The contribution of ambient aerosols to 'wax degradation' and decreasing drought tolerance

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Background

The foliar accumulation of hygroscopic aerosols on leaves is a neglected factor of air pollution. Previous measurements had suggested, that spraying with salt aerosols caused the impression of 'wax degradation', and increased transpiration and minimum epidermal conductance (g_{min}) (Burkhardt and Pariyar, 2014; 2016).

Here, we addressed plant responses to aerosol reduction through exclusion of ambient aerosols.

SEM (beech)

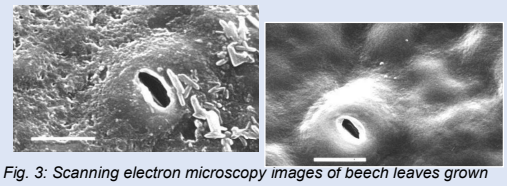

Fig. 3: Scanning electron microscopy images of beech leaves grown in unfiltered, ambient air (left) and filtered air (right). Deposited aerosols rather appear as crusts than as crystalline entities. ***Scales****: 10 µm.*

SEM (silver fir)

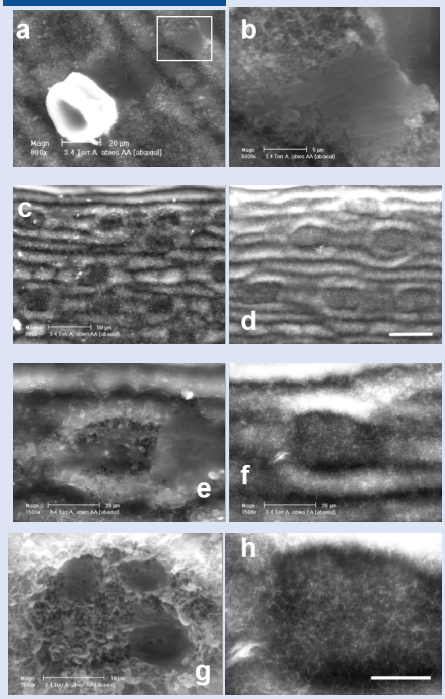

Figure 4: Scanning electron microscope images of surfaces of silver fir needles. (a): Large aerosol particle dissolving on the surface of an AA needle. The white rectangle marks the area detailed in (b). (c), (e) and (g): Surface of a representative AA needle, showing amorphous structures derived from aerosol deposition. (d), (f) and (h): Surface of a representative FA needle. ***Scales:*** *(a): 20µm; (b): 5µm; (c) and (d): 50µm; (e) and (f): 20µm; (g) and (h): 10µm*

Carbon isotopes

Table 1: Carbon isotope $\delta^{13}C$ values from fir needles of different ages (1-, 2 year old). Sample size $n = 10$. Values (mean ± SE), and statistical significance (p) values are shown.

	FA	AA	p
Fir year 1	−27.51 ± 0.22	−27.42 ± 0.19	0.745
Fir year 2	−27.46 ± 0.15	−26.98 ± 0.13	0.023

Figure 1: Pine seedlings in ventilated greenhouse. Filtered air (FA) or unfiltered, ambient air (AA) was introduced from the tubing in the rear and below the tables.

Figure 2: g_{min} determination of pine needles by drying curves

Conclusions

- Deposited, ambient aerosols caused the impression of 'degraded wax' in SEM images.
  The 'degraded wax' symptom was highly correlated with forest decline in the 1980s and 1990s.
- Ambient aerosols reduced g_{min}, which is an indicator of reduced drought tolerance.
- The co-occurrence of 'degraded wax' and reduced drought tolerance in AA plants suggests a common cause.
  The results support the 'hydraulic activation of stomata' hypothesis: Hygroscopic action of deposited aerosols makes stomata become leaky (Fig. 6).

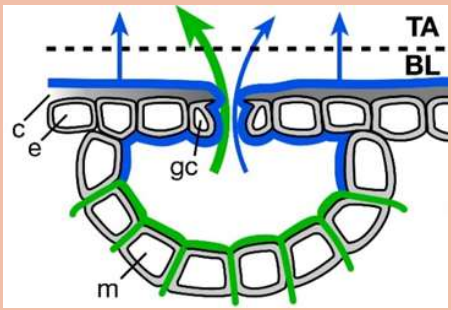

Fig. 6: „Hydraulic activation of stomata" (HAS) by thin water films (blue). The films are formed by deliquescent hygroscopic aerosols and subsequent salt creep into the stomata. Green: Situation without hydraulic activation. Guard cells (gc, mesophyll cells (m), cuticula (c), epidermal cells (e), leaf boundary layer (BL), turbulent atmosphere (TA).)

Burkhardt J. et al. (2018): Camouflaged as 'degraded wax': hygroscopic aerosols contribute to leaf desiccation, tree mortality, and forest decline. *Environmental Research Letters*, **13**(8):085001.

Burkhardt J. and Pariyar S.(2014): Particulate pollutants are capable to 'degrade' epicuticular waxes and to decrease the drought tolerance of Scots pine (Pinus sylvestris L.). *Environmental Pollution* **184**: 659-667.

Burkhardt J. and Pariyar D. (2016): How does the VPD response of isohydric and anisohydric plants depend on leaf surface particles? *Plant Biology* **18**: 91-100.

Methods

Scots pine, silver fir, common oak, and common beech seedlings were grown in greenhouses (Fig. 1), ventilated with ambient air (AA) and with filtered air (FA). Filtration reduced aerosol number to ~ 1% and aerosol mass on leaves and needles to ~ 10 %. Ozone and other trace gases were little affected by filtration (Burkhardt et al., 2018). AA and FA leaves and needles were studied using

- **Scanning electron microscopy (SEM)**
  Oak and beech leaves were unsputtered, pine and fir needles were gold-sputtered for observation
- **Minimum epidermal conductance (g_{min})**
  g_{min} was determined by leaf drying curves (Fig. 2).
- **Carbon isotopes ($\delta^{13}C$)**

SEM (Scots pine and oak)

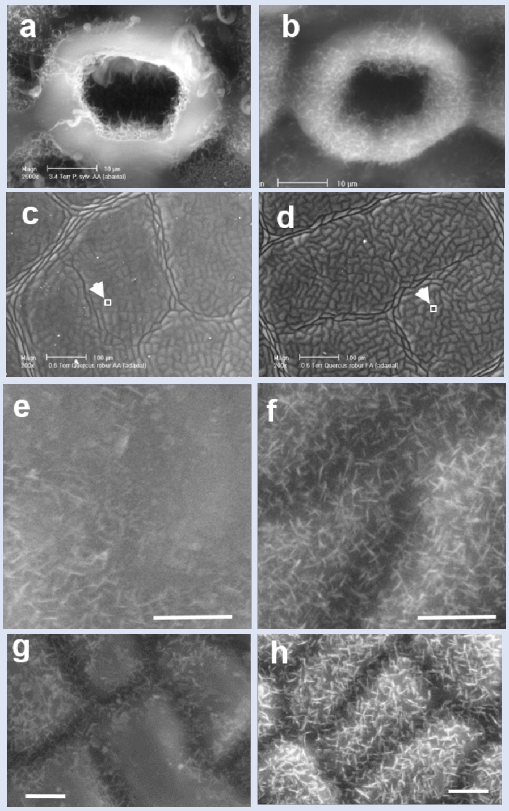

Figure 5.(a) and (b): Scanning electron microscope (SEM) images of surfaces of Scots pine needles. (a): AA, (b): FA. (c)–(h): Common oak leaves. (c) and (e): AA. (e): Detail of (c), indicated by white rectangle. (d) and (f): FA. (f): Detail of (d), indicated by white rectangle. (g): AA, additionally sprayed with Na-fluorescein aerosols of 0.5µm diameter; (h): FA. ***Scales****: (a), (b), (e)–(h): 10µm; (c) and (d):100µm.*

Minumum epidermal conductance

Table 2: Minimum epidermal conductance g_{min} (mmol m^{-2} s^{-1}) of one-year-old needles of fir and pine, and leaves of oak. Sample size (n) and statistical significance (p) values are shown.

	FA	AA	n	p
Fir	0.316 ± 0.015	0.388 ± 0.024	10	0.023
Pine	0.100 ± 0.011	0.130 ± 0.009	7	0.017
Oak	0.371 ± 0.017	0.475 ± 0.022	11	0.003