and in the case of monocotyledonous weeds, the preparation Fusilade Forte 150 EC, at a dose of 1.5 dm·ha^{-1}, based on the active substance fluazifop-P-butyl (a compound from the aryloxy phenoxy group) was used. This treatment was performed from the stage of developing the first pair of leaves by potato plants to the beginning of tuber formation phases or after completing inter-row cultivation before inter-row closure (phase 12–40 on the BBCH scale). To control late blight, fungicides containing the active substances cyazofamid, fluopicolide, mancozeb, mandipropamide, and difenoconazole were used. The occurrence of the potato beetle was limited by using neonicotinoids and pyrethroids. Potatoes were planted in the second half of April at a spacing of 75 × 33 cm. The plot size for harvesting was 25 m^2. The seed material was in EU class A, following the standards contained in the regulation of the Minister of Agriculture and Rural Development [20].

Potato harvesting was conducted using an elevator digger during the technical maturity period of tubers (99° on the BBCH scale) [21], which, for early varieties, occurred in mid-August and for mid-early varieties, in the first decade of September. During tuber harvesting, the tuber yield was determined, and samples were taken from beneath 10 plants for yield structure determinations, which were classified by fractions: <28, 28–35, 35–50, 55–60, >60 mm in diameter [22]. Marketable tuber yield was defined as the yield of tubers with a diameter >35 mm, excluding those damaged by pests or mechanically to a significant extent, following the requirements contained in the Journal of Laws of the Republic of Poland of 26 November 2014, item 165 [20].

2.3. Characteristics of Potato Varieties

The differences between the varieties concern their earliness (length of the vegetation period) and the color of the flesh, culinary type, starch content, and yield. The consumption type of the examined varieties can be defined from B (general utility) to BC (general utility to mealy). The 'Innovator' variety is distinguished by the highest yield in COBORU tests [23,24], while 'Verdi' has the highest starch content in tubers. The cultivars 'Lady Claire', 'Innovator', and 'Lilly' had different starch contents (Figure 3).

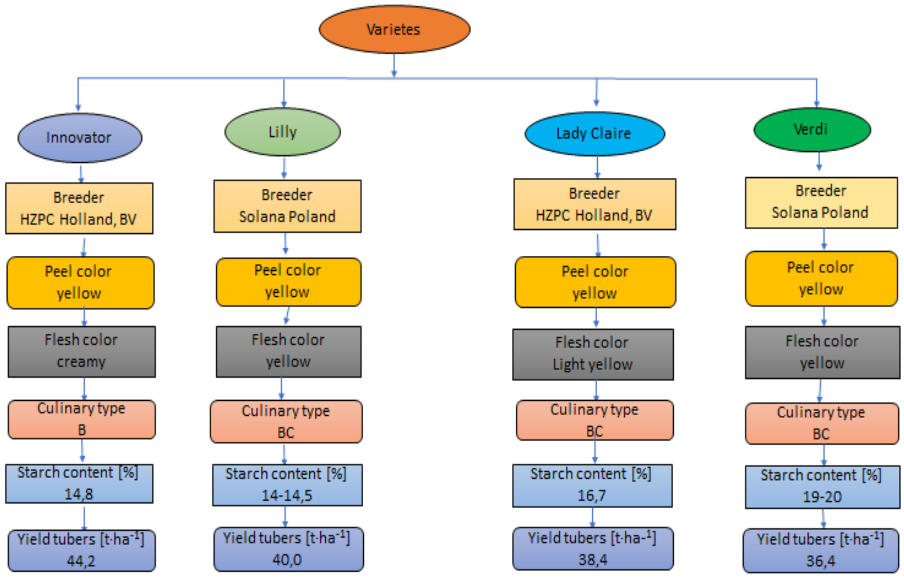

Figure 3. Characteristics of the tested varieties: Source: own.

2.4. Characteristics of the Supporter Biostimulator

The full name of the preparation is SUPPORTERR YIELD MODULATOR' Spiess-Urania Chemicals GmbH European Community Trademark, No. 014199475 Figurative mark [18]. The product was introduced to the market on the basis of the Act on Fertilizers and Fertilization of 10 July 2007—Article 5 [25]. The product Supporter® is not subject to classification and labeling criteria according to Regulation (EC) No. 1272/2008 (CLP). Plant growth promoter. Marketed by: CERTIS EUROPE B.V. Sp. z o.o. Polish branch, Al. Jerozolimskie, Warsaw, Poland, issued on the basis of registration LSN 008304-00/00 obtained in Germany by Spiess-Urania Chemicals GmbH; Frankenstraße 18b; D-20097 Hamburg [18]. Supporter biostimulator is designed to enhance crop productivity, particularly in key crops like potatoes and corn. Its formulation includes synthetic and SL (specialized) amino acids, which facilitate improved nutrient uptake and promote stronger root systems. This leads to accelerated plant growth and increased resilience to environmental challenges such as drought and nutrient deficiencies. The biostimulator also contains natural ingredients like seaweed extracts and other organic compounds that further boost plant health by improving photosynthetic efficiency, promoting larger root systems, and enhancing their stress tolerance [18].

Mechanism of Action: Nutrient Uptake: Amino acids in Supporter enhance nutrient absorption, ensuring plants receive optimal nourishment, even in nutrient-poor soils [18].

Root Development: The product strengthens root systems, allowing plants to access water and nutrients more effectively, especially during drought or stress [18].

Stress Resistance: Supporter increases resilience to environmental stressors like heat, drought, and nutrient scarcity by regulating stress-related hormones and boosting plant metabolism [18].

In essence, Supporter helps crops optimize their growth potential, leading to higher yields and better adaptation to challenging conditions [18]. The global biostimulator market is expected to grow significantly. In 2023, the market was valued at around $3.71 billion and is expected to reach $7.54 billion by 2031 [FAO 2023]. Currently, Europe dominates this market, but biostimulators such as Supporter are increasingly being adopted worldwide, especially in regions such as North America, Latin America, and Asia Pacific [19].

2.5. Soil Conditions

Each year, before starting the experiment in accordance with PN-R-04031 [26], 20 soil samples were taken as standard from the arable layer (0–20 cm) to create a sample weighing approximately 0.5 kg. These samples were analyzed to determine the granulometric composition of the soil, the content of available forms of phosphorus, potassium, and magnesium, soil pH, and humus [27]. Soil pH was measured in a suspension of 1 mol KCl dm^{-3} and in a water suspension using the potentiometric method [28]; available magnesium was determined using the Schachtschabel method [29]; available forms of phosphorus and potassium—by the Egner–Riehm method [30,31]. The content of mineral forms of nitrogen in the soil was determined by the extraction method. This extract dissolves mineral nitrogen, which was then analyzed. Nitrate nitrogen (NO_3^-) was determined spectrophotometrically using the colorimetric method. Ammonium nitrogen (NH_4^+) was determined colorimetrically using Nessler's method. The results were used to calculate fertilizer doses according to the needs of crops, using the Fotyma method.The humus content was determined using the Tiurin method, adapted by Simakov [32]. Soil pH was measured potentiometrically. Macro- and microelement analysis employed Atomic Absorption Spectrometry (AAS). The results of soil analysis were compared with standard values provided by the Institute of Fertilization and Soil Science—National Research Institute [33]. Compost assessment involved specific procedures: dry mass, organic matter, and pH were evaluated according to [34] standards, with K, Ca, and Mg determined by PB 27, 2nd edition, 6 April 2009, and N assessed per [34] guidelines, while P was analyzed following PB 26, 2nd edition, dated 26 April 2009.

Mineral nitrogen levels were computed using the methodology outlined by Fotyma et al. [35]. Table 1 shows the content of macroelements (P_2O_5, K_2O, and Mg) and the pH_{KCl} reaction in the soil in 2015–2017 in four different towns in Poland: Kędrzyno, Barankowo, Ryn, and Głubczyce.

Table 1. Content of available forms of phosphorus, potassium, magnesium humus, and soil reaction (2015–2017).

Years	Macroelement Content [g·kg^{-1}]			N-Min Content (mg N/kg Soil)	pH [in KCL]	Humus [g·kg^{-1}]
	P_2O_5	K_2O	Mg			
				Kędrzyno		
2015	24.8	9.0	3.4	30	5.6	1.01
2016	18.8	18.0	3.9	28	6.0	1.06
2017	17.0	15.0	6.2	32	6.4	1.12
				Barankowo		
2015	31.9	14.8	3.3	32	5.8	1.2
2016	25.0	12.7	3.2	35	6.0	1.4
2017	30.4	12.4	2.9	34	5.9	1.3
				Ryn		
2015	14.5	16.0	3.6	29	6.1	1.1
2016	14.7	17.5	3.8	27	6.3	1.3
2017	15.0	19.0	4.0	31	6.4	1.4
				Głubczyce		
2015	27.8	22.6	11.8	40	6.6	1.8
2016	25.2	21.5	12.8	42	6.5	1.7
2017	21.8	19.1	12.0	43	6.4	1.6

Note: Source of own experiment results, which were made in the Laboratory Central of Agro-Ecological, the University of Life Science in Lublin.

In the village of Kędrzyno, the content of available phosphorus decreased from 24.8 g·kg^{-1} in 2015 to 17.0 g·kg^{-1} in 2017, classifying the soils as phosphorus-poor. The content of available potassium ranged from 9.0 to 18.0 g·kg^{-1}, categorizing it as soil with low to moderate fertility. Meanwhile, the magnesium content increased from 3.4 g·kg^{-1} in 2015 to 6.2 g·kg^{-1} in 2017. The soil pH was slightly acidic to neutral [33]. In the village of Barankowo, the available phosphorus content was high, ranging between 25.0 and 31.9 g·kg^{-1}, while the potassium content ranged from 12.4 to 12.7 g·kg^{-1}. The magnesium content ranged from 2.9 to 3.3 mg·kg^{-1}, and the soil pH was slightly acidic [27,33]. In the village of Ryn, located in the northeast of Poland, the phosphorus content was the lowest (1.5–15.0 g·kg^{-1}), with potassium content being average (16–19 g·kg^{-1}), and the soil pH was slightly acidic [27,33]. In the village of Głubczyce, situated in the south of Poland, the phosphorus content ranged from 25.2 to 27.8 g·kg^{-1} in the years 2015–2016 to 21.8 g·kg^{-1} in 2017. The potassium content was high, ranging from 19.1 to 21.6 g·kg^{-1}, and the magnesium concentration was also high. The soil pH ranged from slightly acidic to neutral [32,33].

The mineral nitrogen (N-min) content, expressed as mg N kg^{-1} soil, varies across the four study sites (Kędrzyno, Barankowo, Ryn, and Głubczyce), reflecting different soil fertility and potential for nutrient uptake: Kędrzyno: The N-min content fluctuated between 28 and 32 mg N·kg^{-1} soil over the study period. This moderate level indicates stable nitrogen availability, which can support consistent crop growth. In Barankowo nitrogen levels ranged from 32 to 35 mg N·kg^{-1} soil, showing slightly higher values compared to Kędrzyno. This suggests that Barankowo has somewhat more fertile soils, potentially allowing for better nutrient uptake. Ryn—here the N-min content was lower, ranging from 27 to 31 mg N kg^{-1} soil. These lower levels suggest that nitrogen supplementation might be more critical in this location to optimize crop performance. In Głubczyce with the highest N-min content, ranging from 40 to 43 mg N kg^{-1} soil, Głubczyce stands out as having a rich nitrogen supply, which can significantly contribute to improved crop yields and reduced need for external nitrogen fertilization. These variations in N-min content across locations highlight the importance of site-specific nitrogen management strategies. Soils with lower nitrogen content (like Ryn) may require more nitrogen inputs to achieve optimal yields, while soils with higher nitrogen (like Głubczyce) can support crops with minimal additional fertilization (Table 1).

The humus content in the examined soils depended on their location. In the case of Kędrzyno, Barankowo, and Ryn, it seemed relatively stable in each year, fluctuating between 1.0 and 1.4 g·kg^{-1} of soil. However, in Głubczyce, the humus content was higher compared to the other villages, ranging from 1.6 to 1.8 g·kg^{-1} of soil. Nevertheless, a decreasing trend was observed in 2016 and 2017, indicating soil degradation or other factors affecting humus content [27].

The organic matter content in the soil is an important indicator of soil quality as it affects its fertility, structure, water retention capacity, and other essential functions [27]. Lower humus content may indicate soil degradation, which may require appropriate actions such as improving agricultural practices or using soil structure-improving agents and humus conservation methods. Thus, soil analysis revealed variability in the content of macroelements and soil pH in the examined villages and years, which may have significant implications for agricultural cultivation and fertilization, especially for adjusting fertilization to changing soil conditions. The soil conditions in the selected villages were diverse. In Głubczyce, predominantly very good and good soils (wheat–beetroot) of class II prevailed. In Kędrzyno, potatoes were cultivated on podzolic soils formed on loamy clays and clayey sands. In Barankowo, in the western part of the country, potatoes were cultivated on podzolic soils, class IV. In the village of Ryn, in the northeast of the country, the experiment was established on proper brown soils formed from various rocks rich in calcium carbonate [27,36].

Soil studies conducted in 2015–2017 showed significant differences in the content of macroelements and soil pH in four locations in Poland (Kędrzyno, Barankowo, Ryn, and Głubczyce). Key soil parameters, such as phosphorus, potassium, magnesium, and pH, differed significantly between locations, which affected potato cultivation conditions. In Kędrzyn, a decrease in phosphorus content and low potassium content were observed, which classifies these soils as poor in phosphorus. In Barankowo, the soil was richer in phosphorus and potassium, and in Ryn, the lowest phosphorus content was noted, which indicates the need for more intensive fertilization. In turn, in Głubczyce, the soils had a high content of macroelements and a stable pH. The variability of humus content, especially in Głubczyce, where its level was higher but showed a downward trend, may suggest soil degradation processes.

2.6. Meteorological Conditions

This study utilized meteorological observation results from COBORU experimental stations located within the research area. The highest rainfall, regardless of the year, was recorded in the West Pomeranian Voivodeship in the town of Kędrzyno (1572.8 mm over 3 years) and in the Opole Voivodeship in the town of Głubczyce (1147.6 mm). The least rainfall, on the other hand, was recorded in the towns of Ryn (1042.9 mm) and Barankowo (1052.9 mm) (Table 2).

Table 2. Total rainfall and average air temperature in Barankowo, Gołubczyce, Kędrzyno, and Ryn in the period May–September (2015–2017).

Locations	Total Rainfall [mm]		
	2015	2016	2017
Barankowo	237.1	306.9	508.9
Głubczyce	218.4	472.3	465.9
Kędrzyno	383.9	476.1	712.8
Ryn	241.3	350.0	451.6
	Average air temperature [°C]		
Barankowo	13.4	15.3	14.1
Głubczyce	15.9	15.7	15.2
Kędrzyno	12.2	14.9	14.0
Ryn	14.5	13.8	14.1

The rainfall level during the growing season in Kędrzyno was highest in 2017 (712.8 mm), while in Głubczyce it was in 2016 (472.3 mm). Kędrzyno is characterized by the highest rainfall totals and relatively lowest air temperatures compared to other locations. The average air temperature during the growing season was highest in Głubczyce, ranging from 15.2 to 15.9 °C, and lowest in Kędrzyno, ranging from 12.2 to 14.9 °C (Table 2). In Barankowo and Ryn, the thermal conditions were similar and ranged, respectively, from 13.4 to 15.3 °C and from 13.8 to 14.5 °C.

In Barankowo, a significant increase in both rainfall totals and air temperatures during the potato growing season was observed in 2017 compared to previous years. In the town of Ryn, higher rainfall totals were recorded in all years of this study compared to Barankowo, while air temperature remained relatively unchanged. In Głubczyce, the highest average air temperature during the plant-growing season was recorded compared to other locations, but rainfall totals remained slightly variable throughout the study period (Table 2).

Additionally, the Sielianinov hydrothermal coefficient values were determined for the potato growing season. This coefficient is a measure of rainfall effectiveness in a given month. Based on these coefficient values, the years 2015 and 2016 in Kędrzyno were classified as fairly humid, while 2017 was classified as very humid (Figure 4). In Barankowo, the years 2015 (k = 0.8) and 2016 (k = 1.0) were classified as dry, while 2017 was classified as very humid (k = 1.9). In Ryn (Warmian–Masurian Voivodeship), the year 2015 was considered dry (k = 0.9), 2016 as fairly dry (k = 1.3), and 2017 as fairly humid (k = 1.8). The Sielianinov hydrothermal coefficient allowed the classification of the year 2015 in Głubczyce as very dry (k = 0.7), 2016 as optimal (k = 1.6), and 2017 as humid (k = 2.1) (Figure 4). The values of the hydrothermal coefficient for the years 2015–2017 helped to identify regions and months with drier or more humid conditions within the study area. Significant spatial variation in the occurrence of extreme pluviometric conditions was also observed during the study period.

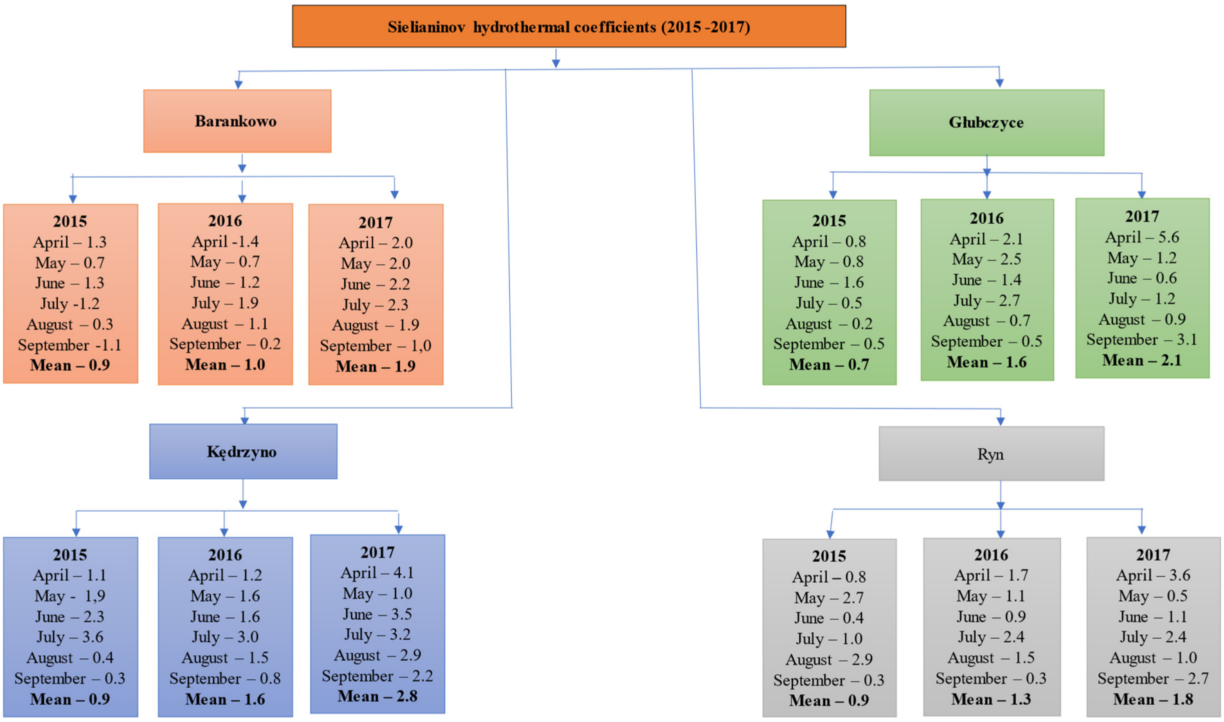

Figure 4. Sielianinov hydrothermal coefficients (2015–2017); Source: own.

The Sielianinov coefficients for the towns of Barankowo and Ryn exhibited a tendency to remain within the range from dry to humid, with values close to each other. The hydrothermal coefficients for Głubczyce showed the greatest variability, with the lowest values in 2015 and the highest in 2017, indicating significant variation in hydrothermal conditions between years. Kędrzyno demonstrated the highest average values of the hydrothermal coefficient in all three years, suggesting a higher level of humidity compared to the other locations (Figure 4).

The value of the hydrothermal coefficient was calculated according to the formula: $k = P/\sum t \times 10$, where: P—monthly sum of precipitation in mm, $\sum t$—monthly sum of air temperatures > 0 °C [37]. Extremely dry month: $k \leq 0.4$; very dry—$0.4 < k \leq 0.7$; dry $0.7 < k \leq 1.0$; fairly dry $1.0 < k \leq 1.3$; optimal $1.3 < k \leq 1.6$; quite humid $1.6 < k \leq 2.0$; humid $2.0 < k \leq 2.5$; very humid $2.5 < k \leq 3.0$; and extremely humid $k > 3.0$.

This study examined meteorological data from various locations to assess rainfall and air temperature patterns during the potato growing season. Kędrzyno recorded the highest rainfall and the lowest air temperatures, while Głubczyce had the highest temperatures but variable rainfall. The Sielianinov hydrothermal coefficient was used to classify the years from 2015 to 2017 by their humidity levels, revealing significant spatial and temporal variations. Kędrzyno consistently exhibited higher humidity levels, while Głubczyce showed the greatest variability in hydrothermal conditions.

2.7. Statistical Calculations

The statistical analysis was conducted using SAS 9.2 software [38]. The analyses were based on a four-factor model (varieties × technologies × locations × years). Years are a random factor. Analysis of variance (ANOVA) was employed, and multiple Tukey's tests were performed to compare means between groups. The significance of the source of variability was assessed using the Fisher–Snedecor test. The Tukey multiple comparison test was performed with a selected significance level of $p = 0.05$. The analysis of variance models included the main effects and interactions between the studied factors, with a particular focus on the main effects and two-way interactions. The multiple comparisons conducted using Tukey's test allowed for a comprehensive analysis of means, identifying statistically homogeneous groups of means through the Least Significant Difference (LSD).

This approach facilitated the identification of significant differences between means, ensuring that only those differences exceeding the critical value for significance were considered meaningful. Tukey's multiple comparison tests enabled detailed comparative analyses, allowing for the identification of statistically homogeneous groups and the determination of the so-called least significant difference. Additionally, descriptive statistics of the studied characteristics were analyzed, and correlation coefficients between the variables were calculated [39].

3. Results

3.1. Total Tuber Yield

In the experiment, the total tuber yield depended on the response of the varieties to the potato cultivation technology (Figure 5). The use of the Supporter substance before potato planting resulted in a significant increase in tuber yield compared to traditional technology, on average by 13.3%. All varieties responded positively with an increase in total tuber yield to the innovative technology using the Supporter preparation before planting; however, only two of them ('Innovator' and 'Lilly') responded with a significant increase in yield. The most productive, regardless of the cultivation technology and years of research, was the 'Lilly' variety with an average yield of 47.95 t·ha^{-1}, while the least productive variety was 'Innovator' with an average yield of 29.93 t·ha^{-1}. The varieties 'Lady Claire' and 'Verdi' were found to be uniform in terms of the value of this feature (Figure 5).

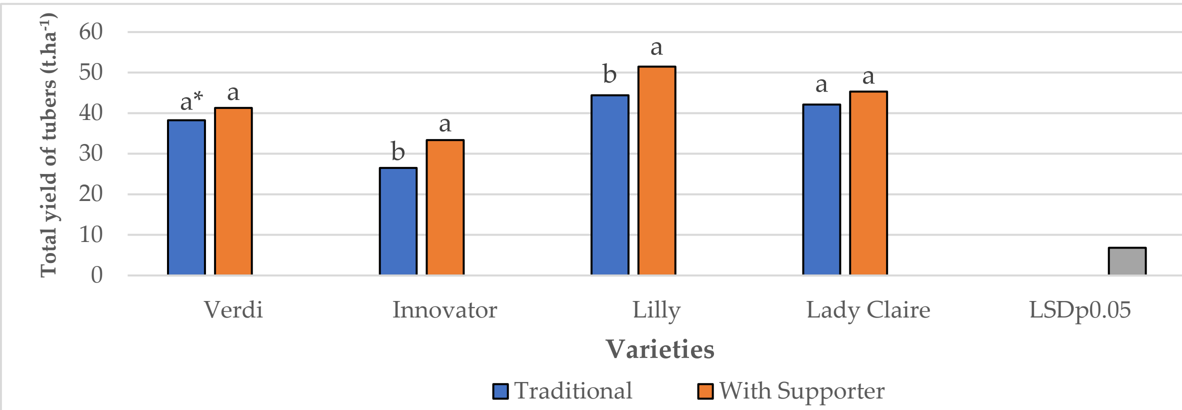

Figure 5. Reaction of potato varieties on the cultivated technology (mean for 2015–2017). * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

The greatest effect of the use of technology with the use of a biostimulator was obtained in the case of the 'Lilly' variety (yield increase under the influence of the Supporter preparation by 26.0%), smaller but significant in the case of the 'Innovator' variety (15.9%), and significantly smaller in the 'Verdi' (7.9%) and 'Lady Claire' (7.6%) varieties (Figure 5).

Geographical location, regardless of experimental factors, had a significant impact on the total tuber yield. The highest value of this trait was found in Barankowo, located in the Wielkopolska province in Poland (47.94 t·ha^{-1}), while the lowest was in Kędrzyno, located in the north-eastern part of the country (29.93 t·ha^{-1}). The total yield of tubers in the localities of Barankowo and Ryn and Głubczyce and Ryn was found to be homogeneous in terms of the value of this feature, and in Kędrzyno it was significantly lower than in all the other localities (Figure 6).

The interaction between research location and cultivation technology also proved significant. In Kędrzyno and Barankowo, situated in the north-western part of the country, a significantly higher yield increase was achieved using the cultivation technology with the Supporter bioregulator (26.0% and 15.9%, respectively) compared to the traditional cultivation method without Supporter. In Głubczyce, located in south-western Poland, and in Ryn, in the north-eastern part of the country, a positive effect was observed with the use of cultivation technology with Supporter (7.9% and 7.6%, respectively) compared to traditional methods; however, these differences were not statistically significant. This was related to the quality of the soil and the meteorological conditions in this locality (Figure 6).

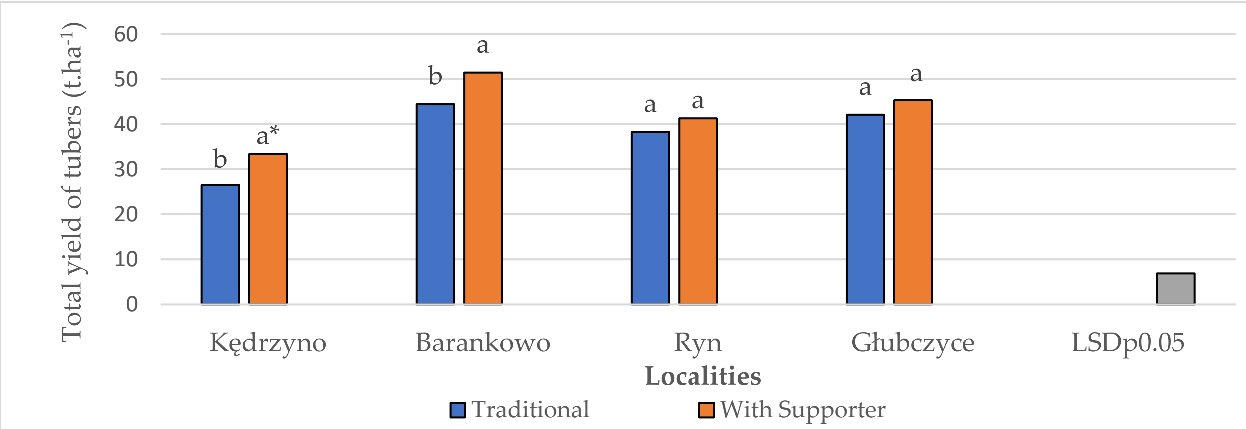

Figure 6. The effect of cultivation technology and location on total tuber yield. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

Meteorological conditions during the study years significantly influenced the total tuber yield. The lowest yields were recorded in the dry 2015, while the highest were in the thermally and precipitationally optimal 2016 (Figure 7). The tested varieties reacted differently to meteorological conditions during the potato vegetation period. In 2015, the weather conditions were less favorable for potato yields, which resulted in lower yields for some varieties (especially 'Verdi' and 'Lady Claire'). 'Innovator' and 'Lilly' varieties showed greater yield stability in different years, suggesting their resistance to changing weather conditions. Statistical differences between yields from different years are significant, as indicated by the letters "a" and "b". Overall, Figure 7 indicates a significant effect of varieties and weather conditions on total tuber yield.

Interaction between technology, variety, and year was not observed (Table 3).

Table 3. The influence of cultivation technology, varieties, and years on the total yield of potato tubers (t·ha^{-1}) (average for location).

Varieties	Technologies					
	Traditional			With Supporter		
	Years					
	2015	2016	2017	2015	2016	2017
'Verdi'	33.19 a *	43.43 a	38.19 a	31.64 a	51.64 a	40.63 a
'Innovator'	20.84 a	30.15 a	28.48 a	36.24 a	27.95 a	35.93 a
'Lilly'	47.48 a	41.87 a	43.92 a	60.52 a	48.28 a	45.62 a
'Lady Claire'	32.47 a	48.64 a	45.26 a	31.26 a	51.12 a	53.59 a
LSD$p_{0.05}$ Varieties × Technologies × Years	ns **					

* Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups; ** ns—not significant at $p_{0.05}$.

Technology with Supporters generally improved yields in all years and for all varieties compared to the traditional technology, although these differences were not always statistically significant. The 'Lilly' variety showed the highest yields, particularly with the Supporter technology in 2015. The differences between the results in different years and technologies were statistically insignificant, indicating that the effects of these factors were similar.

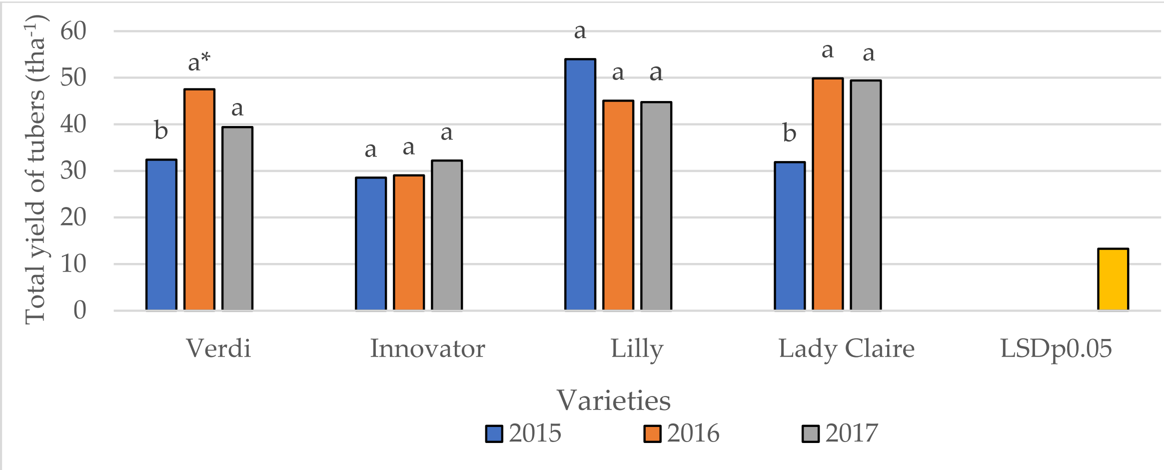

Figure 7. Influence of varieties and conditions meteorological on the total yield of tubers. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

3.2. The Structure of Tuber Yield

The structure of tuber yield depending on all experimental factors is presented in Table 4. The proportion of individual tuber fractions in the total potato yield varied depending on the cultivation technology, variety, location, and harvest year. Among the individual fractions, only those with transverse diameters of 28–35, 50–55, 55–60, and >60 mm showed a different response to cultivation technologies. Potato plants produced a greater mass of tubers with calibers of 28–35 and 50–55 mm but a smaller mass of larger-sized tubers (55–60 and >60 mm in diameter) under the technology using the Supporter biostimulator (Table 4).

Differences in the proportion of individual tuber fractions were also significant among the tested potato varieties. The 'Verdi' variety seemed to produce a greater mass of tubers with diameters < 28 and 35–50 mm compared to other varieties. In contrast, the 'Lilly' variety exhibited the highest proportion of tubers with a diameter of 50–55 mm, while the 'Lady Claire' variety produced the largest mass of the largest tubers in the yield, with calibers of 55–60 and >60 mm. The 'Innovator' variety, however, showed homogeneity compared to the 'Verdi' variety in the production of medium-sized tubers, with a transverse diameter of 35–50 mm (Table 4).

The location of the experiments also significantly influenced the structure of the potato tuber yield. The greatest small-sized tubers were observed in Kędrzyno, located in the northwest of Poland, on soil of IV soil evaluation class, while the largest proportion of large tubers, with diameters of 50–60 and >60 mm, was recorded in Głubczyce, in the south of the country, on soils of I and II evaluation class (Table 4).

Table 4. Share of potato tuber mass by diameter fractions (<28, 28–35, 35–50, 50–55, 55–60, and >60 mm) depending on cultivation technology, potato varieties, and harvest years (%).

Experimental Factors		Tuber Diameter Fractions (mm)					
		<28	**28–35**	**35–50**	**50–55**	**55–60**	**>60**
Technologies	Traditional	2.07 a *	5.84 b	50.49 a	18.62 b	13.06 a	9.92 a
	With Supporter	2.01 a	7.52 a	49.11 a	20.29 a	12.54 b	8.53 b
	$LSD_{0.05}$	ns **	0.75	2.73	0.65	0.37	0.22
Varieties	'Verdi'	3.53 a	8.63 a	58.03 a	16.80 c	9.00 d	4.01 c
	'Innovator'	1.57 b	5.66 bc	56.39 a	19.55 b	10.61 c	6.22 b
	'Lilly'	1.97 b	5.25 c	50.85 b	21.24 a	14.41 b	6.28 b
	'Laidy Claire'	1.11 bc	7.13 b	33.98 c	20.19 ab	17.17 a	20.42 a
	$LSD_{0.05}$	1.51	1.51	5.47	1.30	0.74	0.44
Locations	Barankowo	3.50 a	8.70 a	56.54 a	17.14 c	8.84 d	5,28 c
	Głubczyce	1.66 b	5.60 c	56.32 a	19.78 c	10.65 c	5.99 c
	Kędrzyno	1.80 b	5.02 d	51.43 b	20.31 a	14.23 b	7.21 b
	Ryn	1.19 c	7.40 b	34.90 c	20.56 a	17.48 a	18.47 a
	$LSDp_{0.05}$	0.15	0.43	3.29	1.26	0.96	0.62
Years	2015	1.95 a	8.60 a	57.47 a	18.92 b	10.32 b	2.74 c
	2016	1.97 a	5.70 b	44.96 b	18.23 b	15.43 a	13.71 a
	2017	2.20 a	5.76 b	46.96 b	21.20 a	12.65 b	11.23 b
	$LSD_{0.05}$	ns	1.13	4.10	0.97	0.55	0.33
Mean		2.04	6.68	49.80	19.45	12.80	9.23

* Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups; ** ns—not significant at $p_{0.05}$.

Meteorological conditions during the study years significantly modified the caliber of tubers with diameters of 28–35, 35–50, 50–55, 55–60, and >60 mm. A significantly higher proportion of tubers with calibers of 28–35 and 35–50 mm was observed in the dry year of 2015 than in the other years. Conversely, a significantly higher proportion of large tubers, with calibers of 50–55, 55–60, and >60 mm, was noted in years with optimal thermal–humidity conditions. In 2015, tubers with a diameter greater than 60 mm were significantly less numerous than in 2016 and 2017 (Table 4).

Figure 6 illustrates the response of potato varieties to cultivation technology in terms of the proportion of mass of tubers of individual size fractions. The 'Verdi' variety responded by increasing the proportion of mass of large tubers with diameters of 50–55 and 55–60 mm in the total yield when using the technology with the Supporter biostimulator. The 'Innovator' variety, on the other hand, significantly responded by reducing the proportion of mass of tubers with diameters of 35–50 mm and 55–60 mm to this technology. The 'Lilly' variety responded to the technology with the use of the Supporter biostimulator by significantly increasing the proportion of mass of tubers with diameters of 35–50 mm and decreasing the proportion of mass of tubers with diameters of 55–60 mm. The 'Lady Claire' variety, in turn, responded by a significant increase in the mass of tubers with diameters of 28–35 mm and a simultaneous significant decrease in the proportion of tubers with calibers of 50–55 and 55–60 mm (Figure 8).

There was no interaction observed between locations and varieties, nor between locations and cultivation technologies. However, overall, these studies allow for an analysis of the influence of various factors on the yield of potatoes with different tuber sizes, which can be helpful in optimizing cultivation processes and selecting the best agricultural practices.

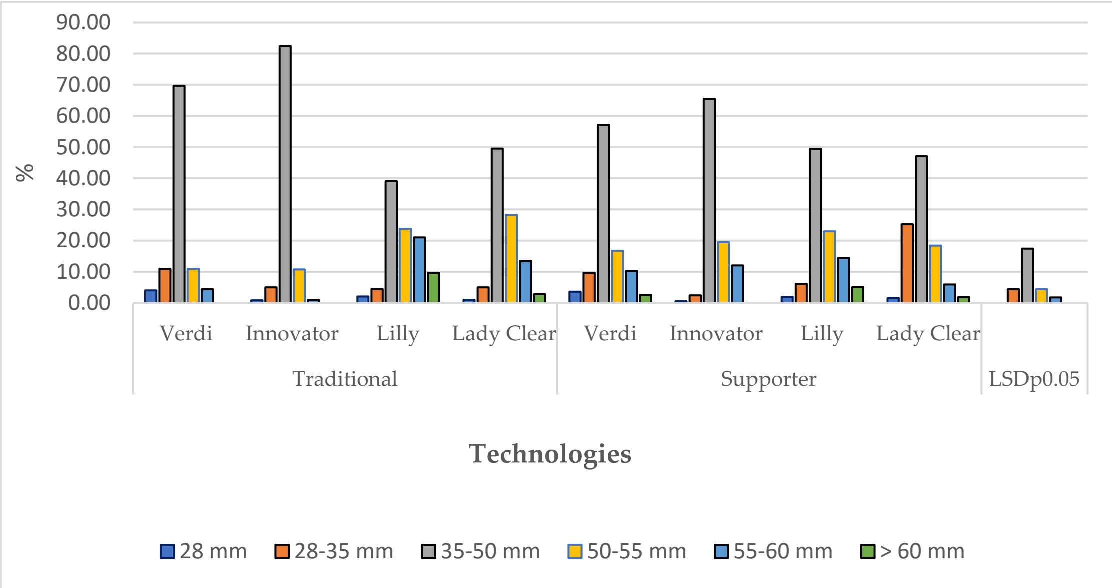

Figure 8. The influence of potato varieties and cultivation technology on the mass share of tubers with a diameter of <28 mm, 28–35 mm, 35–50 mm, 50–55 mm, 55–60 mm, and >60 mm.

3.3. The Share of Marketable Tubers

The impact of experimental factors on the share of marketable tubers is presented in Figure 9 and Table 5. The cultivation technologies did not significantly differentiate the share of marketable tuber mass in the overall yield. However, the factor significantly modifying this characteristic was the genetic traits of the tested varieties and their interaction with cultivation technologies and years of study.

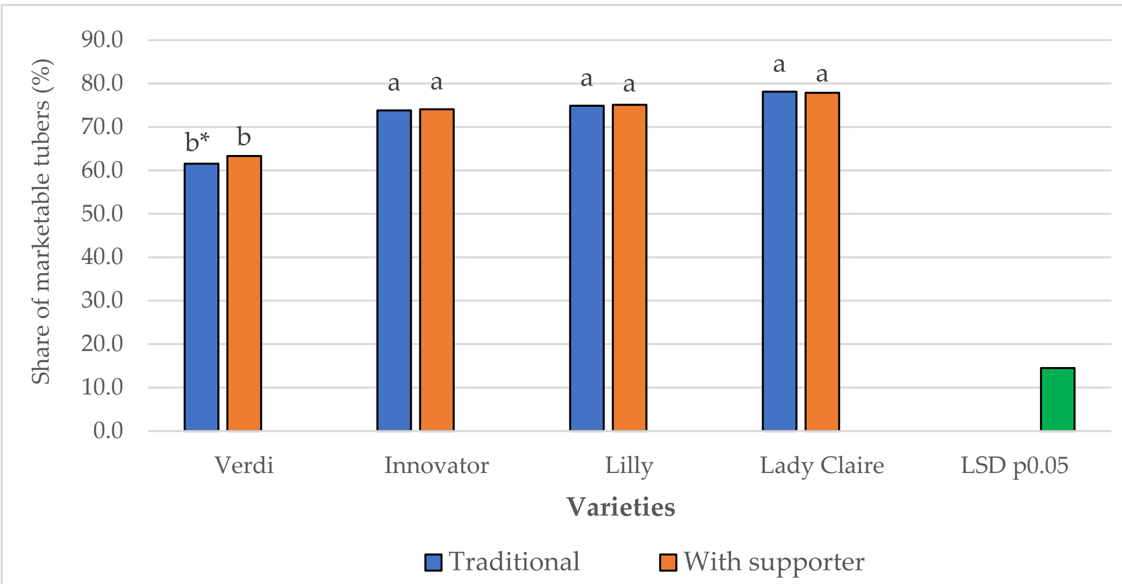

Figure 9. The influence of cultivation technology and varieties on the share of commercial tubers in the total yield. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

Table 5. The impact of cultivation technology, varieties, and years on the share of commercial tubers in the total yield (t·ha^{-1}) (average for location).

Varieties	Technologies					
	Traditional			With Supporter		
	Years					
	2015	2016	2017	2015	2016	2017
'Verdi'	60.95 a *	69.51 a	54.14 a	61.42 a	72.89 a	55.63 a
'Innovator'	83.82 a	61.40 a	76.22 a	87.20 a	61.93 a	73.05 a
'Lilly'	74.92 a	75.93 a	73.81 a	77.97 a	64.35 a	83.02 a
'Lady Claire'	76.26 a	84.21 a	73.91 a	61.50 a	86.36 a	85.74 a
LSD $p_{0.05}$						
Technologies × Varieties × Years	ns **					

* Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups; ** ns—not significant at $p_{0.05}$.

Analysis of the differences between varieties in percentage values proved that the 'Lady Claire' variety achieved the highest share of marketable tubers in the total yield, both in traditional technology (78.1%) and with the use of the Supporter bioregulator (77.9%). The 'Lilly' variety achieved slightly lower values (74.9% in traditional technology and 75.1% with Supporter). The 'Innovator' variety was homogeneous in relation to the 'Lilly' variety (73.8% in traditional technology and 74.1% with Supporter). The 'Verdi' variety obtained the lowest share of marketable tubers in the tested varieties (61.5% in traditional technology and 63.3% with Supporter). In the case of the 'Verdi', 'Innovator', 'Lilly' varieties, and 'Lady Claire', the differences between the traditional technology and the one using the Supporter bioregulator were statistically insignificant, which means that these varieties were homogeneous in terms of their response to the cultivation technology. The variety with the lowest share of marketable tubers was 'Verdi', while 'Lady Claire' had the highest share of mass of these tubers, with 'Lilly' and 'Innovator' being homogeneous in terms of this characteristic. The tested varieties showed varied reactions to the applied cultivation technologies. Both traditional and cultivation technologies using the biostimulator Supporter showed the lowest share of marketable tubers with the 'Verdi' variety (Figure 9).

The tested varieties exhibited varied reactions to the meteorological conditions in the years of study. In the dry 2015, the highest share of marketable tubers in the total yield was noted for the 'Innovator' variety, while the lowest was noted for the 'Verdi' variety. In 2016 and 2017, with an adequate supply of water to the soil, the largest mass of tubers of a size corresponding to marketable tubers was produced by the 'Lady Claire' variety. On the other hand, the lowest share of tubers of this fraction was noted for the 'Innovator' and 'Verdi' varieties, respectively (Figure 10).

Homogeneous in terms of the value of this trait in 2015 and 2017 were the following varieties: 'Innovator', 'Lilly', and 'Lady Claire'; in 2016: 'Verdi', 'Lilly', and 'Laidy Claire' (Figure 10).

Table 5 presents data on the impact of cultivation technologies, different potato varieties, and years on the percentage of commercial tubers in the total yield. The LSD test at $p_{0.05}$ indicates that there were no significant differences in the percentage of commercial tubers when considering the interaction between technologies, varieties, and years. This suggests that the variation observed among the different technologies, varieties, and years was not statistically significant.

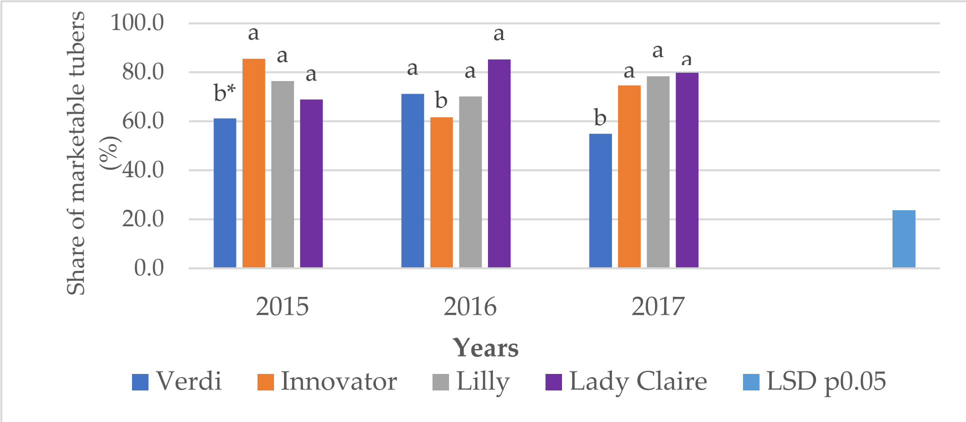

Figure 10. The influence of variety and year on the share of marketable tubers. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

It was also observed that there was an interaction between the research locations and cultivation technologies. In three locations: Kędrzyno, Głubczyce, and Ryn, the cultivation technology using the biostimulator Supporter showed a significant increase in the share of marketable tuber mass compared to traditional cultivation technology. In Barankowo, however, a positive trend towards increasing the share of marketable tubers was noted with the Supporter technology (Figure 11).

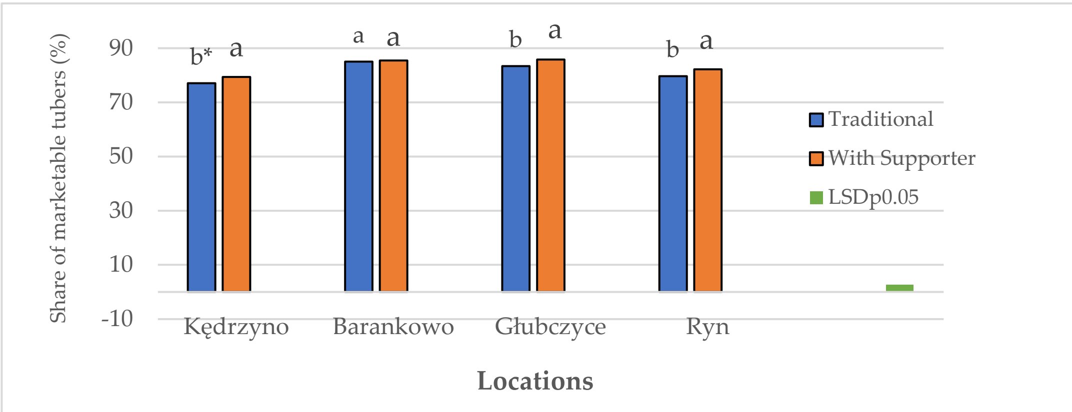

Figure 11. The influence of cultivation technology and locations on the percentage of the mass of commercial tubers. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

3.4. Yield of Marketable Tubers

The yield of marketable tubers was influenced by all experimental factors, but most significantly by the applied cultivation technologies. Thanks to the use of the biostimulator Supporter, the marketable yield increased by 21.1% compared to traditional technology. This effect depended on meteorological conditions in the years of this study. The greatest effect in the form of an increase in marketable yield by 8.3 t ha^{-1}, which was an increase of 33.7%, was obtained in the dry year of 2015; a slightly lower but statistically significant effect was obtained in 2017—by 6.0 t ha^{-1}, which was 22.3%, compared to the traditional technology. In 2016, when the plants had the best water supply, the effect of using the Supporter preparation was beneficial but statistically insignificant (Figure 12).

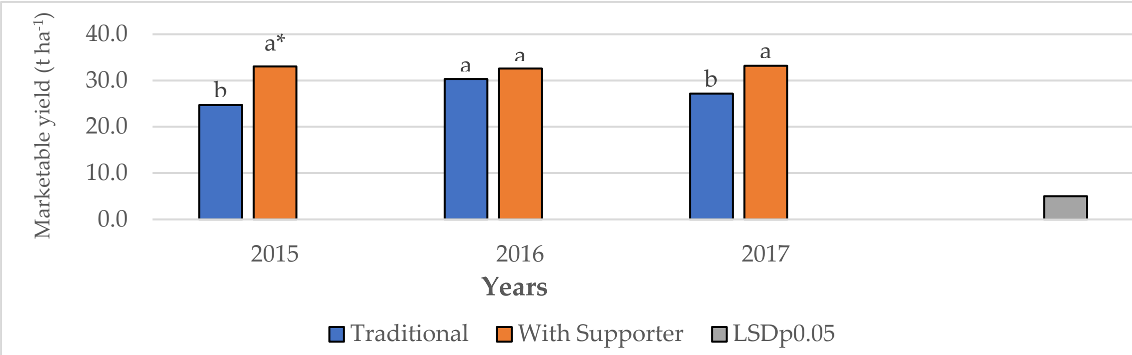

Figure 12. The influence of cultivation technology and years on the marketable yield of tuber. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

The highest marketable yield was obtained by the 'Lady Claire' variety, while the 'Lilly' variety was homogeneous in terms of this characteristic, and the least productive was the 'Innovator' variety. The highest yield of marketable tubers was achieved in the optimal thermohydrometric year of 2016; the year 2017 was homogeneous compared to 2016, while the lowest yield was obtained in the dry year of 2015 (Figure 13).

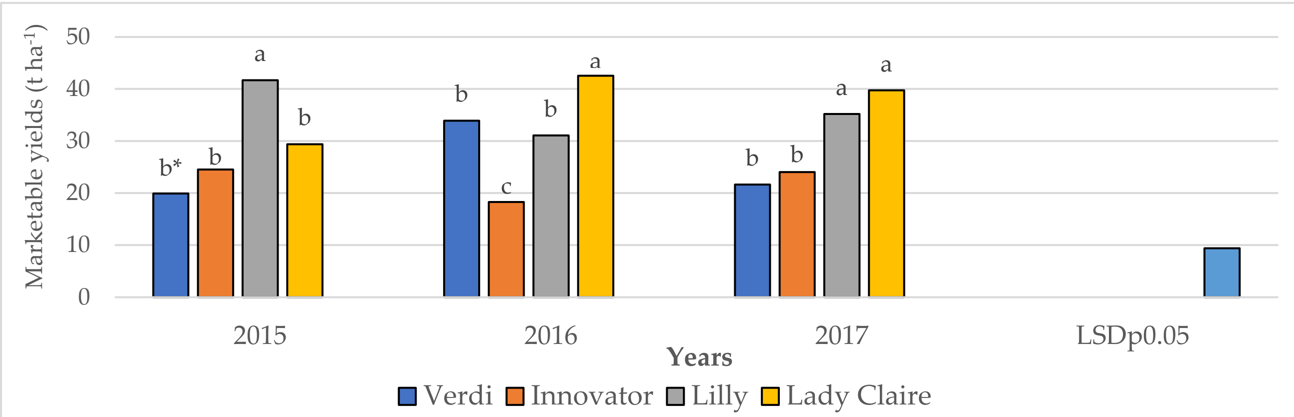

Figure 13. The influence of varieties and years on the marketable yield of tubers. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

In the dry 2015, the highest marketable yield was produced by the 'Lilly' variety, while in years with a higher hydrothermal coefficient—by the 'Lady Claire' variety. The lowest marketable tuber yield, both in the dry 2015 and in 2017, with moderate rainfall, was produced by the 'Verdi' variety and in the wet 2016—by the early 'Innovator' variety. In 2015, the 'Innovator' and 'Lady Claire' varieties; in 2016, the 'Verdi' and 'Lilly' varieties; and in 2017, the 'Verdi' and 'Innovator' varieties, as well as 'Lilly' and 'Lady Claire' varieties, were homogeneous in terms of this trait (Figure 13). The varieties 'Verdi' and 'Innovator' showed different profitability over the years, with some improvement noted in 2017. The 'Lilly' variety consistently exhibited high yields throughout all years, regardless of the cultivation technology. The 'Lady Claire' variety showed relatively stable yields over the years, with only minor fluctuations.

The studied varieties showed a varied response to cultivation technologies. Almost all varieties, except for the early 'Verdi', responded with a significant increase in marketable yield to the application of cultivation technology using the Supporter bioregulator, compared to the traditional technology (Figure 14).

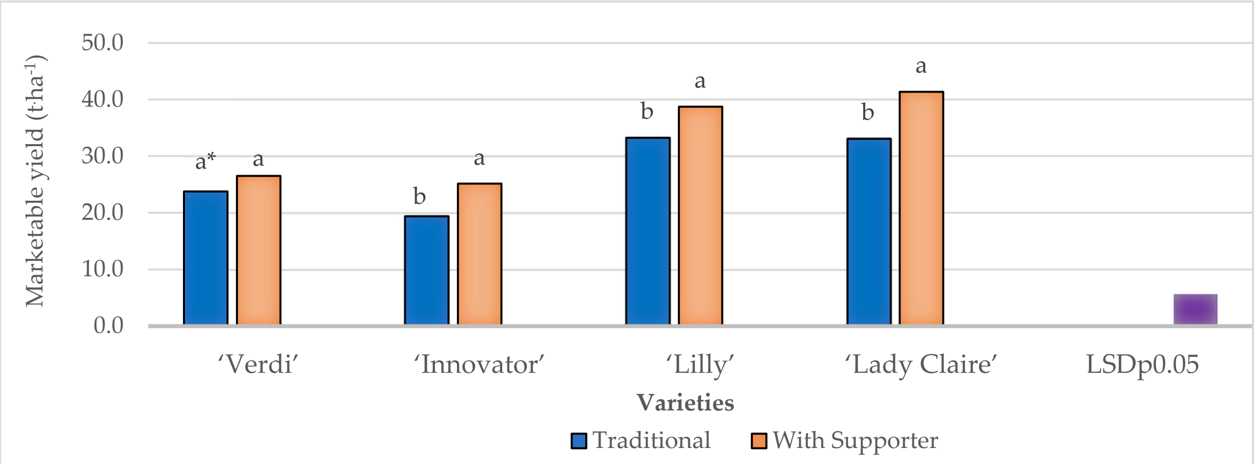

Figure 14. The influence of cultivation technology and varieties on the marketable yield of tubers. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

Table 6 shows the impact of different cultivation technologies, potato varieties, and years on the marketable yield of tubers. It assesses the performance of four potato varieties ('Verdi', 'Innovator', 'Lilly', and 'Lady Claire') under two cultivation technologies: traditional and with Supporter, over three years.

Table 6. The impact of cultivation technology, varieties, and years on marketable yield (t·ha^{-1}) (average for location).

Varieties	Technologies					
	Traditional			With Supporter		
	Years					
	2015	2016	2017	2015	2016	2017
'Verdi'	20.41 a *	30.19 a	20.72 a	19.39 a	37.60 a	22.52 a
'Innovator'	17.51 a	18.89 a	21.89 a	31.55 a	17.69 a	26.17 a
'Lilly'	36.12 a	31.17 a	32.45 a	47.24 a	30.94 a	37.95 a
'Lady Claire'	24.81 a	40.94 a	33.49 a	33.92 a	44.14 a	45.97 a
LSD$p_{0.05}$ Varieties × Technologies × Years	ns **					

* Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups; ** ns—not significant at $p_{0.05}$

Although there are visible differences in marketable yield between varieties and technologies across different years, these differences are not statistically significant. Therefore, the data suggest that the marketable yield remains relatively stable across various combinations of factors. However, the varieties 'Lilly' and 'Lady Claire' trend to show higher yields with the Supporter technology compared to the traditional method, which may indicate some advantages under specific conditions. Overall, Table 6 indicates that while cultivation technology, variety choice, and year can influence marketable yield to some extent, these factors do not cause statistically significant differences in yield outcomes. Thus, the choice among these factors may depend more on other considerations, such as cultivation costs, ease of implementation, locality, or specific farm conditions.

Significant statistical differences were found in yield between varieties, cultivation technologies, locations, and years. In the case of double interactions, most of these differences were statistically significant. However, triple interactions between technologies, varieties, and years could not be statistically proven, suggesting that the observed variations likely fall within the expected range of natural variability. Therefore, the choice between traditional cultivation methods and those supported by Supporter may depend on factors other than yield, such as profitability, environmental impact, or labor requirements.

The location of the experiment was a significantly influencing factor on marketable yield. It was highest in the Głubczyce in southern Poland (40.5 t·ha^{-1}), and homogeneous in the Ryn locality in the northeast corner of Poland (37.6 t·ha^{-1}), on proper brown soils. The lowest yield levels were found in the Barankowo locality (22.28 t·ha^{-1}), where potatoes were grown on the weakest soils, classified as class IV evaluation (Figure 15). The cultivation technology using the Supporter bioregulator contributed to an increase in the marketable yield of tubers in all locations, with a significant yield increase observed in three locations (Barankowo, Głubczyce, and Ryn), except for Kędrzyn in the northwest of the country. The largest increase in marketable yield, up to 27.5%, was observed in Barankowo, Greater Poland Voivodeship. A smaller effect was observed in Głubczyce in the south of Poland (a 19.8% increase in marketable yield) and in Ryn, in the northeast of Poland (a 14.3% increase) (Figure 15).

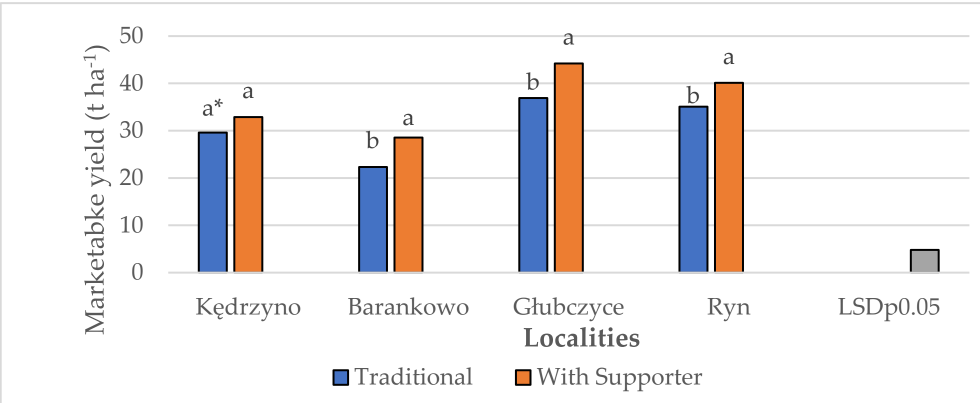

Figure 15. The impact of location and cultivation technology on marketable yield. * Equal-letter notations indicate that the mean values for different groups do not differ significantly from each other. This means that there is no significant statistical difference between the groups, indicating that we cannot reject the null hypothesis, which assumes no differences between the groups.

3.5. Variability of Tuber Yield and Its Characteristics

Table 7 provides descriptive statistics for eight variables, including a dependent variable (y) and eight independent variables (x).

The average values for each variable differ significantly. For example, the mean total tuber yield (y1) is 40.34, while the average shares of tuber mass at different diameters (x2–x6) are significantly smaller. The standard deviation is substantial for most variables, indicating that the data are widely dispersed around the mean. For instance, the standard deviation for total tuber yield (y1) is 10.44. Other variables, such as the shares of tuber mass at different diameters and the commercial yield of tubers, also exhibit varied levels of means, standard deviations, and distributions. Standard errors, on the other hand, are measures of uncertainty in statistical estimates. The larger the standard error, the greater the uncertainty in the estimates. These values are calculated for each variable and can be used to determine the confidence in the estimates. Kurtosis and skewness provide information about the shape and distribution of the data. Positive kurtosis suggests a more peaked distribution, while negative kurtosis indicates a flatter distribution. Skewness measures the asymmetry of the distribution around its mean value. The coefficient of variation (CV), expressed as a percentage, informs us about the degree of variability in the data relative to their mean value. CV values above 100% indicate a high degree of variability.

Table 7. Descriptive statistics of dependent and independent variables.

Specification	y1	x1	x2	x3	x4	x5	x6	x7	x8
Mean	40.34	2.04	6.68	49.80	19.45	12.80	9.23	72.34	30.15
Standard error	0.70	0.49	0.28	0.82	0.62	0.70	0.91	0.86	0.67
Median	38.62	1.74	6.16	50.00	19.12	10.81	4.29	74.26	29.66
Standard deviation	10.44	1.10	4.19	12.29	9.20	10.50	13.89	12.86	10.00
Kurtosis	−0.77	0.03	0.41	1.10	−0.49	−0.72	3.34	2.84	−0.86
Skewness	0.06	0.12	2.17	0.28	0.52	0.74	2.06	−1.24	0.21
Range	47.30	4.46	33.30	71.97	41.23	41.27	52.88	75.38	41.17
Minimum	18.06	0.36	2.32	12.98	2.12	0.00	0.00	17.56	11.27
Maximum	65.36	4.82	35.62	84.95	43.45	41.27	52.88	92.94	52.44
Coefficient of variation, V (%)	25.88	53.92	62.72	24.69	47.30	82.03	150.49	17.78	33.16

y1—total tuber yield, x1—share of the mass of tubers with a diameter of <28 mm, x2—share of the mass of tubers with a diameter of 28–35 mm; x3—mass share of tubers with a diameter of 35–50 mm; x4—mass share of tubers with a diameter of 50–55 mm; x5—mass share of tubers with a diameter of 55–60 mm; x6—mass share of tubers with a diameter >60 mm; x7—share of the mass of commercial tubers; x8—marketable yield of tubers.

Overall, these statistics allow for a better understanding of the dataset characteristics, which can be useful during analysis and interpretation of study results.

Skewness and kurtosis are measures of data distribution shape. These values provide information about the asymmetry and "weakness" of the distribution. Most evaluated variables exhibit some skewness and kurtosis, suggesting that the distributions may be somewhat asymmetrical and may contain outliers.

The range for each variable shows the differences between the maximum and minimum values. The range for total tuber yield (y1) is 47.3, indicating significant variability in tuber mass.

Minimum and maximum values provide information about the range of data. For example, the minimum value of total tuber yield is 18.06, and the maximum value is 65.36.

The coefficient of variation (CV) is used to compare the degree of variability between different sets of data. For individual features in the table, the coefficient of variation for each feature can help understand which of these features has relatively greater variability compared to other features. A high coefficient of variation (e.g., above 50%) indicates large fluctuations around the mean, meaning that the data are highly diverse and may be less stable or less certain.

Conversely, a low coefficient of variation (e.g., below 25%) indicates less variability in the data, suggesting that the data are more stable and less diverse around the mean. Therefore, this coefficient provides information about the degree of variability for each feature and is used to compare data stability between different variables. The higher the coefficient, the greater the variability, and the lower it is, the less variability there is. Therefore, Figure 3 provides comprehensive information about data distribution for dependent and independent variables. Analyzing these data can help us understand the dataset characteristics and make decisions in statistical analysis.

The values of simple correlations between variables are presented in Figure 16.

Figure 16 depicts Pearson correlation coefficients between the dependent variable (y) and the independent variables (x). Coefficients close to 1 indicate a strong positive relationship between variables. For example, the correlation coefficients between y1 (total tuber yield) and x1 (commercial yield) and the tuber mass >60 mm diameter are relatively high (0.86 and 0.45, respectively), suggesting a strong positive relationship between these variables. Coefficients close to −1 indicate a strong negative relationship between variables. Correlation coefficients close to zero suggest little or very weak linear relationships between variables.

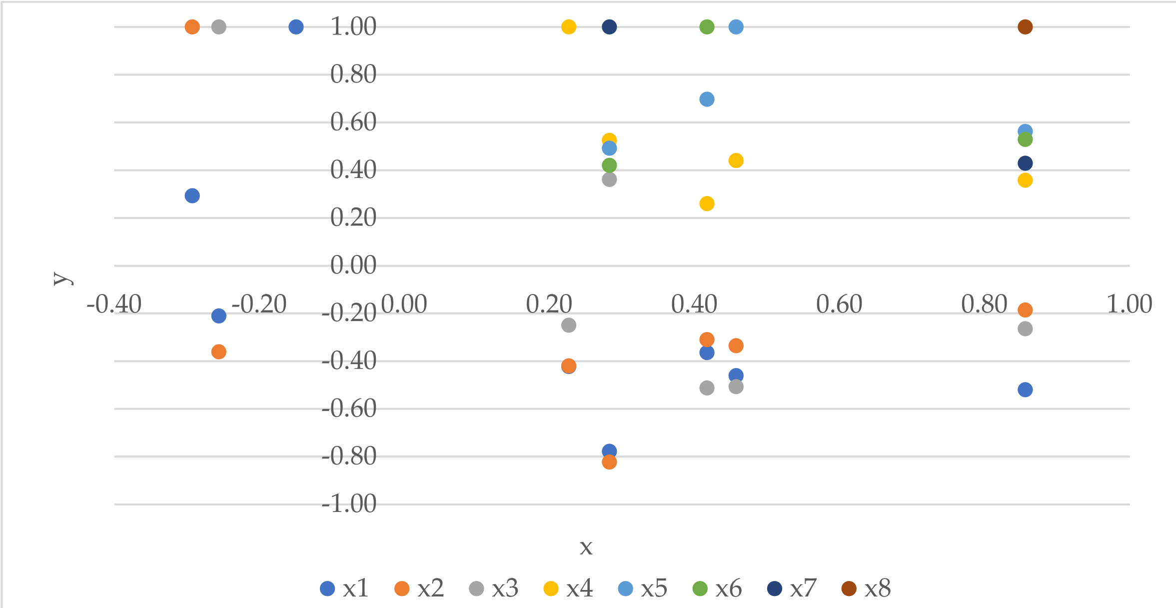

Figure 16. The Pearson correlation coefficients between the dependent variable (*y*) and the independent variables (*x*). *y*—total tuber yield; *x1*—mass share of tubers with diameter <28 mm; *x2*—mass share of tubers with a diameter of 28–35 mm; *x3*—mass share of tubers with a diameter of 35–50 mm; *x4*—mass share of tubers with a diameter of 50–55 mm; *x5*—mass share of tubers with a diameter of 55–60 mm; x*6*—mass share of tubers with a diameter >60 mm; *x7*—share of the mass of commercial tubers; x8—marketable yield of tubers.

Figure 16 shows Pearson's simple correlation coefficients between the dependent variable (y1), representing the total tuber yield, and the independent variables (x1–x8), representing different elements of yield related to tuber size. The correlation coefficient between y1 (total tuber yield) and x1 (share of tubers <28 mm diameter) was r = −0.15, indicating a weak negative correlation. The correlation coefficient between y1 and x2 (share of tubers 28–35 mm diameter) was −0.29, also indicating a weak negative correlation between these variables. A moderately negative correlation (−0.26) was observed between y1 and x3 (share of tubers 35–50 mm diameter). The correlation coefficient between y1 and x4 (share of tubers 50–55 mm diameter) was positive (r = 0.23), though weak. A moderately strong positive correlation (r = 0.46) was observed between y1 and x5 (share of tubers 55–60 mm diameter). The simple correlation coefficients between total yield and the share of tuber mass >60 mm diameter and the commercial yield of tubers were r = 0.42 and r = 0.28, respectively. The strongest positive correlation was found between the total yield and commercial yield of tubers, with a correlation coefficient of r = 0.86.

4. Discussion

4.1. The Impact of Cultivation Techniques on Tuber Yield and Its Structure

Plant life processes are the biological and physiological activities that occur in plants, such as germination, photosynthesis, nutrient uptake, root and shoot development, flowering, and stress resistance. Biostimulators enhance these processes, improving the plant's ability to absorb nutrients, tolerate environmental stressors, and promote growth and development, resulting in healthier plants and better yields. These processes are fundamental to the overall health, productivity, and resilience of a plant throughout its life cycle [40–43]. Studies conducted by Deising et al. [41], Cielucha [44], and Wharton et al. [45] have shown that covering seed surfaces with chemical substances not only increases yield but also improves its quality parameters. Additionally, it aids in reducing losses caused by above-ground pests such as the Colorado potato beetle [46].

According to the manufacturer [18], the Supporter preparation works by stimulating the development of the plant's root system, which is particularly important in the early growth stages. The active substances in the preparation meet the nutritional requirements of soil microorganisms, leading to symbiosis in the root zone and intensifying plant growth. Increased potato yields after the application of pre-sowing seed treatments have been observed in both domestic and foreign studies. Treating potato seed tubers with biological preparations, as reported by Orzaliyeva et al. [47], enhances yield by accelerating the pace of plant growth and development, increasing the assimilation surface area, and boosting resistance to potato diseases. Research by Pytlarz-Kozicka and Zagórski [48] showed that the use of Trianum + Proradix WG and Proradix WG seed treatments increased both total and commercial potato yields compared to the control. Studies by Pytlarz-Kozicka and Słabicki [49] evaluating the effects of Prestige 290 FS and Nuprid 600 FS seed treatments also demonstrated their positive impact on potato yields. Gazdanova et al. [50] found that the use of biological preparations increased potato yields, with the highest yield rates observed in the variant with the Biobacterial BisolbiSan. Gleń-Karolczyk et al. [6] also noted an increase in potato yields after treating tubers with Polyversum WP and Serenade ASO preparations, although it was not as effective as using growth stimulators such as Kelpak SL, Em Farma TM, soil conditioner UGMax, or Biogen Revital. The similarities between these preparations are that most of them (e.g., Supporter, Polyversum WP, Kelpak SL) contain natural ingredients such as seaweed extracts, microorganisms, or organic substances that stimulate plant growth by improving soil structure, nutrient uptake, and increasing stress resistance.

Preparations such as Supporter and Trianum + Proradix WG often focus on supporting the development of the root system, which improves the availability of nutrients and resistance to environmental stress. The common goal of these products is also to increase both the quantity and quality of crops, which is confirmed by research on various biopreparations, as in the case of Biobacterial BisolbiSan or Serenade ASO.

These preparations differ in composition; some biostimulators, such as Supporter, contain synthetic and natural amino acids, while others, such as Trianum + Proradix WG or Biobacterial BisolbiSan, are based on microorganisms that enter into symbiosis with plants. Preparations such as Prestige 290 FS and Nuprid 600 FS are chemical plant protection products that also act as insecticides.

Their scope of action is also different. Products such as Kelpak SL or Em Farma TM act mainly as growth stimulants thanks to the content of phytohormones from algae, while preparations such as Polyversum WP or Serenade ASO have a more biological protective effect against pathogens.

Mechanism of action: Supporter works through symbiosis in the root zone, supporting plant development at an early stage, while Prestige 290 FS has an insecticidal effect, which directly affects the protection of plants against pests and not only their development.

Our research conclusions confirm the effectiveness of these products in increasing yields, but the variety of ingredients and mechanisms of action shows that their effectiveness may vary depending on the growing conditions and plant specificity.

The alternative hypothesis was confirmed in this study, indicating that the use of the biostimulator Supporter led to a significant increase in tuber yield by increasing the proportion of large tubers in the yield (Tables 3 and 4).

4.2. The Impact of Varieties on Yield and Its Quantitative Characteristics

In the studies on the impact of varieties on yield and its quantitative characteristics, we conducted an analysis of the yield of several different potato varieties. We found significant differences in yield among different varieties of these species, regardless of cultivation techniques, years, or locations. Some varieties showed higher yields compared to others, which may be significant in terms of crop productivity.

Furthermore, analyzing quantitative characteristics of the yield, such as yield mass per unit area, structure of tuber mass of individual size fractions, or the proportion and yield of marketable tubers, we noticed that individual varieties exhibit different characteristics (Tables 3–5). Some varieties may have a higher yield mass per unit area, while others may appear more efficient in producing yield per plant. Similar observations regarding the yield of varieties have been noted in the works of other authors [2,3,51–53].

The yield analysis also allowed us to assess how the tested potato varieties perform in different environmental conditions. Some varieties proved to be more resistant to, for example, drought stress or other adverse meteorological and environmental phenomena, which may affect their ability to maintain stable yield under various cultivation conditions.

Genetic studies suggest that the response of potato varieties to different types of light may be associated with genetic diversity [54,55]. Adjusting the ratio of active phytochrome to total phytochrome can significantly improve plant production and yield quality. Potato plants respond differently to different types of light—red light may lead to elongation of stems and production of small leaves, while blue light may result in shorter, sturdier plants with well-developed leaves. Adding green light to red and blue light may increase chlorophyll content, photosynthesis, and production of smaller-sized tubers. A high proportion of red and blue light may increase tuber production, while adding green light may favor the production of smaller-sized tubers [55–57]. The spectral composition's effect on potato yield quality supports the findings of increased or decreased tuber size based on light type. Balancing red and blue light enhances the formation of commercial-sized tubers, while green light's influence, though beneficial for chlorophyll, might limit tuber size. These effects emphasize the need for precision in managing light exposure for optimal crop yield, aligning with the results presented in the manuscript. In summary, our research has shown the significant impact of potato varieties on yield and its quantitative characteristics. This allowed us to better understand which varieties may be more suitable in terms of yield performance under different cultivation conditions.

4.3. The Influence of Environmental Conditions on Yield and Its Structure

The threat to potato crops from excessive soil moisture during the growing season was lower than drought, which could significantly reduce the quantity and value of tuber yield (Table 4). In four mesoregions of Poland, diverse thermo-hydric conditions affected potato yield, with the best conditions occurring in the south of Poland and the worst in the northeast of the country.

Research by Kalbarczyk and Kalbarczyk [56] showed that optimal conditions for potato yield include average air temperature during May–September (15.2 °C), lower than average rainfall in May (45 mm), moderate rainfall in June (65 mm), and above-average rainfall in July (90 mm), August (75 mm), and September (60 mm). Rainfall deficits compared to potato requirements, especially in north-western and central-western Poland, can lead to yield reduction.

Studies by Skowera et al. [37,57] also indicate spatial and temporal differences in rainfall deficits during potato cultivation in Poland. According to them, the highest risk of rainfall occurs in June, which is unfavorable for potatoes, as potato plants are then in the tuberization phase and forming new tubers.

Optimization of potato yield also depends on the amount of light. Adjusting the ratio of active phytochrome to total phytochrome can significantly improve plant production and yield quality. Research on the influence of different types of light on potatoes has shown that red light may lead to stem elongation and production of smaller leaves, while blue light may favor shorter, sturdier plants with well-developed leaves. Adding green light to red and blue light may increase chlorophyll content, photosynthesis, and production of smaller-sized tubers [55].

Soil type and class significantly affect potato yield and tuber structure due to variations in chemical composition (nutrients, pH, and organic matter), soil structure (granulation and porosity), and water properties (retention and drainage). Locations with nutrient-poor soils (e.g., Barankowo and Kędrzyno) saw reduced root development and lower yields compared to nutrient-rich soils like Głubczyce. Soil structure impacts root growth, while water availability and temperature also influence plant development. Favorable conditions, such as those in Głubczyce, result in better yield and tuber quality [27,32,55,57–60].

4.4. Local Conditions and Yield

In our research on the impact of location on potato yield and tuber structure, several significant aspects were observed, such as adaptation to local microclimates and soils, as well as variety adaptation to specific climatic and soil conditions. Growing locations can have a significant impact on potato yield, especially locations with different soil, climatic, and topographic conditions, which may favor different potato varieties or cultivation practices, ultimately leading to yield variation. Mocek [27] suggests that local environmental factors, such as growing region, soil type, and organic carbon content, should be considered. Our research results confirm this. The best overall and commercial yield was obtained in Głubczyce on Class I or II of soil, while the lowest yield was observed in Barankowo on Podzolic soil in Class IV.

Analysis of potato tuber yield structure, such as size, shape, weight, and the proportion of tubers in different size fractions, revealed significant differences between locations. Soil and climatic conditions can influence tuber development, leading to variability in their structure in different localities and geographic locations. The greatest miniaturization of tubers was observed in Kędrzyn, located in north-western Poland, where the soil was in Class IV. Conversely, the highest proportion of large-sized tubers (diameter of 50–60 mm and >60 mm) was observed in Głubczyce, in the southern part of the country, where soils were in Class I or II (Table 4).

Environmental factors such as soil moisture, temperature, sunlight, precipitation, and topographic conditions have a significant impact on potato yield and tuber structure. Locations with similar climatic conditions may exhibit similar yield patterns and tuber structural characteristics. Similar observations regarding potato yield in different terrain conditions were made by Kalbarczyk and Kalbarczyk [56] and Pszczółkowski et al. [58].

Variety adaptation to local conditions: our research suggests that different potato varieties may exhibit varying degrees of adaptation to local conditions. Varieties better adapted to specific environmental conditions in a given location may achieve higher yields and exhibit more favorable tuber structural characteristics.

4.5. Phenotypic Variability of Yield and Its Traits

Yield variability is a characteristic marked by fluctuations in the quantity of produced yields across different years or locations. It is a natural process that can be influenced by various factors, such as variability in climatic, meteorological, or microclimatic conditions. Additionally, yield variability may result from fluctuations in soil conditions, variability in cultivation practices, or interactions with fertilizers, biostimulators, or pesticides. Yield variability significantly impacts the stability of agricultural production, farmers' profits, and supply in the agricultural market. Therefore, it is an important research area in agriculture, and farmers often undertake actions to mitigate the impact of yield variability through various management strategies.

In the conducted research, the total yield of potato tubers (y1) was characterized by a relatively low coefficient of variation (CV) of 25.9% (Table 6). This means that the differences in tuber yield between different samples are relatively small compared to the average yield value. On the other hand, the shares of potato tuber mass in different size categories (x1–x6) exhibited varied variability, with the highest coefficient of variation observed for the share of tuber mass with a diameter above 60 mm (x6)—as much as 150.5%. This may suggest that the distribution of tuber masses in this category is more diverse than in other size categories. The share of commercial tuber mass (x7) was characterized by a relatively low coefficient of variation of 17.8%, suggesting that differences in the mass of commercial tubers are relatively small compared to their average value. The yield of commercial tubers (x8) exhibited moderate variability, with a coefficient of variation of

33.16%. This means that differences in the yield of commercial tubers between different samples are moderately large compared to the average yield value.

Overall, the analysis of the coefficient of variation allows us to understand how diverse the examined traits are and how significantly they differ between different samples. This can be useful when planning actions aimed at optimizing potato cultivation processes and improving yield performance.

4.6. Potato Variety Response to Growth Biostimulator

Biostimulators are often used in agriculture to help plants, including potatoes, better cope with abiotic stresses such as drought, salinity, or extreme temperatures. Under these conditions, biostimulators improve plant morphology and function by enhancing root development, which aids in water and nutrient uptake, and boosting photosynthetic efficiency. Morphologically, they promote larger root systems and improved leaf area, while functionally, they activate enzymatic pathways, increase nutrient transport, and regulate stress-related hormones. This results in improved resilience and overall productivity of potato plants under stress [52,61–67].

In the conducted research, the variety 'Lilly' exhibited the best response to the biostimulator Supporter in terms of both total and commercial yield. In agricultural practice, the application of biostimulators may involve applying these substances to the foliage, soil, or through the plant's root system. The effectiveness of biostimulators depends on the type of substance used and the environmental and genetic characteristics of the potato variety (Table 4). The relationship between the share of commercial tubers in the total yield and cultivated varieties was also observed by Pytlarz-Kozicka and Zagórski [48]. The highest share of large tubers in the total yield (>50 mm in diameter) was obtained by Baranowska et al. [61] when applying the herbicide Avatar 293 ZC and the GreenOK Universal-PRO preparation, confirming the influence of genotype–environment interaction. This was also confirmed by other authors.

Research by Pardo-García et al. [65] on the impact of biostimulators on secondary metabolism showed that those derived from agricultural substances can improve plant productivity by activating the expression of key enzymes for phenylpropanoid synthesis, such as PAL. Studies by Ertani et al. [66] demonstrated that biostimulators increased PAL enzyme activity in maize leaves. Biostimulators also enhance chlorophyll content, which is crucial for the photosynthesis process.

Therefore, the Supporter preparation acts as a biostimulator, improving the efficiency of nutrient utilization, tolerance to abiotic stresses, and plant quality characteristics. It complies with the regulations of the European fertilizer substances legislation.

4.7. Impact of Biostimulators on Environmental Stress and Market

The role of soil conditions in shaping potato yield is crucial, as nutrient content, soil pH, and structure directly affect plant growth efficiency and, consequently, crop size and quality. The use of a bio-growth regulator such as 'Supporter' can help mitigate the negative effects of poor soils by improving nutrient use efficiency and supporting better plant growth in diverse soil conditions. In particular, in areas with lower phosphorus or potassium levels, 'Supporter' can support plants in better utilizing available resources, which can lead to increased yield, as shown in the results of studies where the use of Supporter increased yield by over 13%.

In summary, accurate soil analysis allows for better adjustment of fertilization and plant support strategies, and the use of bio-regulators such as 'Supporter' can positively affect crop performance, especially in lower quality soils.

Researchers Pytlarz-Kozicka and Zagórski [48] found minimal rates of potato infection by diseases, ranging from 2.8% to 5.0% of plants affected by pathogens and from 2.5% to 4.9% by viruses. Noaema et al. [7] demonstrated the role of the Supporter preparation in reducing the occurrence and severity of Rhizoctonia solani on potato tubers, irrespective of the variety. Additionally, they observed significantly higher yields of seed potatoes due to the reduction of this pathogen on potato plants. Gazdanova et al. [50] showed that the use of biological preparations for seed treatment positively affects potato tuber sprouting, increasing it by 6.3% to 8.7% compared to the control variant. They also demonstrated their high efficacy against fungal potato pathogens such as *Rhizoctonia solani*, ranging from 37.5% to 100%, resulting in a significant increase in potato yield. *Phytophthora infestans* is not a fungal pathogen but an oomycete (water mold). *Oomycetes* are distinct from true fungi, despite having similar characteristics like filamentous growth and spore production. They belong to a different biological kingdom, *Stramenopila* (also called Chromista), which includes algae and other water molds.

Treating potato seedlings with biological preparations by Novikova et al. [68] resulted in nearly a twofold increase in yields compared to the control. Furthermore, during the flowering stage, the biological effectiveness of these preparations reached close to 90% under optimal conditions and 50–75% under conditions of hydrothermal drought.

In the conducted research, the use of the bioregulator Supporter resulted in an increase in total potato tuber yield by 13.3% and commercial yield by over 20%, attributed to the increased mass of tubers in the 50–60 mm and >60 mm size categories. Potato yield was largely determined by the interaction of experiment location and cultivation technology. According to Noaema et al. [7], the biostimulator Supporter, when used at a lower concentration (half the recommended dose), significantly reduces the occurrence of rhizoctonia on potato tubers.

The use of biostimulators can have varied effects on environmental stress, depending on specific conditions, the type of biostimulator used, and its composition. Some biostimulators may assist plants in better coping with environmental stress by stimulating their natural resistance to stress factors such as drought, soil salinity, or high temperatures. The alternative hypothesis was confirmed in this study, indicating that the use of the biostimulator Supporter led to a significant increase in tuber yield by increasing the enhancing plant tolerance to environmental stresses [67,68].

Research on the mechanisms of action of the biostimulator Supporter in the context of plant resistance may be crucial for agriculture, especially considering changing environmental conditions and increasing demands for sustainable food production.

The global biostimulators market is expanding rapidly, driven by the need for sustainable agricultural practices and improving crop resilience to stress. Europe holds a leading position in the market, with a value of around USD 1.43 billion in 2023. Key countries like Italy, Spain, and Germany are the main consumers, while organizations like the European Biostimulators Industry Council promote growth in this area. North America is the second-largest market, witnessing steady growth, particularly with advancements in biocontrol technologies. The Asia–Pacific region is also showing significant expansion due to the rise in sustainable agriculture practices in countries such as India and China [19,69].

Specific data on global production volumes of the biostimulator Supporter and market penetration are less publicly available. However, as a biostimulator, Supporter benefits from the same growing demand for products that improve crop yields and stress tolerance. Biostimulators such as Supporter are increasingly used not only in Europe but also in regions such as North America and Asia, where sustainable agriculture is in a growth phase. While European markets are leading the way in terms of regulatory frameworks and use, non-European producers can and are beginning to adopt similar biostimulators as awareness of environmental sustainability and crop health grows [19].

4.8. Correlations between Yield and Its Component Traits

The conducted research confirmed the existence of various degrees of relationships between parameters related to potato tuber yield. Both positive and negative correlations were observed between different variables. A strong positive correlation (r = 0.86) was found between the total tuber yield and commercial yield, suggesting that a higher overall yield translates into a greater proportion of tubers suitable for sale. On the other hand, a weak negative correlation between total yield and the proportion of smaller-sized tubers (e.g., <28 mm in diameter) indicates that a larger overall yield does not necessarily lead to a proportional increase in the share of the smallest tubers. Moderate correlations between different tuber fractions (e.g., from 28 to 60 mm) and total yield suggest some relationships between tuber size distribution and overall yield, although they are not as strong as the correlation between commercial yield and total tuber yield.

Analyzing these relationships is often presented as a complex and multidimensional problem. Studies on potato tuber yield consider many factors such as weather conditions, soil, cultivation methods, as well as tuber traits, leading to diverse correlations between individual parameters. The interaction between variety and environment has been identified as a significant factor influencing tuber yield variability and structure. It is also essential to consider tuber size distribution because a higher overall yield does not always translate into a greater proportion of tubers of desired sizes.

Recent research aims to identify factors influencing these relationships, such as plant genetics, environmental conditions, cultivation methods, and fertilization, to better understand and optimize processes related to potato tuber yield.

4.9. Summary

The discussion on potato tuber yield and its structure highlights the significant impact of cultivation techniques, variety selection, and environmental conditions. The use of biostimulators, such as the Supporter preparation, has been shown to enhance tuber yield by stimulating root development and improving plant resistance to environmental stress. Research has consistently demonstrated that biostimulator "Supporter" improves not only total yield but also the proportion of larger tubers, which is very important in particularly commercial production.

Varietal differences are also critical, as certain potato varieties perform better in terms of yield and resistance to environmental factors like drought or suboptimal temperatures. Genetic diversity influences how potato plants respond to different light conditions, affecting tuber size and overall yield. This study further underscores the role of environmental conditions, particularly soil quality and moisture levels, in shaping potato yield. Optimal conditions, such as well-drained soil and appropriate rainfall, can significantly enhance productivity, while adverse conditions, such as drought, can severely limit yield.

Local factors such as soil type and regional climate further influence tuber yield and quality. For instance, regions with higher soil organic matter and favorable climatic conditions tend to produce better yields and larger tubers. Additionally, yield variability across different locations and years is a natural process impacted by factors like weather patterns and cultivation practices.

Finally, this study reveals correlations between yield and its components, particularly the strong relationship between total tuber yield and commercial yield. However, not all yield increases are evenly distributed across tuber size fractions, indicating a need for careful management of both total yield and the desired tuber size distribution.

5. Towards the Future

This consideration provides fertile ground for research aimed at elucidating the complex relationship between biostimulators and agroecosystems, fostering the evolution of sustainable agriculture paradigms. It also underscores the potential of biostimulators in shaping agricultural practices and formulating agro-environmental policies. Key directions for future research include:

This study suggests that the use of the Supporter bioregulator in potato cultivation can significantly enhance tuber yield and influence tuber size distribution. The choice of potato variety and the specific environmental conditions, such as location and weather, also play critical roles in determining the final yield and its characteristics. This information can be utilized to optimize potato production strategies, considering both yield quantity and quality based on market requirements and environmental conditions.

Integration of biostimulators into agricultural practices, such as the use of the Supporter biostimulator, heralds a new era for sustainable agriculture. Ongoing research aimed at elucidating the mechanisms of biostimulator action and their environmental interactions will facilitate further refinement.

Exploration of synergies between biostimulators and other sustainable agriculture methodologies, such as agroecology and precision farming, promises to optimize agricultural productivity while minimizing environmental impact. Standardization of biostimulator production and implementation, such as Supporter, is necessary to unlock their full potential and support transformations towards sustainable agriculture.

Prospects for research on growth stimulants and biostimulators in potato cultivation are promising and encompass several key areas, including:

Optimization of biostimulator composition and action: Further research is needed on the composition of biostimulators and their effects on plants to better understand which components are most effective in stimulating potato growth. These studies may lead to the development of more efficient biostimulator formulations tailored to different growing conditions.

Mechanisms of biostimulator action: Understanding the molecular and physiological mechanisms through which biostimulators influence plants, including growth processes, root development, photosynthesis, and stress resistance, is important. Such research can help identify specific metabolic pathways and genes responsible for plant responses to biostimulators.

Optimization of dosage and application: Studies on optimal biostimulator dosing and application methods are essential to ensure maximum efficacy of these substances with minimal environmental impact and may help reduce production costs for farmers.

Field and long-term studies: Conducting field and long-term studies to assess the effectiveness of biostimulators in various potato growing conditions and their impact on yield, tuber quality, and plant health is important. Such research can provide practical guidance on the best practices for using biostimulators in real-world growing conditions.

Sustainable agriculture: Research on biostimulators can contribute to promoting sustainable agriculture by increasing plant productivity and resilience, reducing chemical inputs, and improving the efficiency of natural resource utilization.

As research progresses in these areas, further development and refinement of biostimulators can be expected, which may bring benefits to agriculture by increasing potato cultivation efficiency while simultaneously reducing negative environmental impact.

6. Conclusions

Conclusions and Future Directions Based on Conducted Research on the Impact of the Plant Bioregulator Supporter on Potato Yield and Quality are following:

The use of Supporter led to a significant increase in potato yields. The total tuber yield increased by 13.3%, while the commercial yield increased even more, by 21.1% compared to traditional cultivation methods. This shows the effectiveness of Supporter in increasing both the overall and commercial potato production. It has been demonstrated too that the plant bioregulator Supporter positively influences not at all potato yield and the quantitative and qualitative characteristics of the obtained produce. Therefore, the application of Supporter may constitute an effective strategy for improving potato production efficiency, which is crucial for ensuring food security.

Enhanced Environmental Resilience: Plants treated with the biostimulator Supporter exhibited greater resistance to environmental stresses such as drought or high temperatures. Consequently, further research on the mechanisms of action of Supporter in the context of plant resilience may be important for agriculture.

Variability in Yield Patterns: Some of the studied varieties showed stable yield patterns (e.g., 'Lilly' and 'Lady Claire'), while others were more variable in their productivity, regardless of the analyzed experimental factors.

Influence of Cultivation Location: Crop location significantly impacts potato yield and tuber structure. Understanding these differences can aid in better adapting cultivation practices and selecting varieties to specific local conditions, potentially increasing potato cultivation efficiency.

Environmental Factors: Environmental factors during the study years resulted in differences in potato yield and tuber structure depending on soil type and meteorological conditions. Considering these differences is important when planning potato cultivation and making decisions regarding fertilization and plant care.

Cultivation technology, potato varieties, and location have a significant impact on the total and marketable yield of tubers, but these differences are not always statistically significant. The use of the Supporter bioregulator increased yields in most cases, which suggests that it can be a cost-effective method of improving crop performance under specific conditions. The selection of the appropriate technology and variety should take into account specific local conditions and other factors influencing the yield and profitability of potato crops.

Correlations in Yield Parameters: Strong positive correlation (r = 0.86) between total tuber yield and commercial yield suggests that higher total yield translates into a greater commercial yield. However, the weak negative correlation between total yield and the proportion of smaller tubers suggests that higher yield does not necessarily mean a proportional increase in the share of the smallest tubers. Relationships between tuber size distribution and total yield were confirmed, although not as strong as in the case of commercial yield.

Future Research Directions: Continued research on the impact of Supporter on potato yield in different environmental conditions and soil types is necessary to gain a more comprehensive understanding of its effects. Studies on optimizing doses and application methods of Supporter are also important, as they may contribute to even better results in potato production.

Towards Sustainable Agriculture: In the context of the growing need for sustainable agriculture, further research on the impact of Supporter on crop production efficiency can contribute to the development of more environmentally friendly and efficient cultivation practices, thus meeting the increasing food needs of society.

The research on the bioregulator Supporter demonstrated its effectiveness in enhancing potato yield and quality, with a 13.3% increase in total tuber yield and a 21.1% rise in commercial yield. Supporters also improved plant resilience to environmental stress and showed variability in its effectiveness across different potato varieties and cultivation locations. The findings highlight the importance of tailoring cultivation practices to specific local conditions and varieties to maximize yield. Future research should focus on optimizing application methods and exploring Supporter's potential to support sustainable agriculture and food security.

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