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# Yield and resistance of potato cultivars with colour flesh to potato late blight

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**ABSTRACT**

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The resistance to potato late blight (as AUDPC – the area under the disease progress curve) and yield were evaluated in precise field experiments with 13 colour-fleshed potato cultivars. Red Emmalie and Blaue Anneliese were the most profitable cultivars of potatoes with coloured flesh, the overall yield did not differ statistically from the control cv. Agria. Cv. Blaue Anneliese resistance to potato late blight was considerably better than both control cultivars, other 2 cultivars HB Red and Red Emmalie were similar to cv. Agria. Surprisingly, cv. Russet Burbank was found to be more resistant than most cultivars tested. A statistically significant weak dependence ($r$ = 0.36) between the percentage of infestation of plants in the T6 evaluation date (6–8 August in individual years) and the yield was detected, the slightly stronger ($r$ = 0.40) was the correlation between AUDPC values and total yields.

**Keywords**: *Solanum tuberosum*; yellow-, purple- and red-fleshed tubers; *Phytophtora infestans*

Potato (*Solanum tuberosum* L.) is the world's fourth most important food crop after maize, rice and wheat (Umemoto et al. 2016). In addition to the cultivars of yellow and white flesh, the cultivars with a non-traditional purple and red pulp have recently begun to grow in many countries of the world (Hamouz et al. 2016). They are appreciated by the sympathizers of healthy nutrition, especially for their high content of antioxidants (Kotíková et al. 2016). In this type of newly grown cultivars with coloured flesh, there is a lack of information on their cultivation characteristics in the literature, especially on the environmentally friendly cultivation technologies with reduced inputs of agrochemicals. Of the parameters studied, the resistance to potato late blight *Phytophtora infestans* (Mont.) de Bary, which is one of the most destructive diseases of potatoes (Fry 1978), is very important as it is the main biotic constraint to the production of potato production worldwide (Forbes et al. 2014). In this context, the aim of this work was to determine the yield potential and resistance to potato late blight in the thirteen currently available cultivars of potato cultivated in integrated agriculture, compared to the profitable cultivars of the world assortment – the yellow-fleshed Dutch cv. Agria and the white flesh American cv. Russet Burbank. Furthermore, it aimed at determining to what extent these characteristics are influenced by the genotype of the cultivar, purple and red flesh colour, environmental and year conditions.

## MATERIAL AND METHODS

**Plant material**. Potato tubers for assessment were grown from 2012 to 2014 in the Czech Republic in precise field experiments with 4 replicates (2 rows, 75 × 30 cm, 11.25 $m^2$, standard size of the testing trials of the Central Institute for Supervising and Testing in Agriculture) at the Czech University of Life Sciences Research Station in Prague. Basic

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Table 1. Basic characteristic of weather in the vegetation period in experimental years

| Location | Month | Average temperature (°C) | | | | Σ precipitation (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | normal | 2012 | 2013 | 2014 | normal |
| Praha Uhříněves | April | 9.7 | 13.4 | 9.63 | 8.2 | 39.8 | 17.2 | 32.4 | 46.0 |
| | May | **15.9** | 12.9 | 14.0 | 13.4 | 59.3 | 82.4 | **117.8** | 65.0 |
| | June | **18.5** | 17.7 | 17.5 | 16.3 | 60.3 | **157.9** | *32.6* | 74.0 |
| | July | 19.5 | **21.9** | **20.6** | 18.2 | **87.1** | 61.8 | **178.6** | 74.0 |
| | August | 19.8 | 19.8 | 17.6 | 17.5 | 83.6 | 89.3 | 58.6 | 72.0 |
| | September | 14.7 | 14.0 | 15.5 | 14.0 | 33.3 | 49.0 | 87.6 | 49.0 |
| Average IV–IX | | **16.4** | **16.6** | **15.8** | **14.6** | – | – | – | – |
| Σ IV–IX | | – | – | – | – | 363.4 | 457.6 | 507.6 | 380.0 |

Values in bold – above normal; values in italic – below normal

characteristics of weather during the vegetation period in experimental years are presented in Table 1. Critical period May–July was warmer than normal in the year 2012, the precipitations were higher in July 2012 and distinctly higher in June 2013 and May and July 2014.

Samples of 13 cultivars were evaluated in the trials – control cv. Agria with yellow flesh, white-fleshed Russet Burbank (2013 only), 8 cultivars with purple and 3 cultivars with red flesh (Table 2). Seed tubers were obtained from abroad and from the Gene Bank of the Potato Research Institute Havlíčkův Brod, Czech Republic. Potatoes were grown with integrated, environmentally friendly technology (without the use of herbicides and mineral nitrogen fertilizers). In the autumn, manure was ploughed into the soil at a rate of 30 t/ha. The weed control was done by mechanical cultivation on both sites, from planting to covered rows. Two sprays with Spintor (0.15 L/ha) were made in Uhříněves for the control of Colorado beetle. The protection against potato late blight was based on three preventive spraying with Flowbrix preparation (copper oxychloride, 2.3 L/ha). Experimental crops were not damaged by potato late blight.

**Yield of tubers**. Yield of tubers was determined at harvest time in physiological maturity of crop stand. Yield of tubers above 40 mm (marketable tubers) was determined after grading on sieve with 40 mm width of mesh and share of marketable tubers was counted.

**Resistance to potato late blight**. The evaluation of resistance of potato plants to potato late blight was conducted in the Uhříněves locality in the same years in a separate experiment. Potatoes of 13 cultivars on plots with ten plants each were grown in the same way as in the previous experiment but they were left untreated against potato late blight. Evaluation was commenced each year

Table 2. The effect of the cultivar on the total yield, yield of marketable tubers and the share of marketable tubers (locality Uhříněves; average of four replicationsaverage 2012–2014)

| Cultivar/ Flesh colour | Total yield | Marketable tubers yield | Share of marketable tubers |
|---|---|---|---|
| | (t/ha) | | (%) |
| Agria/y | 38.18$^{ab}$ | 35.73$^{a}$ | 93.70$^{ab}$ |
| Blaue Anneliese/p | 34.49$^{abc}$ | 29.46$^{bcd}$ | 85.41$^{cde}$ |
| Blaue Elise/p | 29.33$^{cde}$ | 24.35$^{cde}$ | 82.28$^{e}$ |
| Blaue St. Galler/p | 24.55$^{ef}$ | 22.34$^{ef}$ | 90.68$^{abcd}$ |
| Blue Congo/p | 30.09$^{cde}$ | 28.44$^{cde}$ | 96.23$^{a}$ |
| Bora Valey/p | 26.91$^{de}$ | 25.62$^{cde}$ | 95.10$^{a}$ |
| Salad Blue/p | 26.32$^{de}$ | 24.36$^{cde}$ | 91.33$^{abc}$ |
| Valfi/p | 32.40$^{cde}$ | 30.41$^{abc}$ | 93.81$^{ab}$ |
| Vitelotte/p | 15.86$^{g}$ | 12.46$^{g}$ | 72.64$^{f}$ |
| Highland B. Red/r | 17.42$^{g}$ | 14.83$^{g}$ | 85.44$^{cde}$ |
| Rosemarie/r | 29.07$^{cde}$ | 15.53$^{g}$ | 53.00$^{g}$ |
| Red Emmalie/r | 40.71$^{a}$ | 35.37$^{ab}$ | 87.02$^{bcde}$ |
| Russet Burbank/w | 24.40$^{e}$ | 24.16$^{de}$ | 95.18$^{a}$ |
| Cultivar average | 27.83 | 24.22 | 86.40 |
| *HSD* | 6.35 | 6.21 | 7.56 |

Differences between means with the same letter are not significant. Flesh colour: w – white; y – yellow; p – purple; r – red

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on the date when the first incidence of potato late blight appeared on the test stands (11 July 2012, 3 July 2013 and 1 July 2014), and was followed by evaluation at weekly intervals until death (T1, T2, ..., T7). During evaluation of potato late blight, the percentage of damaged leaf area was evaluated (estimation method – average value of three evaluators) for individual cultivar. From these data, the value of the resistance of individual cultivars to potato late blight was counted as the AUDPC value – the area under the disease progress curve (Fry 1978, Forbes et al. 2014) – obtained from repeated measurements. A lower value of AUDPC means higher resistance.

**Statistical analysis**. Obtained results were statistically evaluated by the analysis of variance (ANOVA) method. The differences between mean values were evaluated by the Tukey's *HSD* (honestly significant difference) test in the SAS computer program (SAS Institute, Carry, USA), version 9.4 at the level of significance $P = 0.05$.

## RESULTS AND DISCUSSION

**Yield, marketable yield, share of marketable tubers > 40 mm**. From the results of potato cultivation with integrated cultivation technology, it is obvious that for two most profitable cultivars of potatoes with coloured flesh the overall yield did not differ statistically from the control cv. Agria (Table 2), which is considered to be above average profitable among the traditional yellow cultivars. Cv. Red Emmalie (red flesh) reached 6.62% higher yield against cv. Agria, on average for three years. Cv. Blaue Anneliese declined by 9.66% in the yield against control. For other cultivars with coloured flesh, the decline in yield was already evident, compared to the cv. Agria (100%) the yield ranged from 84.86% for the cv. Valfi to 41.54% for the cv. Vitelotte. The reported yield differences among cultivars indicate a significant effect of the genotype on the yield within the group of cultivars with coloured flesh. The influence of the potato cultivar on yield was also demonstrated by Affleck et al. (2008). This is confirmed by Zarzyńska et al. (2017) who identified the relationship between root system size and the architecture of potato cultivars and the yield of tubers. Also, Iwama (2008) stated that the mass of roots of potato generally indicates a positive correlation with the yield of tubers. Rykaczewska (2017) also discovered the same conclusions under stress conditions. In our experiments the yield did not depend on the red or violet colour of the flesh, since in both of these flesh colours the cultivars were high and low in yield.

The yield of market tubers ranged from 12.46 t/ha for cv. Vitelotte to 35.73 t/ha for cv. Agria (Table 2). The order of the cultivars in terms of marketable yield of tubers compared to the total yield changed in several cases. The highest yield of market tubers was achieved by the control cv. Agria. The cv. Red Emmalie was exceeded in the yield of market tubers by 1.00%; the difference between these cultivars was inconclusive. The limit of minimum significant difference was not exceeded by the yield difference of the cv. Valfi (with the third highest yield of marketable tubers) compared to the control cv. Agria. On the other hand, the cv. Blaue Anneliese declined from third place in total yield to fourth place in the yield of marketable tubers. It is related to the creation of an above-average number of tubers under the plant, which is characteristic for this cultivar.

Significant cultivar variations in the number of tubers deposited under the tuft and their influence on the yield of marketable tubers were also demonstrated by Affleck et al. (2008). The worldwide white-fleshed cv. Russet Burbank ranked 11$^{th}$ in the overall yield for the weather and growing conditions, but was 9$^{th}$ in the yield of marketable tubers. De Jong et al. (2011) indicated that Russet Burbank is the most widely grown cultivar in the United States and Canada where it is a profitable cultivar; however, the natural and growing conditions in the Czech Republic are quite different from these areas.

An important finding related to the overall yield and yield of marketable tubers is the fact that some cultivars with coloured flesh (Red Emmalie, Blaue Anneliese, Valfi), in the conditions of integrated cultivation technology, have matched the control cv. Agria, which is considered as suitable cultivar for non-intensive methods of cultivation including integrated and organic farming. In another group of cultivars with coloured pulp (Blue Congo, Bora Valey, Salad Blue, Blaue Elise), the yield of marketable tubers against the cv. Agria declined by 20.40% to 31.85%; for this type of cultivars with higher health benefits for human nutrition and with a higher sale price it may not endanger

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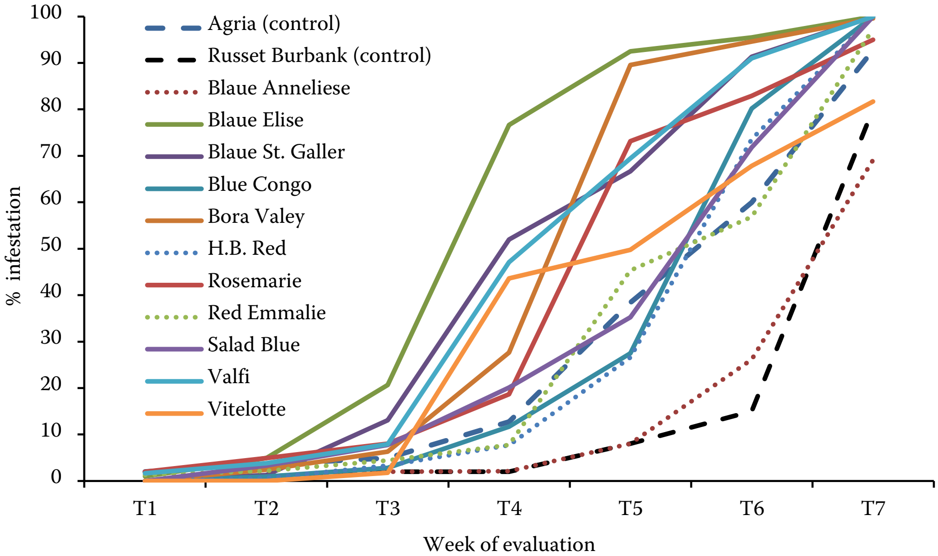


Figure 1. Course of potato late blight infection at individual cultivars (average 2012–2014)

the profitability of their cultivation. Seven out of eleven cultivars with colour flesh exceeded the yield level of 24 t/ha.

The yield of marketable tubers in a three-year average ranged from 53.00% to 96.23% (Table 2), but nine out of eleven cultivars with coloured pulp were found to have market yields above 82%. Only the cvs. Rosemarie and Vitelotte regularly exhibited market yields at a low level, which is related to the use of an exceptionally high number of tubers under the tuft. Zarzyńska and Pietraszko (2015), in their experiments with conventional and organic potato cultivation, found that the four cultivars used differed significantly in terms of all tuber yield and size distribution parameters. They show the cultivars' influence on the share of small, medium and large tubers, which correlates with the number of tubers placed under the plant.

**Resistance to potato late blight**. Comparison of traditional yellow cv. Agria and white cv. Russet Burbank with other tested cultivars (Figure 1) shows different course of infection among cultivars in time. Cv. Blaue Anneliese resistance to potato late blight was considerably better than both control cultivars, and other two cultivars (HB Red and Red Emmalie) were similar to cv. Agria.

The resistance of cultivars to potato late blight must be evaluated locally. Russet Burbank has been tested in our experiment for only one year for comparison because it is generally susceptible to potato late blight in the USA (Staples 2004); surprisingly, it was found to be more resistant than most cultivars tested. This illustrates the importance of breeding on resistance for specific local conditions. Local resistance of the cv. Russet Burbank to potato late blight was also found by Andreu et al. (2010) in Argentina.

Table 3 lists the annual values of AUDPC of all cultivars and their multiannual averages. The lowest AUDPC had the slower course of infection, as shown in Figure 1. In each year the temperature

Table 3. Evaluation of potato late blight in field experiment without fungicide treatment (AUDPC (area under the disease progress curve) values); locality Uhříněves, 2012, 2013, 2014 (evaluation of 10 plants of each cultivar in 1 replication)

| Cultivar | 2012 | 2013 | 2014 | Average |
|---|---|---|---|---|
| Blaue Anneliese | 176.6 | 1279.0 | 601.5 | 685.7$^{b}$ |
| Russet Burbank[1] | – | 817.0 | – | 817.0 |
| HB Red | 1205.3 | 1975.0 | 1034.5 | 1404.9$^{ab}$ |
| Rote Emma | 990.4 | 2733.5 | 627.3 | 1450.4$^{ab}$ |
| Agria | 690.1 | 2523.0 | 1147.0 | 1453.4$^{ab}$ |
| Blue Congo | 1019.0 | 2128.0 | 1354.0 | 1500.3$^{ab}$ |
| Salad Blue | 2070.8 | 1820.0 | 811.0 | 1565.3$^{ab}$ |
| Vitelotte | 910.3 | 3369.5 | 956.5 | 1745.4$^{ab}$ |
| Rosalinde | 1846.5 | 1573.5 | 2226.5 | 1882.2$^{ab}$ |
| Bora Valey | 1760.9 | 2715.5 | 2168.0 | 2214.8$^{ab}$ |
| Valfi | 1833.8 | 3180.0 | 1632.5 | 2215.4$^{ab}$ |
| Blaue St Galler | 1791.8 | 3960.5 | 1518.0 | 2423.4$^{a}$ |
| Blaue Elise | 1903.5 | 3410.0 | 2832.5 | 2715.3$^{a}$ |
| Cultivar average | 1349.9$^{B}$ | 2555.6$^{A}$ | 1409.1$^{B}$ | 1698.1 |

$HSD_{cultivar}$ 1640.2; $HSD_{year}$ 566.37; differences between means with the same letter are not significant, [1]cultivar was not used in statistic evaluation

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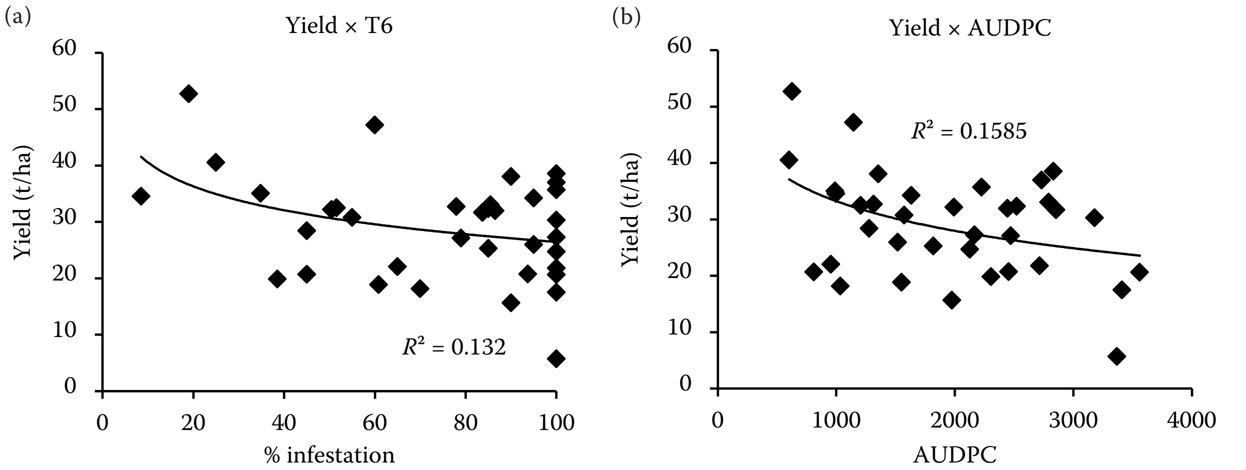


Figure 2. Correlation between (a) yield and % of infestation in T6 and (b) yield and AUDPC (area under the disease progress curve) value

and the amount of precipitation were decisive for the course of the infection. The worst from this view was the year 2013, the best was 2012 (Table 1). The highest average of AUDPC was associated with a high sum of precipitation in June 2013. Similarly, the high rainfalls in July 2014 had little impact on the average AUDPC value.

However, the leaf surface infection is decisive for the level of yield. Correlation analysis revealed a statistically significant weak dependence ($r$ = 0.36) between the percentage of infestation of plants in the T6 evaluation date (6–8 August in individual years) and yield (Figure 2a), the slightly stronger ($r$ = 0.40) was the correlation between AUDPC values and total yields (Figure 2b). The decisive influence on the AUDPC values was the level of plant infestation in T4, T5 and T6 (significant correlation coefficients 0.78, 0.88 and 0.82, respectively).

Sedláková et al. (2011) argued that the value of AUDPC is the objective evaluation of the disease course. They detected yield dependence on the AUDPC value using simple linear regression ($r$ = –0.56), confirming the assumption that the more hardly cultivars resist the attack of the pathogen, the more easily the pathogen destroys a larger part of the yield. In general, the value of resistance decreases with an increase in cultivar yield and quality potential.

Potato late blight is a significant deleterious factor that can completely destroy potato stalks in years of intense infectious pressure (Guenthner et al. 2001). But the disease itself is less affecting to the yield. Sedláková et al. (2011) found that potato late blight contribute to a change in yield by 31%. It means that a series of other factors will contribute to change in yield levels. Mantecón (2007) found a 33.85% increase in total tuber yield in potato late blight-treated variants in a 10-year experiment. Influence of locality and cultivar yield ability is more important, in company of year effects (Pazderů et al. 2015). Higher rainfalls aggregated with lower temperatures during the formation of tubers contribute to better formation of tubers (Govindakrishnan and Haverkort 2006). Combination of higher precipitation with higher average temperatures results in more intensive potato late blight progress.

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