

Evaluation of New Strawberry Cultivars for their Potential Use in Organic Farming and in *Verticillium*-infested Soils

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Summary

As part of a research project 13 cultivars were planted in 2005 at 11 sites in 5 different Austrian regions. The aim was to find new cultivars tolerant to the soil-borne pathogen *Verticillium dahliae* and to leaf/fruit diseases, with high yield and good fruit quality, to serve as alternative to 'Elsanta', a highly susceptible cultivar regarding soil-borne diseases. Infestation with *V. dahliae* was evaluated in 2005 and 2006 at 7 sites and in 2007 at 3 sites. Moreover marketable yield, percentage of different categories of unmarketable fruits, plant vigour, and incidence of the blossom weevil *Anthonomus rubi*, of chlorosis and of leaf spot diseases were assessed on 2 of the sites in 2006 and 2007.

'Elsanta' showed the highest infestation with *V. dahliae* whereas 'Salsa' and 'Daroyal' were most tolerant. 'Daroyal', 'Queen Elisa', 'Eva' and 'Dora' showed very high plant vigour. 'Dora', 'Eva', 'Queen Elisa' and 'Daroyal' recorded significantly higher losses by the blossom weevil than 'Alice'. Highest marketable yield

per plant had the late ripening cultivars, particularly 'Salsa' and 'Sonata'. Of all early ripening cultivars tested, 'Darselect' showed the highest yield, followed by 'Elsanta', 'Daroyal' and 'Alba'.

Summing up all the results, 'Alba', 'Alice', 'Daroyal', 'Darselect' and 'Salsa' can be recommended for organic production. 'Elsanta' and 'Sonata' had high yield under organic farming conditions, but are highly susceptible to *V. dahliae*. 'Salsa', 'Daroyal', 'Alice', 'Record' and 'Queen Elisa' are suitable for growing in *Verticillium*-infested soils. As new alternatives to 'Elsanta', the early ripening cultivars 'Alba', 'Clery', 'Daroyal' and 'Queen Elisa' can be used, though 'Clery' and 'Queen Elisa' had rather low yield under organic farming conditions and 'Alba' and 'Clery' are only partially tolerant to *V. dahliae*. 'Divine' and 'Dora' had low yield and are susceptible to *Verticillium*-wilt and 'Record' is prone to grey mould. These cultivars cannot be recommended for organic production.

Key words. soil-borne pathogens – wilt – cultivar – organic farming – on-farm trials

Introduction

Soil-borne pathogens (*Verticillium*, *Phytophthora*, *Pythium*, *Cylindrocarpon*, *Fusarium*, *Sclerotinia*, etc.) cause plant loss and yield decrease in many Austrian strawberry regions. A reduction through wide crop rotation is not possible because of long-living spores. The use of soil fumigants is forbidden and other methods of reducing soil-borne pathogens effectively are not found yet. 'Elsanta', the main early-mid season strawberry cultivar in parts of Europe, though convincing because of good fruit characteristics and high yield, is highly susceptible to soil-borne pathogens (BARTH et al. 2002, SPORNBERGER et al. 2005).

The aim of this study was to find new cultivars which combine tolerance to *V. dahliae* and other diseases with a high yield, a high percentage of marketable fruits and with consumer acceptance, which should be achieved by carrying out trials on farms with different farming systems and climate conditions in the main Austrian strawberry regions. To find early-ripening cultivars with these qualities is of particular interest for farmers because strawberries in the beginning of strawberry season gain high prices at the market.

First results of these trials were already published (SPORNBERGER et al. 2006). In this paper, the results of 3 following years are summarized.

Materials and Methods

Cold stored plants of 12 cultivars ('Alice', 'Alba', 'Clery', 'Daroyal', 'Darselect', 'Divine', 'Dora', 'Eva', 'Record', 'Queen Elisa', 'Salsa', 'Sonata') and of 'Elsanta' as control were planted in April–June 2005 at 11 sites on 9 farms in 5 different regions of Eastern Austria (20–48 plants each cultivar and site, 1–4 replications per site). 2 of the farms were 'organic', all others were managed conventionally. The content of microsclerotia of *V. dahliae* in the different soils was determined using the wet-sieving method described by HARRIS et al. (1993). From each site (area on which the trial was planted) a bulked sample of 25 cores (to a depth of 20 cm) was taken using a soil borer. The infestation risk for susceptible cultivars was estimated using the scheme of HARRIS et al. (1993): <0.3 vital microsclerotia g⁻¹ soil = very low risk, 0.3–0.6 = low risk, 0.6–2.0 = medium risk, 2.0–5.0 = high risk, >5.0 = very

Table 1. Infestation with *Verticillium dahliae* (means of 2005–2006, resp. 2005–2007), infestation risk and climatic characteristics of the evaluated sites.

Site	Degree of infestation 1–4 (<i>Verticillium dahliae</i>)	Microsclerotia g ⁻¹ soil	Infestation risk (for susceptible cultivars)	Mean annual precipitation (mm)	Mean precipitation VI–VIII (mm)	Mean annual temperature (°C)
Strebersdorf	1.07	0.0	Low	520.0	177.1	9.8
Kremsmünster	1.09	7.8	Very high	957.5	331.3	8.8
Gleisdorf**	1.12	4.6	High	817.0	342.6	8.4
Jedlersdorf**	1.33	6.6	Very high	520.0	177.1	9.8
Wiesen 2**	1.33	6.6	Very high	617.3	212.6	9.5
Wiesen 1	1.66	10.4	Very high	617.3	212.6	9.5
Breitstetten	2.00*	1.5	Medium	524.7	178.3	9.5

* the high value is probably in partly caused by plant losses probably due to overfertilisation

** sites where evaluation was done in 2007

high risk. Infestation with *V. dahliae* was evaluated in late summer at 7 sites in 2005 and 2006 and at 3 sites in 2007. Symptoms of *V. dahliae* were examined with a rating schema concerning the infestation strength: 1=plants without symptoms, 2=outer leaves wilting, young leaves without symptoms, 3= young leaves stunted, 4=plant died.

In 2006 and 2007, at 2 sites in the North East of Vienna, where plants were organically grown and no plant treatments were done, plant vigour, occurrence of leaf spot diseases (leaf scorch caused by *Diplocarpon earliana* and leaf spot caused by *Mycosphaerella fragariae*) and chlorosis were estimated with a rating schema ranging from 1 (very low) to 9 (very high). The incidence of the blossom weevil (*Anthonomus rubi*) was assessed in percentage of destroyed flowers. Marketable yield was determined and unmarketable fruits were divided according to the cause of damage.

Statistical analysis of data was made with SPSS 12.0 (Variance analysis with post hoc S-N-K-test, $P < 0.05$).

Results

Content of microsclerotia and plant infestation with *Verticillium dahliae*

The amount of microsclerotia of *V. dahliae* of the 11 soils ranged from <0.3 (2x) to 10.4 microsclerotia g⁻¹ soil. Following amounts in between were found: 1.4; 1.5; 1.7; 3.4; 4.6; 6.6; 6.6 and 7.8 microsclerotia g⁻¹ soil. The content of microsclerotia, the infestation risk and the climatic characteristics of the 7 sites where infestation with *V. dahliae* was evaluated are shown in Table 1, as well as the mean infestation degree of these sites. At 'Strebersdorf', 'Kremsmünster' and 'Gleisdorf', the degree of infestation was very low, whereas at 'Jedlersdorf' and 'Wiesen 2' it was about three times higher and at 'Wiesen 1' it was two times as high as at 'Jedlersdorf' or 'Wiesen 2'. At 'Breitstetten' many plants with heavy symptoms and many dead plants were assessed, leading to the highest infestation degree of the quoted sites.

'Salsa' had hardly any symptoms of *Verticillium*-wilt at any site, all other cultivars showed more symptoms

(Fig. 1). 'Salsa', 'Daroyal', 'Alice', 'Record' and 'Queen Elisa' were significantly less affected than 'Dora', 'Clery', 'Divine', 'Sonata' and 'Elsanta' and can be regarded as tolerant to *V. dahliae*. 'Elsanta' was at significance the most susceptible cultivar. The mean infestation degrees of 'Eva', 'Alba' and 'Darselect' were in the middle field. There were significant interactions between cultivar and site, cultivar and year, and site and year (data not shown).

Ripening time and yield

'Alba' and 'Divine' were the earliest cultivars in ripening time. 'Clery', 'Daroyal', 'Queen Elisa', 'Darselect', 'Dora' and 'Eva' started with the first picking nearly the same time as 'Elsanta', all other cultivars started later (data not shown).

In general yield was higher in late-ripening than in early-ripening cultivars. In the mean of 2006 and 2007, 'Salsa' was the most productive cultivar, followed by 'Sonata', 'Record' and 'Alice'. Among the early-ripening cultivars, the traditional cultivars 'Darselect' and 'Elsanta' had the highest yield. Comparable amounts of healthy fruits were produced by 'Daroyal' and 'Alba'. The yield of 'Clery', 'Eva', 'Queen Elisa', 'Dora' and 'Divine' was lower.

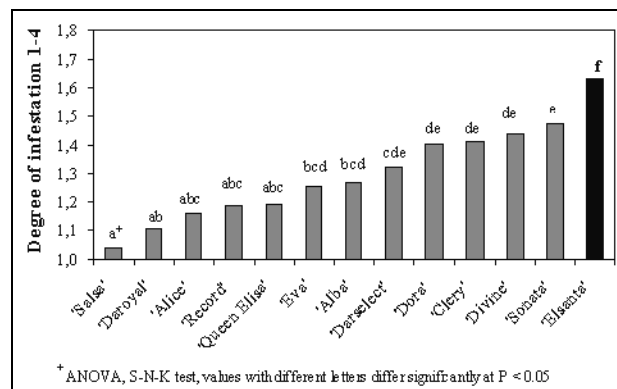


Fig. 1. Infestation with *Verticillium dahliae* (means of 2005–2007 at 7 sites).

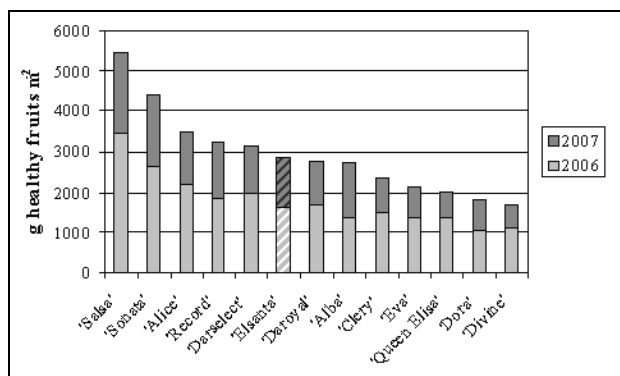


Fig. 2. Yield of healthy fruits per m² (sums of 2006 and 2007; means of 2 sites resp.).

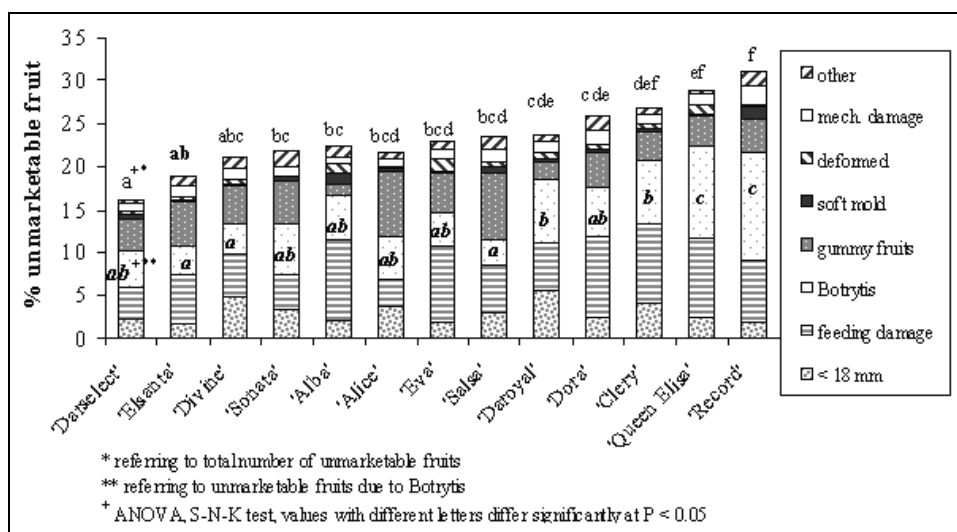
In 2007, yield was approximately 2/3 of 2006, except for 'Alba' which produced the same quantity of fruits in both years (Fig. 2).

Percentage of unmarketable fruits

Feeding damage, infestation with *Botrytis cinerea* and desiccation (= gummy fruits) were the primary reasons for unmarketable fruits (Fig. 3). There were significant differences among the cultivars in all 3 parameters (statistical data only shown for *Botrytis*-infested fruits).

The greatest losses due to unmarketable fruits showed 'Record' and 'Queen Elisa' what can be ascribed to a high susceptibility to *B. cinerea*. 'Darselect' had a high percentage of marketable fruits, as well as 'Elsanta', according to low infestation with *B. cinerea*. 'Salsa' and 'Divine' proved to be highly tolerant to grey mould. Many gummy fruits were harvested from 'Salsa', 'Alice', 'Elsanta', 'Sonata', 'Eva' and 'Divine'. In comparison, 'Alba' and 'Daroyal' produced very few fruits with such symptoms.

In the end of the harvest period, especially in the second year, an increasing number of fruits with diameter <18 mm were harvested. 'Daroyal', 'Divine' and 'Clery' produced many fruits too small for marketing.



* referring to total number of unmarketable fruits
 ** referring to unmarketable fruits due to Botrytis
 + ANOVA, S-N-K test, values with different letters differ significantly at P < 0.05

Plant vigour and incidence of chlorosis, leaf spot diseases and the blossom weevil

'Daroyal', 'Queen Elisa', 'Eva' and 'Dora' showed high plant vigour. 'Elsanta' had a weak plant growth. In general the incidence of chlorosis and leaf spot diseases was weak to moderate, but there were significant differences between the cultivars. Infestation with leaf spot diseases (*Diplocarpon earliana* and *Mycosphaerella fragariae*) was lowest at the cultivars 'Alba', 'Queen Elisa', 'Sonata' and 'Daroyal' and highest at 'Salsa'. Chlorosis was observed at a higher level at 'Darselect', 'Elsanta', 'Sonata', 'Divine' and 'Eva'. None or hardly any problems with chlorosis had 'Queen Elisa', 'Alba' and 'Clery'. The percentage of infested flowers by the blossom weevil was between 15,4 % ('Alice') and 36,0 % ('Dora'). 'Dora', 'Eva' and 'Queen Elisa' were significantly more attacked than 'Alice', 'Darselect', 'Clery', 'Sonata', 'Divine', 'Salsa', 'Record', 'Elsanta' and 'Alba' (Table 2).

Discussion

Contents of microsclerotia and infestation with *Verticillium dahliae*

The infestation risk of the sites was estimated as high or very high excluding the site 'Strebersdorf' where no microsclerotia were found at all and the site 'Breitstetten'. A good correlation between infestation degree and content of microsclerotia was only found at sites with a low mean annual precipitation. At sites where there is a mean annual precipitation of 800–1000 mm year⁻¹, hardly any symptoms were detected despite a high or very high infestation risk. In dry regions and in periods when no irrigation is done (after harvest), infested plants suffer more than healthy plants from water stress, because *V. dahliae* produces a decrease in leaf water potential and in leaf relative water content (GOICOECHEA et al. 2000). So, besides the inoculum concentration and the cultivar, the water availability, influenced by climate, by cultivation practices like irrigation and tillage and by soil characteristics, may play an important role. DAVIS et al. (2001) studied different abiotic soil factors in relation to *Verticillium*-wilt

Fig. 3. Percentage and components of unmarketable fruits (means of 2006 and 2007 at 2 sites).

Table 2. Plant vigour, incidence of leaf spot diseases, of chlorosis and of the blossom weevil (means of 2006 and 2007 at 2 sites).

Cultivar	Plant vigour*	Infestation with leaf spot diseases*	Incidence of chlorosis*	Incidence of the blossom weevil**
'Alba'	5.11	1.56	1.20	24.4
'Alice'	4.44	2.89	2.40	15.4
'Clery'	4.33	3.11	1.40	19.3
'Daroyal'	6.78	1.89	2.60	26.6
'Darselect'	4.67	3.67	4.20	17.9
'Divine'	3.67	3.56	3.20	19.8
'Dora'	5.44	2.89	2.00	36.0
'Elsanta'	3.56	3.00	3.60	21.2
'Eva'	5.44	3.22	2.80	35.2
'Queen Elisa'	5.56	1.67	1.00	31.9
'Record'	4.56	4.00	1.80	21.0
'Salsa'	4.22	4.22	3.20	20.6
'Sonata'	4.44	1.78	3.60	19.5

* 1 = very low. 9 = very high

** % attacked flowers

on potato and reported on a correlation between wilt severity and organic matter content, organic N, cation exchange capacity, lime content and other soil factors. Therefore disease severity cannot be predicted precisely only by determining the content of microsclerotia. An irregular spreading of microsclerotia in a soil makes it even more difficult.

In the mean of all sites, we observed clear differences in the susceptibility between the cultivars. SHAW (1997) distinguished resistant, intermediate and susceptible strawberry cultivars, according to the inoculum concentration at which plants showed symptoms. The term 'resistance' is not precise because also from plants without wilt symptoms *V. dahliae* can be isolated. Types of strawberries with the highest degree of 'resistance' are therefore highly tolerant (OLBRICHT and ULRICH 2006). One of the most important aims of strawberry breeding is a high tolerance to soil-borne pathogens. In our study, some cultivars ('Salsa', 'Daroyal', 'Alice', 'Record', 'Queen Elisa') showed a high field tolerance towards *Verticillium*-wilt. Of these cultivars, only very few plants were affected, rare symptoms occurred only at sites with good conditions for *V. dahliae*. 'Elsanta' and 'Sonata', an offspring of 'Elsanta', turned out to be particularly unsuitable for *Verticillium*-infested soils. Looking at all cultivars, a graduation of tolerance can be observed.

Yield, average fruit weight and percentage of marketable fruits

The early-ripening cultivars in our study had less yield than the late-ripening cultivars, but fruits of early-ripening cultivars can be sold at higher prices. 'Alba' and 'Daroyal' were ripening earlier than 'Elsanta' and had a similar yield. 'Clery', 'Eva', 'Queen Elisa', 'Dora' and 'Divine' produced less healthy fruits than 'Elsanta', at least in our trial under organic farming conditions. The low yield of these cultivars was partly due to a high number of *Bot-*

rytis-infested fruits ('Queen Elisa' and 'Clery') and due to feeding damage ('Queen Elisa', 'Clery', 'Eva' and 'Dora'). 'Divine' had a relatively high percentage of marketable fruits, but nevertheless a low productivity. Some cultivars had a higher average fruit weight than 'Elsanta' what is, combined with a regular fruit shape, an important characteristic for marketing. In our trial, 'Elsanta' and 'Darselect' proved a low susceptibility to grey mould. The amount of gummy fruits did not correlate with a high infestation degree of *Verticillium*-wilt as was assumed before, but is probably related to water stress in general. 'Salsa' had the highest amount of gummy fruits, probably because the plants were stressed to supply the many fruits with water.

Plant parameters and incidence of the blossom weevil

High plant vigour causes effective weed suppression. Additionally, a high leaf/fruit ratio increases the sugar content of fruits (CARLEN et al. 2005). 'Daroyal', 'Queen Elisa' and 'Alba' showed high vitality and robustness against leaf spot diseases and chlorosis in contrast to the weak growing plants of 'Elsanta' and 'Divine'. In the first year, a mentionable loss of flowers due to the blossom weevil occurred only at one site, whereas in the second year the blossom weevil caused a mentionable damage at both sites. TERRETTAZ et al. (1995) set the thresholds at 10 % of flowers for 1-year-old plants and 25 % for 2-year-old plants. At the higher affected site, 'Queen Elisa', 'Eva' and 'Dora' recorded losses up to 50 %. SIMPSON et al. (1997) found that there was a heritable basis for the susceptibility to *A. rubi*. In a paper of SIMPSON et al. (2002) 'Alice' is referred to as a rather resistant cultivar what was confirmed in our study. In our trial, early-ripening cultivars were more attacked, which may be related to the emerging time of the weevils, but there were also early-ripening cultivars with relatively few infested flowers which indicate a heritability of resistance independent of the pa-

parameter 'time of harvest'. At affected sites and especially in organic farming, the use of resistant cultivars can diminish or resolve the risk of a reduced yield.

Conclusive remarks

Given the presented results, 'Alba', 'Alice', 'Daroyal', 'Darselect', 'Elsanta', 'Salsa' and 'Sonata' can be recommended for organic production, because of high yield under organic farming conditions, whereas 'Clery', 'Eva' and 'Queen Elisa' are classified as suitable for only a limited extent. 'Clery' had a weak plant vigour, paired with a high number of unmarketable fruits. 'Eva' and 'Queen Elisa' had high fruit losses due to the blossom weevil, 'Queen Elisa' produced accessorially a high amount of *Botrytis*-infested fruits. 'Divine', 'Dora' and 'Record' cannot be recommended for organic production at all, in case of 'Divine' and 'Dora' because of very low yield and in case of 'Record' because of high susceptibility towards *Botrytis*. 'Elsanta', 'Sonata', 'Divine' and 'Dora' proved to be particularly unsuitable for growing in *Verticillium*-infested soils, 'Salsa', 'Daroyal', 'Alice', 'Record' and 'Queen Elisa' proved to be suitable.

As new alternatives to 'Elsanta', the early-ripening cultivars 'Alba', 'Clery', 'Daroyal' and 'Queen Elisa' can be used, though 'Clery' and 'Queen Elisa' had low yield under organic farming conditions and 'Alba' and 'Clery' are only partially tolerant to *V. dahliae*. To see if these new cultivars meet the demands concerning fruit quality and to find good marketing strategies, their fruit characteristics were studied at different harvest dates (WEISSINGER 2008, submitted). As a result, 'Alba', 'Clery' and 'Queen Elisa' are very suitable for fresh marketing whereas 'Daroyal' is particularly suitable for processing.

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