

# Rapid mixing of *Venturia inaequalis* populations between IPM and organic apple orchards in the Lower Elbe region

R.W.S. Weber<sup>1</sup>

## Abstract

Repeated surveys of *Venturia inaequalis* (apple scab) for resistance to benzimidazole (MBC) and strobilurin (QoI) fungicides were conducted in the Lower Elbe region of Northern Germany. Resistance to both compounds was ubiquitous in abandoned orchards within the 'Altes Land' core area, but very rare in the periphery. In the Altes Land, double resistance was common among isolates from standard scab-sensitive cultivars under Integrated Pest Management or organic management. It was rare on scab-resistant (Vf) cultivars in 2021 and 2022, but showed an increase in 2025, indicating that Vf-breaking *V. inaequalis* strains had overcome their reproductive isolation. These findings suggest that large coherent apple-producing regions such as the Altes Land are subject to a rapidly evolving, highly adaptable population of *V. inaequalis*. Implications for apple scab management are briefly discussed.

**Keywords:** Fungicide resistance, organic production, population dynamics, *Venturia inaequalis*, Vf resistance

## Introduction

Scab, caused by *Venturia inaequalis* (Cooke) G. Winter, is the most fundamental disease in apple production worldwide (MacHardy, 1996). It is favoured by the mild and humid climate prevailing in northwestern Europe, including the Lower Elbe region in Northern Germany. Its core area, the Altes Land, features over 8,000 ha of coherent fruit orchards, of which apple trees comprise 90%. Organic orchards currently take a 20% share of the total acreage, and these are interspersed among orchards under Integrated Pest Management (IPM). Fruit farms outside the Altes Land are embedded in an agricultural landscape of fields and grassland, and are usually separated from one another by distances of about 1-5 km.

*Venturia inaequalis* undergoes sexual reproduction on fallen leaves in the winter months, leading to the discharge of wind-dispersed ascospores from bud break until the end of flowering. As soon as fresh scab lesions emerge, they continuously release asexual conidia by rain-splash, and these carry the infection through to autumn. Scab control relies heavily on frequent fungicide applications from early spring into summer, aided by sophisticated warning systems. Nonetheless, both organic farmers and their IPM colleagues have suffered severe scab epidemics in 2023, 2024 and 2025 (Weber & Heyne, 2024; Weber & Kruse, 2025). Hope rests on apple cultivars harbouring monogenetic resistance (Vf) to *V. inaequalis*. However, Vf-breaking strains have emerged in organic farms in the Lower Elbe region and elsewhere (Buchleither, 2021). An early regional record of such a Vf resistance breakage was on cv. 'Dalinbel' at the Esteburg experimental station in 2015 (Fig. 1).

In the Altes Land, *V. inaequalis* appears to be capable of rapidly adapting to regional production conditions, as indicated by Vf breakage and also by the successive spread of strains with resistance to synthetic fungicides, viz. methyl benzimidazole carbamates (MBC) in 1974, demethylation inhibitors (triazoles) in 1996, quinone-oxidoreductase inhibitors (QoI) in 1998, and anilinopyrimidines in 2005 (reviewed by Weber *et al.*, 2025). Each of these resistance developments was accompanied by a failure of scab control strategies and by heavy

---

<sup>1</sup> Esteburg Centre, DE-21635 Jork; Dept. of Food Science, Aarhus University, DK, roland.weber@lwk-niedersachsen.de

economic losses. In order to avoid similar calamities in future, large-scale regional fungicide resistance surveys have been conducted in the Lower Elbe region in 2014, 2021 and 2022. In these studies we found *V. inaequalis* isolates with MBC and QoI resistance to be widespread in the Altes Land core area both in IPM and in organic orchards on conventional cultivars (e.g. 'Elstar', 'Jonagold', 'Braeburn'), but not in organic orchards on *Vf* cultivars, indicating the *de novo* origin of *Vf*-breaking strains and their reproductive isolation within organic production (Busch & Weber, 2025; Weber *et al.*, 2025).

In the wake of the severe 2025 scab season, a new fungicide resistance survey was initiated. In addition to IPM orchards, this included organic farms with conventional and *Vf*-resistant cultivars in order to examine whether the *Vf*-breaking population of *V. inaequalis* had overcome its reproductive isolation. MBC and QoI resistances were chosen as markers because they are unequivocally detected by simple tests. Furthermore, they are not associated with any fitness deficits, meaning that there is no selective pressure against them in the absence of fungicide applications (McGee & Zuck, 1981; Frederick *et al.*, 2014). The results of this survey shed light on the highly dynamic nature of the *V. inaequalis* population in a coherent and intensive fruit production area such as the Altes Land.



Figure 1: Breakage of *Vf*-based resistance on cv. 'Dalinbel' by *Venturia inaequalis* in the Esteburg experimental orchard in 2015. Ascospore infections (large scab lesions) appeared on the fruits of very few trees and gave rise to conidial infections which were spreading within these trees during the summer (small satellite lesions).

## Material and Methods

Leaves with fresh scab lesions were collected from IPM, organic or abandoned orchards throughout the Altes Land area from mid-June to late July 2025. Leaves were stored at 2°C for a maximum of 3 weeks before analysis. For each orchard, 5-15 lesions from different leaves were processed individually for fungicide resistance analysis. Using a micropipette, conidia were collected from each scab lesion in 50-100 µl distilled water and diluted to 500 µl in a sterile Eppendorf tube. Single droplets (17 µl) were placed on an agar plate containing a selective medium (see below), incubated for 24-30 h at 20°C, and evaluated for germ-tube growth with a light microscope at 100× final magnification. As described and illustrated by Weber *et al.* (2025), growth on fungicide-augmented agar was characterised as absent,

stalled at germination, reduced (<50%) or uninhibited (>50%) as compared to the fungicide-free control.

For characterising resistance to MBC fungicides, a stock solution of Cercobin FL<sup>®</sup> (BASF SE, Ludwigshafen, Germany) was added to cooling 1% (w/v) malt extract agar after autoclaving to give final thiophanate-methyl concentrations of 1 ppm and 50 ppm. For QoI resistance testing, a stock solution of Flint<sup>®</sup> (Bayer CropScience, Monheim, Germany) was added to give final concentrations of 0.1 ppm and 10 ppm trifloxystrobin. For this fungicide, the cooling malt extract agar was also augmented with 100 ppm salicyl hydroxamic acid (Carl Roth, Karlsruhe, Germany) in order to inhibit the activity of alternative oxidases which would otherwise obscure the test results (Weber & Hahn, 2011).

For the purposes of the present research, MBC resistance was defined as uninhibited growth at 1 ppm thiophanate-methyl, at which concentration sensitive isolates displayed characteristically coiled, shortened germ-tubes. QoI resistance was characterised by full growth at 0.1 and 10 ppm trifloxystrobin, whereas susceptible isolates showed no germination at 10 ppm and aborted or no germination at 0.1 ppm (Weber *et al.*, 2025).

The methods deployed in the 2025 survey were identical to those of previous surveys in 2014, 2021 and 2022 (Weber & Kruse, 2015; Weber, 2022; Weber *et al.*, 2025). Data from these previous surveys are used in the present article to place the 2025 data in the context of space and time.

For data analysis purposes, the Altes Land core area was considered to be delimited by the shore of the Elbe river to the north, the A26 motorway to the south, and the cities of Hamburg and Stade to the east and west, respectively (Fig. 2). Groups of non-commercial trees or old orchards were defined as abandoned when they were >15 years old and it was known or apparent that they had been free from any fungicide input for at least 10 years. These were scattered throughout the Altes Land area and the periphery.

## Results

In preliminary studies, *V. inaequalis* isolates with resistance to MBC and QoI fungicides had been absent or rare in abandoned orchards located in peripheral areas of the Lower Elbe region, whilst they had been ubiquitous and very frequent in orchards of a similar age and habit within the Altes Land. Large-scale surveys confirmed these initial observations in a striking manner. All available data from 2014 to 2025 are summarised in Fig. 2.

Focusing on the Altes Land in greater detail, each survey included comparisons between IPM orchards, organic orchards with conventional (i.e. highly scab-susceptible) cultivars, and others with scab-resistant (*Vf*) cultivars. Wherever possible, sampling included at least one conventional and one *Vf*-resistant cultivar from each organic farm. Comparing samples collected in 2021-2022 with those from 2025, certain developments over time become apparent (Fig. 3). In 2021-2022, nearly 100% of isolates from IPM orchards and 44% from conventional cultivars in organic orchards showed double MBC and QoI resistance, whereas the great majority (83%) of isolates from *Vf* cultivars were sensitive to both fungicides. By 2025, double-resistant isolates in organic farms had increased their share to 64% on conventional cultivars, and had also emerged on *Vf* cultivars (21%).

The full value of such data often becomes apparent only in retrospect, and unfortunately there was only one organic farm that was sampled in both surveys. This example (Fig. 4) illustrated the pattern described above. Notably, fungicide-resistant isolates were not detected in the *Vf* cultivar 'Dalinbel' in 2021, whereas four years later such isolates were readily found. Moreover, in the neighbouring 'Braeburn' orchard the share of isolates with double resistance had increased. The spectrum of resistances (MBC or MBC + QoI) was identical between isolates from the *Vf* and conventional cultivars.



in 2022 (Palm *et al.*, 2004; Weber *et al.*, 2025), even though, to the best of our knowledge, the tree had never been sprayed with these or any other fungicides before 2003, and never since.

The dimensions of space and time should be addressed. The double-resistance phenotype was present in all but one abandoned orchards in the Altes Land (77% of *V. inaequalis* isolates), but in only two sites in the periphery, including the solitary roadside tree in Winsen.

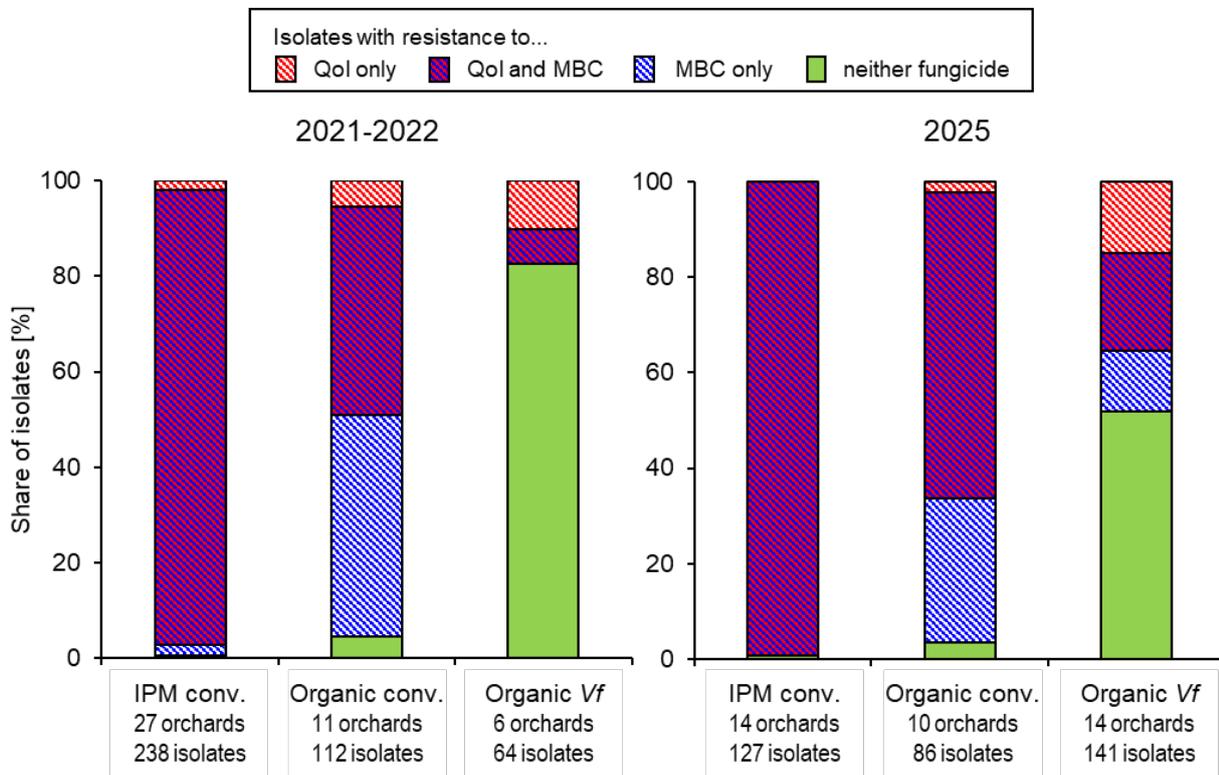


Figure 3: Shares of *Venturia inaequalis* isolates with QoI and/or MBC resistance in IPM orchards planted with conventional cultivars, and orchards under organic management with conventional or Vf cultivars. Data from the Altes Land are summarised for 2021-2022 (left) and 2025 (right).

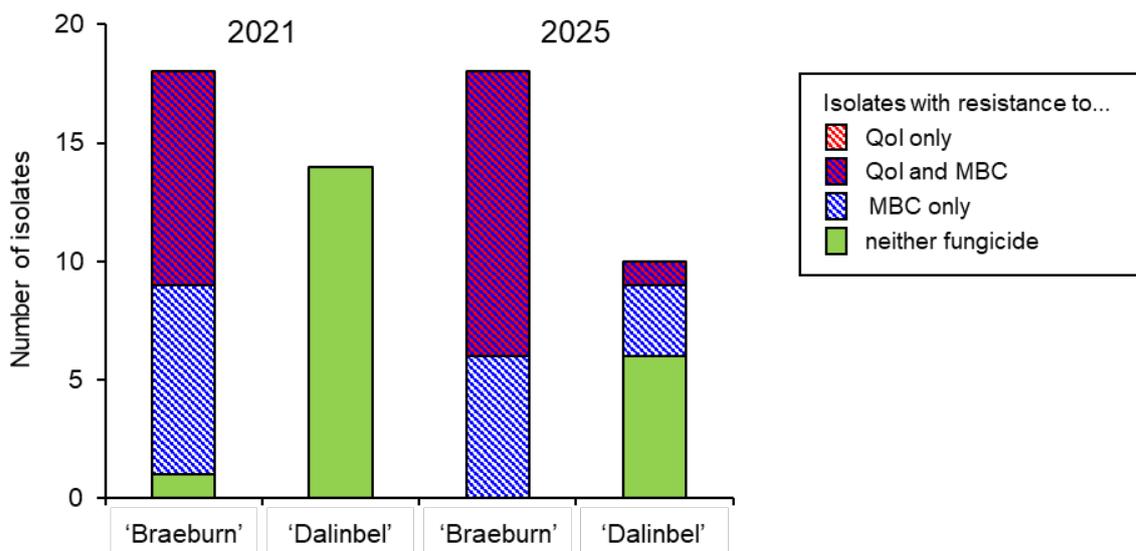


Figure 4: Occurrence of *Venturia inaequalis* isolates with resistance to MBC and QoI fungicides in an organic orchard located in the Altes Land, featuring the conventional cultivar 'Braeburn' and the Vf cultivar 'Dalinbel'. Data are given for separate samplings in 2021 and 2025.

Such a contrast between a near-saturation of the Altes Land and the near-absence outside indicates that the distance between neighbouring orchards in the periphery must be an effective barrier to genetic exchange in *V. inaequalis*. In other words: The close physical proximity of orchards in the Altes Land seems to permit a rapid mixing of genetic material within the population which does not happen outside where populations with local characteristics prevail.

Secondly, isolates capable of overcoming *Vf* resistance were initially sensitive to both fungicides, indicating that they had arisen under organic orchard management conditions where they were reproductively isolated. The appearance of MBC and QoI resistance in *Vf*-breaking strains, as observed in 2025, is interpreted as an indication of the onset of a genetic exchange. An alternative hypothesis – the immigration of *Vf*-breaking strains from IPM orchards – can be discounted because we have not yet seen any scab symptoms on *Vf* cultivars in IPM in the Altes Land or elsewhere in Northern Germany.

A rapid genetic exchange within the local *V. inaequalis* population bodes ill for future scab control strategies because it means that strains combining a resistance to current fungicides with the ability to break *Vf* resistance might arise. These would undermine the value of *Vf* cultivars to IPM. Further, a population capable of a dynamic evolutionary development might adapt to more subtle features of our apple cultivars such as field resistance. In this sense the scab susceptibility of cultivars such as ‘Topaz’ or ‘Santana’ after a large-scale *Vf* resistance breakthrough becomes a burning issue. Buchleither (2021) has examined this topic in the Lake Constance region, and we have also conducted a survey of the severity of scab on such cultivars in the wake of increasing cases of *Vf* breakage in the Lower Elbe region during the preceding 2-3 years (R. Weber, P. Heyne and N. Oeser, in preparation).

## References

- Buchleither, S. (2021). Schorf widerstandsfähige Apfelsorten. Anfälligkeit und mögliches Einsparpotenzial für fungizide Pflanzenschutzmaßnahmen. *Obstbau* **46**: 616-623.
- Busch, R. & Weber, R.W.S. (2025). Fungizidresistenzen und die Mobilität von *Venturia inaequalis* an der Niederelbe. *Mitteilungen des Obstbauversuchsrings des Alten Landes* **80**: 161-164.
- Frederick, Z.A., Villani, S.M., Cooley, D.R., Biggs, A.R., Raes, J.J. & Cox, K.D. (2014). Prevalence and stability of qualitative QoI resistance in populations of *Venturia inaequalis* in the northeastern United States. *Plant Disease* **98**: 1122-1230.
- MacHardy, W.E. (1996). *Apple Scab. Biology, Epidemiology, and Management*. St. Paul, USA: APS Press.
- McGee, D.C. & Zuck, M.G. (1981). Competition between benomyl-resistant and sensitive strains of *Venturia inaequalis* on apple seedlings. *Phytopathology* **71**: 529-532.
- Palm, G., Kuck, K.-H., Mehl, A. & Marr, J. (2004). Aktueller Stand der Strobilurin-Apfelschorf-Resistenz an der Niederelbe. *Mitteilungen des Obstbauversuchsrings des Alten Landes* **59**: 291-295.
- Weber, R.W.S. (2022). Status der Fungizidresistenz beim Apfelschorf (*Venturia inaequalis*) an der Niederelbe. *Mitteilungen des Obstbauversuchsrings des Alten Landes* **77**: 97-102.
- Weber, R.W.S. & Hahn, M. (2011). A rapid and simple method for determining fungicide resistance in *Botrytis*. *Journal of Plant Diseases and Protection* **118**: 17-25.
- Weber, R.W.S. & Heyne, P. (2024). Auswirkungen des Klimawandels auf den Apfelschorf (*Venturia inaequalis*). *Öko-Obstbau* **2/2024**: 4-7.
- Weber, R.W.S. & Kruse, P. (2015). Die Schorfjahre 2013 und 2014 an der Niederelbe. *Mitteilungen des Obstbauversuchsrings des Alten Landes* **70**: 110-123.
- Weber, R.W.S. & Kruse, P. (2025). Analyse der Apfelschorfsaison 2024. *Mitteilungen des Obstbauversuchsrings des Alten Landes* **80**: 65-81.
- Weber, R.W.S., Busch, R. & Wesche, J. (2025). Spatial and temporal aspects of fungicide resistance in *Venturia inaequalis* (apple scab) populations in Northern Germany. *MDPI BioTech* **14**: 44.