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Yield potential of potatoes with colored flesh in central-eastern Poland

Abstract. This work presents the results of the researchers' study, including a three-year (2021, 2022, 2023) field experiment that was a single-factor trial with three replicates, using table potatoes as the test plant. Eight potato cultivars with different flesh colours were tested: Bora Valley – dark purple flesh, Vitelotte Noire – purple, Blaue Annelise – purple, Salad Blue – purple, Provita – purple, Rote Emmalie – red, Herbie 26 – red, and Eurostar – light yellow. The following parameters were measured: total tuber yield, marketable yield (tubers with a diameter of ≥ 35 mm, free from external and internal defects), and large tuber yield (potatoes with a diameter > 50 mm). The analysed yields were significantly influenced by the cultivars and weather conditions during the study years. Among the coloured cultivars, the highest average total yields were recorded for Rote Emmalie, Provita, and Bora Valley cultivars; the highest marketable yields for Bora Valley, Provita, and Rote Emmalie; and the highest large tuber yields for Bora Valley and Provita. In 2021 (relatively dry) and 2022 (optimal conditions), tuber yields were significantly higher than in 2023 (a very dry year).

Keywords: *Solanum tuberosum* L., cultivars, total yield, marketable yield, large tuber yield

INTRODUCTION

Agriculture is currently experiencing numerous transformations, including the adoption of new cultivation technologies, a transition from conventional to integrated and organic farming systems, and responses to environmental challenges that necessitate a reduction in the use of synthetic fertilizers and pesticides while promoting biodiversity. Additionally, advancements in plant breeding, such as the introduction of new agricultural crop cultivars, and generational changes are evident [Sroka et al. 2019, Peltonen-Sainio et al. 2020]. Concurrently, climate change poses substantial threats, including droughts, heatwaves, precipitation deficits, and milder winters, all of which alter and frequently exacerbate the prevalence of plant diseases and pest infestations [Zarzyńska et al. 2017, von Gehren et al. 2023]. The potato (*Solanum tuberosum* L.), the fourth most important crop globally, is one of the principal agricultural crops whose cultivation and utilisation practices are affected by such changes. It is a major food crop worldwide, playing a key role in ensuring food security. The Food and Agriculture Organization of the United Nations (FAO) recognises the potato as an exceptional crop due to the high nutritional value of its tubers and its capacity to produce substantial dry matter per unit area [Devaux et al. 2021, Lal et al. 2023]. It is cultivated in over 160 countries, with yields and consumption patterns varying widely. Global average yields are approximately 21 tonnes per hectare; in the EU-27, they reach 36.3 tonnes

per hectare, with the highest yields recorded in Germany and the Netherlands (43.8 and 42.2 tonnes per hectare, respectively). In Poland, the average yield is 30 tonnes per hectare. Global per capita annual potato consumption is around 32 kg; in Poland, it is 82 kg – approximately 40% higher than the EU average [Dzwonkowski 2024]. Globally, there are around 4,000 potato cultivars, most of which originate from the Andes. In the European Union, approximately 1,650 cultivars are listed in the Common Catalogue of Cultivars of Agricultural Plant Species (CCA), while in Poland, 119 *Solanum tuberosum* cultivars were registered in 2025 [European Commission 2023, Lenartowicz 2025]. Consequently, there is substantial cultivar diversity. Growing consumer interest in health-conscious diets and lifestyles has further driven demand for nutritious raw materials and products, including potatoes. This has created opportunities for both new and older, appealing potato cultivars. Rising societal awareness has, in recent years, heightened interest in potatoes with coloured flesh, which contain all the valuable nutrients of white-fleshed tubers while also possessing health-promoting anthocyanin compounds [Bech 2020, Pino and Vergara 2021, Zarzecka et al. 2022]. The most of coloured cultivars originate from Peru and Bolivia. In Poland, breeding efforts at the Zamarte Potato Breeding Station led to the registration of the first Polish cultivars, Provita, in the National Register of Cultivars in 2021. This cultivar, characterised by purple skin and flesh, is adapted to the Polish climate, suited to light soils, and requires moderate fertilizer inputs. Its yield, ranging from 22 to 37 tonnes per hectare, is lower than that of conventional cultivars, and produces medium-sized tubers. However, it is rich in polyphenolic compounds, making it significantly healthier than yellow – or cream-fleshed cultivars [Bech 2020, Nowacki 2021, Lenartowicz 2025]. This study aims to evaluate the yield performance of both older and newer table potato cultivars with coloured flesh – European and non-European – under varying weather conditions. The research hypothesis assumed that in Polish conditions it is possible to obtain optimal yields of potato tubers of both the domestic Provita cultivar and selected foreign cultivars.

MATERIALS AND METHODS

Description of the study

The field experiment was conducted over three years (2021, 2022, 2023) at the Agricultural Experimental Station of the University of Siedlce. The soil of the experimental site was classified as a Haplic Luvisol with a sandy clay texture, according to the World Reference Base for Soil Resources [WRB 2015]. Each year, before the experiment commenced, soil samples were collected from a depth of 0–30 cm. The soil reaction was acidic to slightly acidic (pH in 1 N KCl ranging from 5.00 to 5.62), with a medium content of available potassium (123–159 mg kg⁻¹) and magnesium (46.0–64.0 mg kg⁻¹). Potatoes were cultivated annually following winter triticale. The experiment was a single-factor trial with three replicates, involving eight table potato cultivars. The cultivars were characterised by their country of origin, year of registration (where applicable), and flesh colour as follows: Bora Valley (Korea, not registered, dark purple), Vitelotte Noire (Peru-France, not registered, purple), Blaue Annelise (Germany, 2007, purple), Salad Blue (United Kingdom, 2007, purple), Provita (Poland, 2021, purple), Rote Emmalie (Germany, 2004, red), Herbie 26 (Czech Republic, not registered, red), and Eurostar (The Netherlands, 2013, light yellow). In the experiment, organic manure (farmyard manure at 25 t ha⁻¹) and mineral fertilisation (phosphorus at 44.0 kg P ha⁻¹, potassium at 124.5 kg K ha⁻¹ and nitrogen at 100 kg N ha⁻¹) were applied. Potato tubers were planted manually with a row spacing of 0.675 m and an intra-row spacing of 0.40 m between plants. Crop protection measures were implemented in accordance with national methodological recommendations [Wójtowicz et al. 2023].

Plant material

The research material consisted of tuber yields obtained from the field experiment. The assessed parameters included total yield, marketable yield, large tuber yield, and their proportions relative to the total yield. Immediately prior to harvest, ten plants were randomly sampled from each plot, and their tubers were weighed. Using a square calibrator, the tubers were subsequently sorted into size fractions based on diameter: <35 mm, 35–50 mm, 51–60 mm, and >60 mm. Tubers with a diameter of ≥35 mm

were classified as marketable, while those ≥ 50 mm in diameter were considered large tubers. Total yield comprised the combined weight of the tuber samples from the ten selected plants and the tubers harvested from the entire plot. Marketable yield comprised tubers ≥ 35 mm in diameter, free from external and internal defects. Large tuber yield consisted of tubers with a diameter > 50 mm. All values were converted to a per-hectare basis [Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 29 października 2003 r.].

Statistical analysis

The results obtained from the experiment were subjected to analysis of variance (ANOVA) for eight cultivars across three study years. The significance of differences between means was verified using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p \leq 0.05$ [Trętowski and Wójcik 1991].

Meteorological conditions

Weather conditions during the potato growing season varied across the study years (Table 1). In 2021, precipitation and air temperature were close to the long-term averages for the study area, amounting to 292.8 mm and 15.4°C, respectively. Based on the Sielianinov hydrothermal index, this was a relatively dry year. The following growing season, 2022, was cooler (14.8°C), with a similar precipitation level (289.0 mm), and was classified as an optimal year. In 2023, precipitation was notably low (185.5 mm), while the average air temperature during the season was 16.6°C, exceeding the long-term average by 1°C, making it a very dry year. Wójtowicz et al. [2023] state that from May to September, high temperatures require at least 350 mm of precipitation, while approximately 250 mm is sufficient in cooler years.

Table 1. Precipitation, air temperature and Sielianinov hydrothermal index during the conduct of the experiment in months IV–IX

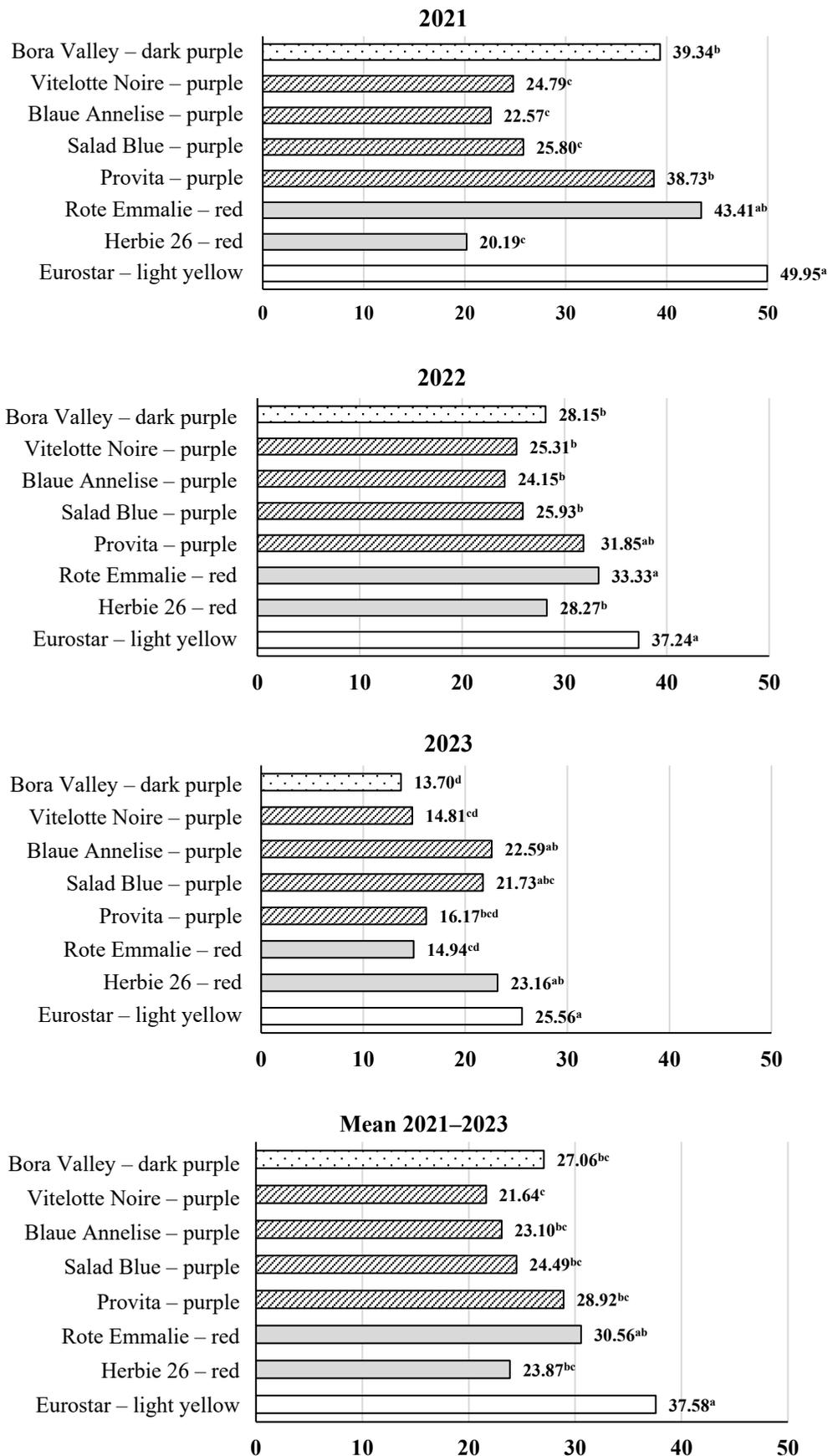
Years	Precipitation (mm)	Air temperature (°C)	Sielianinov hydrothermal index (K)*
2021	292.8	15.4	1.2 – relatively dry
2022	289.0	14.8	1.4 – optimal
2023	185.5	16.6	0.7 – very dry
Multi-year period 2002–2024	293.0	15.6	–

* Skowera et al. 2014

RESULTS AND DISCUSSION

Potato tubers are a staple food in human diets across most countries, making the quantity and quality of harvested yields significant for producers, consumers, and processing industries [Barbaś et al. 2023, Ortiz et al. 2024]. Potato yield and chemical composition are influenced by multiple factors, including cultivars, weather conditions, and cultivation technologies [Zarzyńska et al. 2017, Cima et al. 2020, Ginter et al. 2024]. In recent years, potatoes with coloured flesh (red or purple) have garnered increasing interest from researchers and consumers due to their enhanced nutritional value, appearance, and flavour [Vaitkevičienė et al. 2019]. Statistical analysis of the results revealed that total tuber yields across the study years, and their three-year average, were significantly influenced by the cultivated cultivar and weather conditions (Figure 1, Table 2). The highest average total yield (37.58 t ha⁻¹) and yields across all growing seasons (49.95, 37.24, and 25.56 t ha⁻¹, respectively) were recorded for Eurostar with light yellow flesh. In 2021, the total yield of Eurostar did not differ significantly from that of Rote Emmalie alone. Other cultivars, both red- and purple-fleshed, yielded significantly less, with the

Figure 1. Total yield of potato tubers ($t\ ha^{-1}$). Means followed by the same letter are not statistically different at the $p \leq 0.05$



lowest yields from Herbie 26 (Figure 1). In the second year (2022), total tuber yields were lower than in the previous season, ranging from 24.15 to 37.24 t ha⁻¹. The yield of Eurostar was not significantly different from two coloured-fleshed cultivars, Provita and Rote Emmalie, while other cultivars yielded less and formed homogeneous groups for this trait. In 2023, the total yield was the lowest, ranging from 13.70 to 25.56 t ha⁻¹. Statistical analysis indicated that the conventional Eurostar cultivar did not differ significantly from three cultivars: Herbie 26 (red), Blaue Annelise (purple), and Salad Blue (purple). The remaining cultivars produced total yields below 20 t ha⁻¹. Winnicki and Bogucka [2018] analysed the yields of the purple-fleshed Blue Congo cultivar and found them comparable to organic potato yields, averaging 24 t ha⁻¹, which are relatively low compared to the 50 t ha⁻¹ achievable from intensively cultivated fields. Gutiérrez-Quequezana et al. [2020] studied four purple-fleshed cultivars and one yellow-fleshed cultivar, demonstrating significant yield differences, with the highest yield from Blue Congo (purple), followed by a statistically lower yield from Van Gogh (yellow), and even lower yields from other coloured cultivars.

Table 2. Potato yields in the years of the study (t ha⁻¹)

Years	Total yield	Marketable yield (≥35 mm diameter)	Yield of large tubers (≥50 mm diameter)
2021	33.10 ^a	23.72 ^a	12.66 ^a
2022	29.28 ^a	22.33 ^a	13.18 ^a
2023	19.08 ^b	14.48 ^b	6.07 ^b
Mean	27.15	20.18	10.64

Means followed by the same letter are not statistically different at the $p \leq 0.05$.

Marketable yield was significantly influenced by the test cultivars (Figure 2). In 2021, Eurostar produced the highest marketable yield, while other cultivars yielded significantly less, with Herbie 26 having the lowest yield. In 2022, Eurostar again had the highest yield, not significantly different from Provita (the Polish truffle-type cultivar) and Bora Valley (dark purple). In 2023, marketable yield, similarly to total yield, was the lowest, with Eurostar achieving the highest (20.53 t ha⁻¹), followed by Blaue Annelise and Salad Blue, while the remaining cultivars had low yields ranging from 11.25 to 14.13 t ha⁻¹. Numerous authors confirm the significant impact of cultivar on total and marketable yields [Eschemback et al. 2017, Cima et al. 2020, Zarzecka et al. 2020, Zarzyńska et al. 2023, Ortiz et al. 2024].

Large tuber yield, comprising potatoes with a diameter >50 mm, is crucial for the processing industry, particularly for producing fries, chips, and snacks [Rytel et al. 2021]. In the study reported here, Eurostar produced the highest average large tuber yield (24.77 t ha⁻¹), while the remaining cultivars yielded significantly lower values (Figure 3).

Weather conditions significantly influenced the yields of the test cultivars (Tables 1 and 2). Average yields – total, marketable, and large tuber – collected in 2021 and 2022 did not differ significantly, as weather conditions in these seasons were favourable for plant growth and development, classified as relatively dry and optimal, respectively. In contrast, 2023, the warmest year with a significant precipitation deficit, resulted in significantly lower yields compared to 2021 and 2022. Several studies have confirmed that air temperature and precipitation during the growing season greatly affect potato yields [Cima et al. 2020, Zarzecka et al. 2020, von Gehren et al. 2023, Zarzyńska et al. 2023]. The proportions of marketable and large tuber yields relative to total yield are crucial for producers, consumers, and processing plants. In this study, among coloured-fleshed cultivars, Bora Valley, Provita, and Blaue Annelise showed the highest share of marketable yield, while Bora Valley, Provita, and Salad Blue had the highest share of large tuber yield (Figures 4 and 5). These cultivars are well-suited to Polish growing conditions. As noted by Winnicki and Bogucka [2018], the presence of coloured cultivars on the market is driven solely by consumer demand, with cultivation practices like to those of conventional cultivars. The Polish truffle-like (purple) cultivar Provita is particularly recommended due to its stable yields, good flavour, and high anthocyanin content. Among purple-fleshed cultivars available on the market, it is the best adapted to Poland's climate and has readily available planting material [Bech 2020, Kita et al.

Figure 2. Marketable yield (≥ 35 mm diameter) of pot ato tubers ($t\ ha^{-1}$). Means followed by the same letter are not statistically different at the $p \leq 0.05$

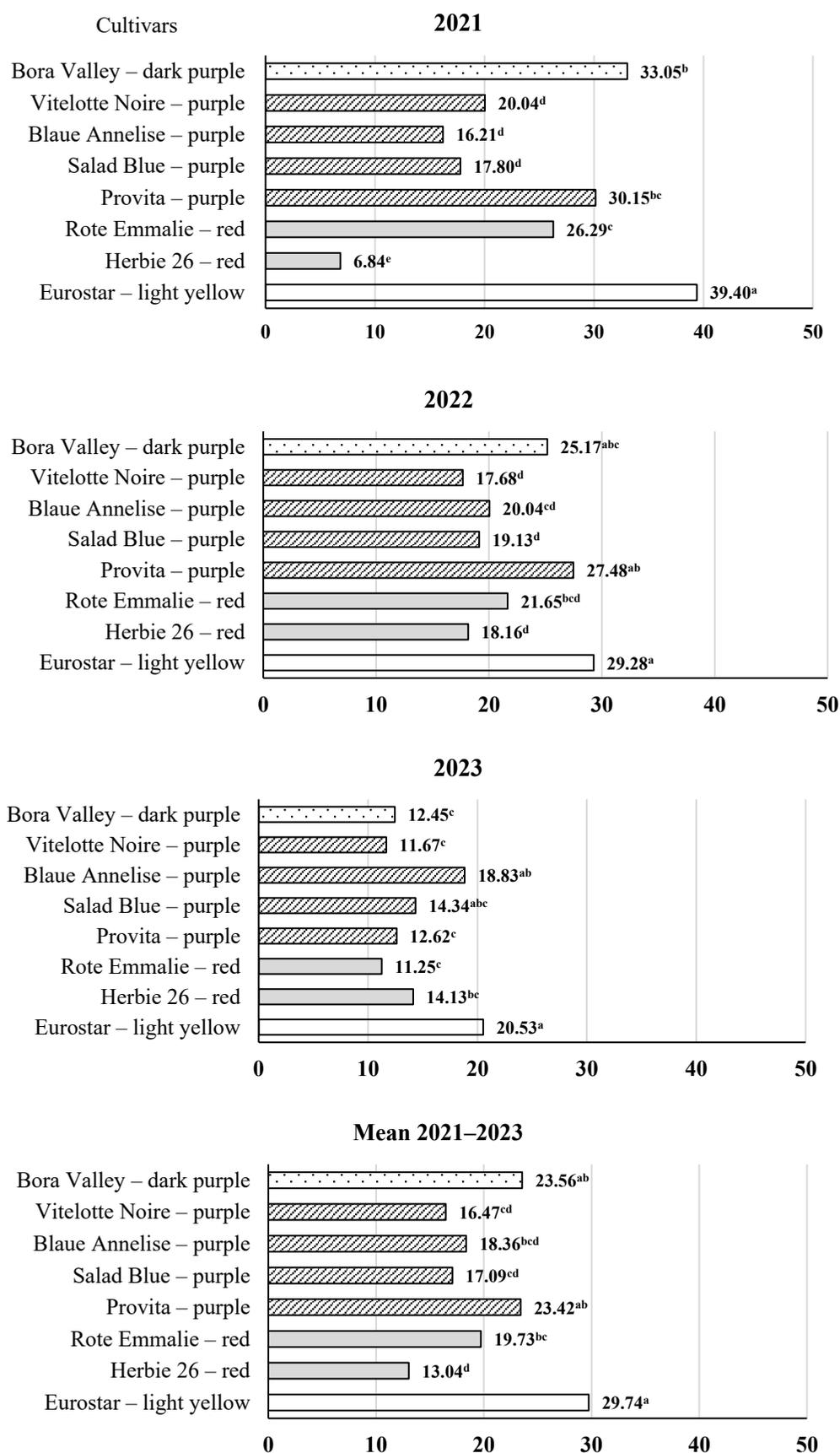


Figure 3. Yield of large (≥ 50 mm diameter) potato tubers (t ha^{-1}). Means followed by the same letter are not statistically different at the $p \leq 0.05$

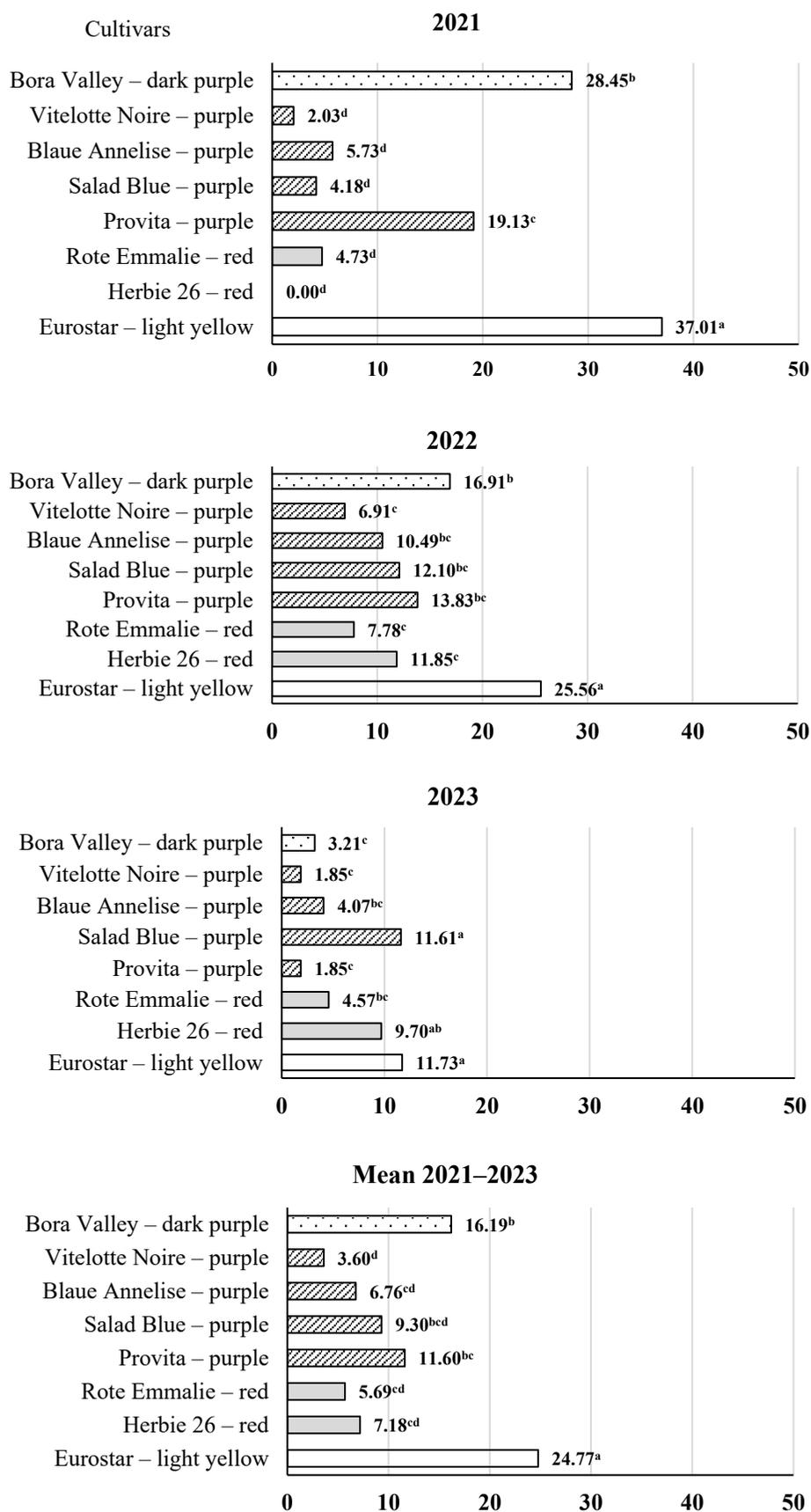
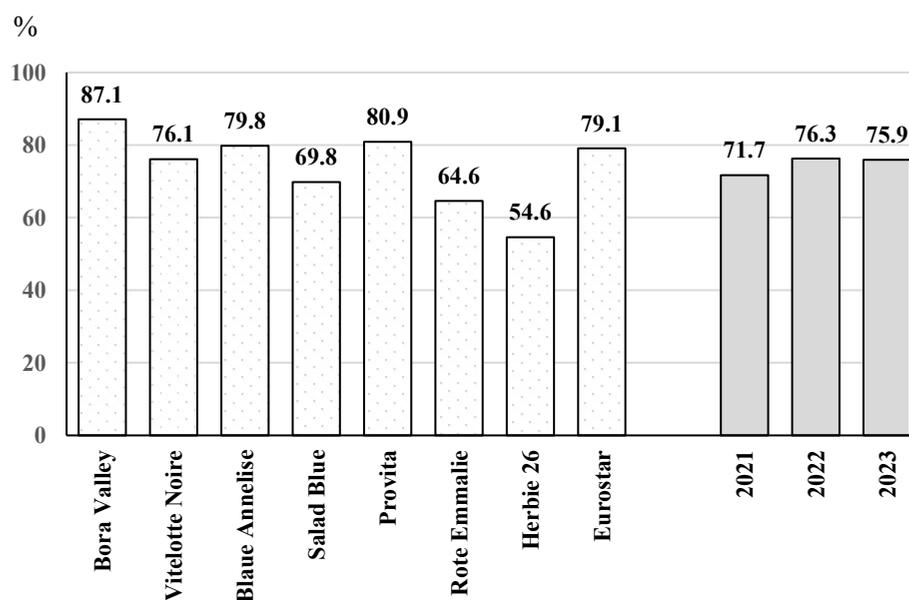
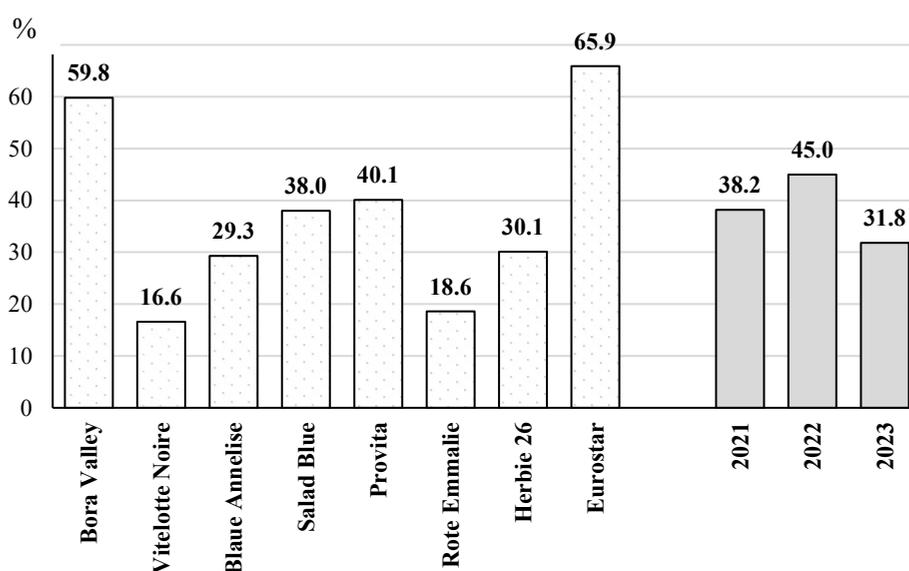


Figure 4. Share of marketable yield (≥ 35 mm diameter) in total yield (%)Figure 5. Share of large tuber yield (≥ 50 mm diameter) in total yield (%)

2022, Piotrkowska and Bech 2022]. Coloured-fleshed potato tubers represent a promising raw material for the development of innovative and attractive products rich in functional compounds [Vaitkevičienė et al. 2019, Bravo et al. 2023]. They can be successfully used for cooking, processing and decorating dishes, which will enrich the range of dishes and increase the content of health-promoting compounds in the diet.

CONCLUSIONS

1. Tuber yields – total, marketable, and large tuber – were significantly influenced by the cultivars. Among coloured-fleshed cultivars, the highest average total yields were produced by Rote Emmalie, Provita, and Bora Valley, the highest marketable yields were recorded for Bora Valley, Provita, and Rote

Emmalie, and the highest large tuber yields for Bora Valley and Provita. These results suggest that these cultivars can be recommended for cultivation under Polish conditions.

2. The highest proportions of marketable yield and large tuber yield relative to total yield among coloured-fleshed cultivars were recorded for Bora Valley and Provita.

3. Meteorological conditions during the potato growing season significantly affected tuber yields. In 2021, with precipitation and air temperatures close to the long-term average, tuber yields were the highest, whereas in 2023, classified as very dry, yields were reduced by 43% (total yield), 39% (marketable yield), and 52% (large tuber yield).

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