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Commercial Quality of Potato Tubers of Different Varieties from Organic and Conventional Production System

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Abstract: Research conducted at the Plant Breeding and Acclimatization Institute—NIR in Poland in 2020–2022 assessed the commercial quality of potato tubers depending on the production system (organic, conventional), variety, and weather conditions prevailing in the years of research. The tuber size distribution and the share of tuber defects was assessed. It was found that all tested factors influenced the commercial quality of the yield but to different extents. The production system had the greatest influence on most of the examined features, followed by weather conditions and the least influential factor being the variety. The production system had the greatest impact on such features as: tuber size distribution (all fractions), pest damage, scab infection, tuber deformations, and share of green tubers. Weather conditions had the greatest impact on scab infection, pest damage, deformation, cracks and share of large tubers. The variety factor had the greatest influence on such features as: deformations, cracks, green tubers, black scarf, and share of the smallest (non-commercial) tubers. In the conventional system, a significantly better tuber yield distribution was found. The share of tuber defects varied depending on the production system. In the organic system, a greater share of defects such as scab (68.3 and 41.3) and pest damage was found (6.8 and 0.2), while in the conventional system, a greater share of deformations (9.2 and 4.9), cracks (5.4 and 2.4), and rust spots (0.61 and 0.06) occurred.

Keywords: potato; production system; variety; commercial quality

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1. Introduction

Public interest in organic food is growing. This is mainly due to a loss of trust in food produced with large amounts of pesticides. The development of organic agriculture in the world has been very dynamic in recent years [1]. However, the increase in the area of individual crops is not uniform. One of the species whose share in organic farming is small is the potato. This is due to the difficulties in growing this crop in organic production systems, mainly with regard to protection against pathogens such as *Phytophthora infestans* and Colorado potato beetle (*Leptinotarsa decelminatea*) [2–5].

Factors that most limit the level of potato yields in organic systems are the substantial restrictions on the use of pesticides and nutrient deficits occurring in some soils as a result of non-mineral fertilizers. These limitations affect plant growth and consequently the yield [6–10]. Potato is very sensitive to water stress [11–13], nitrogen fertilizer deficiency, and is subject to a wide variety of disorders and diseases.

Evidence suggests that organic arable cropping systems generally produce lower, more variable yields than systems employing synthetic fertilizers and chemical crop protection measures [14]. Reviews by De Ponti et al. [15] and Seufuret et al. [16] concluded that organic arable yields average 80% and 75% of conventional production, respectively. Djaman et al. [17] and Zarzyńska et al. [18] also report large differences in yield depending on the production system.

However, the yield gap varies between crop species, with tuber crops having a greater yield gap than cereals. For example, De Ponti et al. [15], report that organic tuber crop production averages 70% that of conventional systems in European studies, but with high variability (37–114%). However, results from long-term factorial studies in which the relative effects and interactions between fertilization and crop protection practices used in organic and conventional farming systems are compared are not currently available.

Potatoes are important components of human diets as they are rich in nutrients and bioactive components which are useful for maintaining a good nutritional status and wellness [19]. The decline in potato production and consumption is an unwanted development because the potato is one of the most environmentally friendly crops. Its production process has a low CO_2 emission footprint and it requires less area per similar dry matter yields than other crops [20]. Apart from the production system, other factors such as soil quality, climatic conditions during the growing season and cultivar play a large role in shaping the level and quality of yield. The significance of cultivars in organic potato production has been undertaken in an earlier publication [21]. Agronomic requirements, however, do not always go hand in hand with the requirements of consumers, who expect mostly good quality product. Therefore, in addition to features that facilitate the cultivation, i.e., high resistance to pathogens and low soil and fertilizer requirements, we should also take into account the commercial quality of the yield, i.e., tuber size distribution and the share of external and internal defects of tubers.

We generally expect better taste and nutritional value from organically grown potatoes at the expense of a slightly worse appearance [21]. The organic fertilizers used in this system, crop rotation rich in perennial plants, and green manures contribute to the increase in infection by diseases such as scab or black scarf [2,22,23]. They are particularly important in the case of table potatoes and potatoes intended for industry.

One important factor which influences farming profitability is the marketable yield, which is impacted by tuber sizes and tuber defects. Marketable tubers are considered to be sized from 35 mm of diameter and larger. The most common external defects of tubers that determine their commercial quality include: common scab, black scurf, deformations, green tubers, cracks, and damage by pests. The most common internal defects are: rust spots on the flesh and hollow hearts. All of these disorders and diseases can tremendously impact tuber yield and the organoleptic quality of the harvested tubers and the processed products.

There are many publications in the literature on the quality of potatoes grown in various production systems, mainly in relation to their chemical composition and nutritional and sensory value [24,25]. However, there are few studies comparing the commercial quality of tubers.

The aim of our research was to assess the commercial quality of potato tubers, i.e., the share of external and internal defects of tubers and tuber size distribution depending on the cultivation system, variety, and atmospheric condition.

2. Materials and Methods

2.1. Experimental Design

The research was carried out in the years 2020–2022 at the Institute of Plant Breeding and Acclimatization in Jadwisin, central Poland on light soil with a granulometric composition of light clay sand. Potato was grown in two production systems: organic and conventional.

Crop rotation used in the organic system: potato → spring barley → a mixture of field peas with fodder peas and spring rye → a mixture of yellow lupine and oats → rye with undersown serradella.

Crop rotation used in the conventional system: potato → spring wheat → winter wheat → lupine.

Both production systems differed in fertilization, weed control methods, and methods of protection against diseases and pests (Table 1).

Table 1. Agronomic inputs in organic and conventional systems.

Crop Production Practice	Organic System	Conventional System
Fertilization	manure—28 t·ha^{-1} + mustard as a catch crop	4–5 t plowed straw + 1 kg mineral nitrogen per 100 kg straw N: 100 kg·ha^{-1} P: 53 kg·ha^{-1} K: 150 kg·ha^{-1}
Weed control	only mechanical	mechanical + herbicides Linurex—1.8·ha^{-1}, Titus + Trend 60 g·ha^{-1} + 0.5 L·ha^{-1}
Colorado potato beetle control	biological insecticide Spin Tor 240 SC (Spinosad) 2 times per season—0.15 L·ha^{-1}	chemical insecticides: Actara—2 times per season 60 g·ha^{-1} Apacz-40 g·ha^{-1}
Late blight control	copper fungicides Miedzian 50 3 L·ha^{-1}—2 times per season	chemical fungicides Ridomil 2 L·ha^{-1}, Revus—0.6 L·ha^{-1}, Ranman 0.2 L·ha^{-1}, Altima 0.4 L·ha^{-1}

The research covered six potato varieties from different earliness groups. All varieties were planted at the same time, i.e., around 23 April, at a spacing of 75 × 33.3 cm in three replications. The main characteristics of the varieties are given in Table 2.

Table 2. Characteristics of potato varieties evaluated in organic and conventional production systems during 2020–2022.

Variety	Maturity Group	Skin/Flesh Color	Resistance to *Phytophthora infestans* *
Pogoria	very early	yellow/yellow	3
Bohun	early	yellow/yellow	3
Ismena	early	yellow/yellow	3
Irmina	mid early	yellow/yellow	4
Gardena	mid early	pink/yellow	7
Jelly	mid late	yellow/yellow	5

* 9—full resistance, 1—no resistance.

2.2. Measurement Methods

After harvesting the crop, the quality of the tubers was assessed, i.e., tuber size distribution of the crop, i.e., the share of tubers of different sizes. The sample consisted of approximately 6 kg of potatoes selected randomly from each plot. The percentage of tubers with a transverse diameter was assessed: below 35 mm, 35–60 mm, and above 60 mm.

The following tuber defects were determined: the share of tubers infected with common scab and black scurf, the percentage of tubers with deformations, cracks, green tubers, tubers damaged by pests and the share of tubers with rust spots and hollow hearts. Share of such defects as: common scab and black scurf, deformations, cracks, green tubers, and tubers damaged by pests was determined as a percentage by weight of a given sample.

The share of tubers with rust spot and hollow hearts was assessed on 20 large tubers as the number of tubers with these defects per 20 large tubers.

The infection of common scab and black scarf disease was assessed using a 9-point scale, in which 9 indicates a healthy tuber with skin free from disease lesions, and 1 indicates a tuber whose skin was infected with common scab or black scarf on at least 50% of the surface (Roztropowicz 1999).

2.3. Statistical Analysis

The obtained data were subjected to statistical analyses using the Statistica program. Three-factor analysis of variance (ANOVA) were conducted to evaluate if studied factors significantly differed from the analysed features. The significance of differences was tested using the Tukey test.

Data on the weather conditions prevailing in the years of study are given in Table 3.

Table 3. Total monthly rainfall (P) and mean monthly temperatures (T) during the vegetative growth period in the years 2020–2022 for Jadwisin.

Year/ Month	IV		V		VI		VII		VIII		IX	
	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)
2020	5.6	8.8	6.3	11.6	113.8	18.7	40.4	19	120.7	20.1	51.8	15.5
2021	37.8	6.9	69.5	12.7	97.2	20.1	124.2	21.9	120.4	17.2	37.5	13.5
2022	3.1	6.9	3.9	13.6	66	19.3	107.3	20.8	25	21.8	50	12

3. Results

3.1. The Significance of the Studied Factors

The production system significantly differentiated the share of all assessed tuber defects, except for black scarf infection and hollow hearts. The variety had a significant impact on such defects as: black scarf infection, deformations, cracks, green tubers, and hollow hearts. Weather conditions prevailing in the years of research had a significant impact on tubers being infected with common scab, black scarf, cracks, green tubers, and pest damage. All examined factors had a significant impact on the share of the smallest (non-commercial) tubers. The share of medium-sized tubers was significantly influenced only by the variety factor, and the share of the largest tubers was significantly influenced by the production system and atmospheric conditions prevailing in the years of study (Table 4).

Table 4. Significance of tested parameters.

Tested Parameter	Crop Production System	Variety	Year
Tuber defects			
Common scab	**	-	**
Black scarf	-	*	*
Deformations	*	**	-
Cracks	**	**	*
Green tubers	*	*	*
Pest damages	**	-	*
Rust spot	*	-	-
Hollow hearts	-	*	-
Tuber size distribution			
Share of small tubers (<35 mm)	**	*	*
Share of medium tubers (35–60 mm)	**	-	-
Share of large tubers (>60 mm)	**	-	*

** significant at $\alpha \leq 0.01$ * significant at $\alpha \leq 0.05$, - not significant;.

The significance of the interaction of the studied factors has not been proven.

3.2. The Share of Tuber Defects and Yield Structure Depending on the Production System

The infection of tubers with common scab was significantly higher in the organic system than in the conventional system and amounted to 68.3% and 41.3%, respectively. Black scarf infection did not differ significantly between production systems. The share of deformed tubers in the organic system was almost two times lower than in the conventional system and amounted to 4.9% and 9.2%, respectively. The share of tubers with cracks was also lower in the organic system than in the conventional system. A similar situation occurred in the case of green tubers. The share of tubers with this defect was also lower in the organic system. The share of tubers with rust spots of the flesh was also significantly lower in the organic system. The share of tubers with hollow hearts was similar in both production systems. The share of small (non-commercial) tubers was more than twice as high in the organic system as in the conventional system, while the share of the largest tubers was almost six times higher in the conventional system. The share of medium-sized tubers was higher in the organic system (Table 5).

Table 5. The share of tuber defects and tuber size distribution depending on the production system.

Tested Feature/Crop Production System	Organic	Conventional
Common scab (%)	68.3a	41.3b
Black scarf (%)	26.2a	31.9a
Deformations (%)	4.9b	9.2a
Cracks (%)	2.4b	5.4a
Green tubers (%)	4.3b	7.5a
Pest damage (%)	6.8a	0.2b
Rust spot (nb/20 large tubers)	0.06b	0.61a
Hollow hearts (nb/20 large tubers)	0.46a	0.22a
Share of small tubers (<35 mm) (%)	10.2a	4.2b
Share of medium tubers (35–60 mm) (%)	84.5a	65.2b
Share of large tubers (>60 mm)(%)	5.3b	30.6a

Means in the same column followed by different letters are significantly different ($p < 0.05$).

Tuber size distribution depending on production system is also shown in Figure 1.

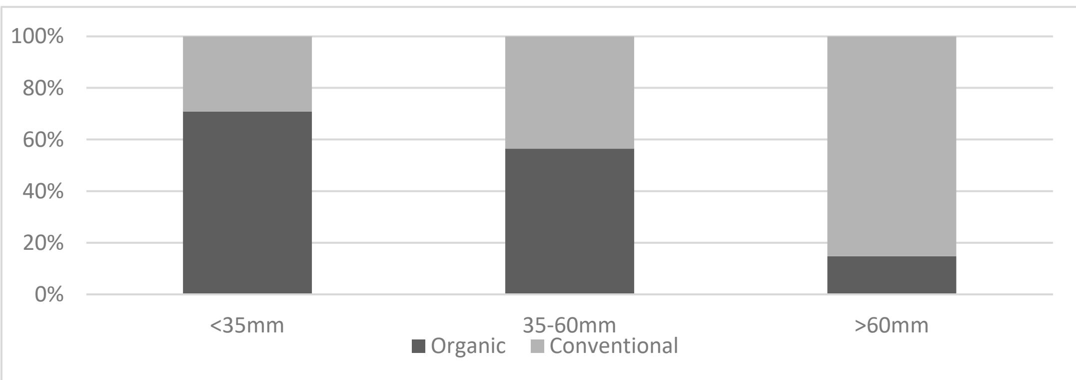

Figure 1. Tuber size distribution depending on production system (2020–2022).

3.3. The Share of Tuber Defects and Yield Structure Depending on the Variety

Tubers of all varieties were infected with common scab, but the infection did not differ significantly between the varieties. The extent of infestation was high, ranging from 45.5%

to 67.9%. Tuber black scarf infection ranged from 12.8% in the Ismena variety to 41.9% in the Pogoria variety. The share of deformed tubers depended on the variety factor and ranged from 3.1% in the Bohun variety to 18.7% in the Gardena variety. The share of cracked tubers also depended on the genotype and ranged from 1.5% (Pogoria variety) to 8.7% (Gardena variety). The share of green tubers depended significantly on the variety factor and ranged from 3.4% in the Bohun variety to 16.5% in the Gardena variety. The share of tubers damaged by pests did not depend on varietal characteristics, nor did the share of tubers with rusty spots on the flesh. The share of tubers with hollowness varied significantly depending on the variety and ranged from 0 in the Bohun and Irmina varieties to up to 1.54 tubers per 20 large tubers in the Ismena variety. Varietal characteristics differentiated only the share of the smallest tubers. The highest share of this size of tubers was recorded in the Bohun variety and the smallest in the Jelly and Pogoria varieties (Table 6).

Table 6. The share of tuber defects and tuber size distribution depending on the variety.

Tested Feature/Variety	Bohun	Pogoria	Ismena	Irmina	Gardena	Jelly
Common scab (%)	60.6a	48.8a	46.8a	59.5a	45.5a	67.9a
Black scarf (%)	24.0ab	41.9a	12.8b	37.2ab	38.1ab	19.7ab
Deformations (%)	3.1a	3.5a	3.5a	5.9a	18.7b	4.2a
Cracks (%)	2.8b	2.8b	3.6b	3.6b	8.7a	4.4ab
Green tubers (%)	3.4b	5.1b	7.7ab	3.5b	16.5a	3.8b
Pest damages (%)	2.8a	3.2a	3.9a	3.2a	5.0a	3.1a
Rust spot (nb/20 large tubers)	0.32a	0.0a	0.0a	0.0a	1.3a	0.56a
Hollow hearts (nb/20 large tubers)	0.0b	0.26b	1.54a	0.0b	1.5a	0.76ab
Share of small tubers (<35 mm) (%)	11.9a	4.9b	6.7ab	8.8ab	7.8ab	3.0b
Share of medium tubers (35–60 mm) (%)	76.3a	71.4a	78.0a	72.8a	77.3a	73.2a
Share of large tubers (>60 mm) (%)	11.7a	23.7a	15.4a	18.4a	14.8a	23.9a

Means in the same column followed by different letters are significantly different ($p < 0.05$).

3.4. *The Share of Tuber Defects and Yield Structure Depending on the Atmospheric Conditions in the Years*

Atmospheric conditions prevailing in the years of research influenced the tuber infection with common scab. A significantly higher scab infection was recorded in 2022. Tuber black scarf infection also depended on atmospheric factors and ranged from 20.5% in 2021 to 39.6% in 2022. The share of deformed tubers was similar in the years of the study. The share of cracked tubers varied significantly in individual years and ranged from 1.7 in 2022 to 5.5% in 2020. The share of green tubers also depended on weather conditions and ranged from 4.4% in 2022 up to 8.5% in 2020. The other assessed tuber defects did not depend significantly on the years of research (Table 7). A significant effect of the years was found in the case of the smallest and largest tubers. The largest share of small (non-commercial) tubers was recorded in 2021 and the smallest in 2022. The opposite situation occurred in the case of tubers with the largest diameter (Table 7).

Table 7. The share of tuber defects and yield structure depending on the year.

Tested Feature/Year	2020	2021	2022
Common scab (%)	38.8b	47.8b	77.7a
Black scarf (%)	27.2ab	20.5b	39.6a
Deformations (%)	7.2a	8.4a	5.7a
Cracks (%)	5.5a	4.6a	1.7b
Green tubers (%)	8.5a	5.0ab	5.0ab
Pest damage (%)	5.3a	0.2b	5.1a
Rust spot (nb/20 large tubers)	0.49a	0.33a	0.20a
Hollow hearts (nb/20 large tubers)	0.82a	0.82a	0.80a
Share of small tubers (<35 mm)	7.0ab	9.9a	4.8b
Share of medium tubers (35–60 mm)	73.4a	78.9a	77.2a
Share of large tubers (>60 mm)	19.7ab	11.2b	23.0a

Means in the same column followed by different letters are significantly different ($p < 0.05$).

3.5. The Magnitude of the Influence of the Studied Factors on the Commercial Quality of Tubers

The impact of the studied factors on selected tuber defects was different. The greatest influence on scab infection was the weather conditions prevailing in the years of research and the production system. Variety and weather conditions had the greatest influence on rust spot infection. The share of deformed tubers depended most on the variety and weather conditions. Tuber cracking depended to the greatest extent on the production system and genotype, and to the least extent on weather conditions. The variety had the greatest influence on the share of green tubers, followed by the production system, and thirdly by weather conditions. Pest damage to tubers was most dependent on the production system and weather conditions. The rusty spots of the flesh depended only on the production system but the hollow hearts depended on the variety.

On the share of non-commercial tubers (<35 mm) the production system had the greatest influence, followed by genotype and weather conditions. The share of medium-sized tubers was most strongly affected by the production system but the share of the largest tuber was most strongly affected by the production system and weather conditions (Table 8).

Table 8. Significance level (F and *p*-value) of the influence of the studied factors on the tested features.

Tested Feature/Parameter	Production System		Genotype		Atmospheric Conditions	
	F	*p*	F	*p*	F	*p*
Common scab	14.189	<0.001	1.060	0.403	10.708	<0.001
Black scarf	1.263	0.269	3.445	0.015	4.714	0.017
Deformations	12.626	0.001	16.207	<0.001	1.624	0.215
Cracks	10.986	<0.001	5.389	<0.001	6.566	0.004
Green tubers	6.685	0.015	5.107	0.002	4.154	0.026
Pest damages	33.165	<0.001	0.309	0.902	7.908	0.001
Rust spot	5.371	0.030	2.054	0.102	0.316	0.731
Hollow hearts	0.607	0.442	3.105	0.040	1.914	0.166
Share of small tubers (<35 mm)	21.028	<0.001	3.777	0.010	5.100	0.013
Share of medium tubers (35–60 mm)	33.084	<0.001	0.432	0.822	1.501	0.241
Share of large tubers (>60 mm)	74.640	<0.001	1.909	0.125	5.738	0.008

4. Discussion

Both the potato tuber yield, its structure, and tuber quality depend on many factors. These mainly include soil and climatic conditions, varietal, and agronomic inputs. Among the agronomic factors the production system plays an important role. In the world, the the primary production systems employed are conventional systems, but alongside these are an increasing number of eco-friendly organic and integrated systems.

Under organic production, potato is subject to different pests, diseases, and limited availability of nutrients, consequently producing lower tuber yields compared to conventionally grown potato [15,16]. Synthetic fertilizers, pesticides, and other non-organic inputs are not allowed under organic production, which creates challenges with regard to nutrient and pest management under organic farming when compared to conventional systems, with lower marketable potato tuber yield in organic production systems [26,27]. The commercial yield is largely determined by the tuber size and share of tuber defects. In our studies, the production system had a significant impact on most of the tested tuber defects and the size of tubers in the yield. In the organic system, a higher share of tubers infected with scab was recorded, which is often confirmed by the literature data [28,29]. There was more pest damage, which is also consistent with the literature data [30].

However, the use of green and animal manures under organic farming rarely has a disease-increasing effect on soil-borne disease infection and severity [31,32]. Some studies have shown that the application of cattle manure overall increases the incidence of soil-borne diseases [27,31,33,34]. Moore et al. [29] pointed out that manure provides optimum conditions for common scab development by altering soil pH level. Tein et al. [30] investigated the effect of management practices on potato tuber diseases such as common scab (Streptomyces spp.), silver scurf (Helminthosporium solani), dry rot (Fusarium spp.), and soft rot (Pectobacterium spp.) and found that the organic systems had significantly more tubers (~39%) infected with common scab (surface cover 4–15%) than in conventional systems (~25%), fewer tubers infected with silver scurf compared to all conventional farming systems, less tubers infected with dry rot in organic systems compared to the conventional systems, and the soft rot infections were not influenced by farming systems. Bernard et al. [28] reported rapeseed rotation reduced all observed soil-borne diseases such as stem canker, black scurf, common scab, and silver scurf by 10% to 52% under organic farming.

As some authors emphasize, the growing conditions in the organic system are more favorable to the development of scab and black scarf, but on the other hand, this system favors the development of antagonistic species [35].

In our research, fewer tuber defects such as deformations, cracks, and green tubers were recorded in the organic system. This was mainly due to the size of the tubers. As mentioned earlier and confirmed by our research, in organic potato cultivation there is a significant reduction in yield. Smaller tubers, however, are less susceptible to deformation, greening, or cracking. Maggio et al. [36] found a 25% reduction in potato marketable yield under the organic system compared to the conventional system with a higher percentage of large tubers under the conventional system. Zarzyńska and Pietraszko [37] compared the tuber yield of four potato varieties grown under organic and conventional management practices and found that the organic system resulted in less-than-optimal plant growth and produced fewer marketable tubers.

Similarly, Kazimierczak et al. [38] reported lower tuber yield of eight potato cultivars grown under an organic system compared to a conventional system, and large fragmentation of the yield.

The commercial quality of tubers also depended on the variety. As already emphasized, the selection of varieties is a factor that largely determines the success of organic cultivation. Great importance is attached to resistance to pathogens. In our research, the varietal diversity in the share of yield defects and yield structure was also large. They concerned most of the features. There was no significant difference in scab infection. However, most reports in the literature provide such a relationship [11,28,30,38]. In our research, the variety had no significant effect on tuber damage by pests and the share of internal defects.

Significant varietal differences regarding the size of tubers in the yield were recorded only in relation to the smallest (non-commercial) tubers. Literature data often indicate significant differences in varieties regarding this fraction of tubers and tubers with the largest diameter [31,38].

Varieties intended for organic cultivation require greater adaptability and greater yield stability [39]. Important features of varieties suitable for organic cultivation include: fast growth rate in the first phase of development, extensive root system, high resistance to main diseases, and low fertilizer requirements [21,40,41]. These features mainly characterize native, older varieties.

However, numerous studies indicate that new varieties are better adapted to worse environmental conditions and have increased resistance to diseases. Consumers are also more accepting of such varieties [42].

The conditions prevailing in the years of research had a significant impact on most of the assessed tuber defects, except for deformations and internal defects. They also had a significant impact on the share of tubers with the smallest and largest diameter in the yield. Such relationships are also confirmed by our previous research [30,37].

Our experiment revealed differences in tuber scab infection depending on the weather conditions prevailing in the years of the study. As we know, this is a factor that largely determines the level of infection. The greatest scab infection of tubers was recorded in 2022, when the amount of atmospheric precipitation was the lowest.

The influence of weather conditions during the growing season on the occurrence of common scab is confirmed by other works [43–45].

In order to improve the commercial quality of potatoes grown in an organic system, it is necessary to ensure the proper selection of varieties as well as appropriate soil moisture conditions.

5. Conclusions

The commercial yield of tubers was influenced by all examined factors, i.e., production system, variety, and weather conditions. The production system had the greatest impact on both the yield structure and the share of tuber defects, followed by the weather conditions and finally the variety. In the conventional system, a significantly better yield structure was found (higher share of marketable tubers). The share of tuber defects varied depending on the production system. In the organic system, a greater share of defects such as scab and pest damages was found, while in the conventional system, a greater share of defects such as deformations, cracks and rust spots occurred.

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