

Supplementary data

TABLE S1. The table summarises hypotheses on the association between grape disease occurrence and vineyard features, crop management, and grape variety features.

The table briefly introduces the tested hypotheses, the relevance in the infection of plant pathogens, the predicted directions of the main effect and the applied variables.

Tested variables	Tested hypotheses			Reference
	Main effect	Predicted direction or effect on variance	Short description and relevance with infection	
Vineyard features				
Slope of the plantation ('Inclination')	gradient variation in climatic and soil conditions	-	Vineyards are often established in sloping areas owing to favourable climatic conditions (e.g., air ventilation, solar radiation), which could modify (reduce) the infection severity.	van Leeuwen <i>et al.</i> (2004)
Row orientation ('Orientation')	prevailing wind direction	+	The row orientation could be linked to the prevailing wind direction, promoting air ventilation along the rows and increasing the spatial dispersion of the air-borne spores.	Mezősi (2017)
Ratio of the surrounding vineyards ('Surrounding vineyard')	amount of inoculum sources	+	Large-scale cultivation of crops facilitates the multiplication of culture-specific plant pathogens over a wider area.	Wolfe (2000)
Plantation age ('Age')	plant condition and infection status	+	The accumulation of endophytic parasites (i.e., viruses, trunk diseases) can increase over time. Such vines are more likely to be infected by other pathogens.	Kovács <i>et al.</i> (2017)
Height of the canopy wall ('Distance')	isolation distance from the soil surface (i.e., infection source)	-	Leaves closer to the soil surface are more exposed to the infection pressure by the pathogens overwintering on the fallen plant parts.	Rossi and Caffi (2012)
Counties of Hungary ('Region')	heterogeneous climatic and soil conditions	increase the variance	The traditional grape and wine-producing regions (i.e., terroir) are based on their environmental characteristics as a source of heterogeneity in pathogen infections among areas.	van Leeuwen <i>et al.</i> (2018)
Crop management				
Inter-row management: application of cover plants or organic materials ('Inter-row')	microclimatic conditions	+	Inter-row crops and organic mulch could favour the microclimatic conditions in grape production, reducing the infection severity.	Guerra and Steenwerth (2012)
Number of pesticide applications ('Treatments')	fungicide application	-	An increased level of chemical plant protection could effectively reduce the general occurrence and symptom severity of fungal pathogen infection.	Hahn (2014), Poole and Arnaudin (2014)
Removing the grape leaves from the cluster zone ('Leaf removal')	microclimatic conditions within the canopy, fungicide coverage	-	Opening the foliage in the cluster zone facilitates less optimal microclimatic conditions for the pathogen infection (i.e., shorter wetness duration and humidity reduction). This facilitates ideal coverage of the pesticide during treatment.	Evers <i>et al.</i> (2010), Romanazzi and Feliziani (2014)

TABLE S2. The table summarises the associations between *Botrytis cinerea* infection occurrence and plantation and crop management characteristics (Predictors) fitted by the Generalized Mixed Effect Model with a negative binomial error structure (GLMM-nb).

We report parameter estimates (β) with their standard errors (SE) and 95% Confidence Intervals (CI). Significant results are highlighted in bold. The asterisks indicate the level of significance of the given predictor (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Model statistics: $R^2(\text{fixed}) = 0.89$, $R^2(\text{total}) = 0.90$.

Predictor	β	CI (lower; upper)	SE	z-value	p-value
Intercept	-0.82	-2.46; 0.82	0.84	-0.98	0.328
Inclination	0.33	-0.17; 0.82	0.25	1.30	0.195
Orientation: N-S	1.14	-0.18; 2.46	0.67	1.69	0.092
Orientation: NE-SW	3.19	1.37; 5.01	0.93	3.44	0.001***
Orientation: E-W	1.56	0.15; 2.97	0.72	2.17	0.030*
Surrounding vineyards	0.63	0.08; 1.18	0.28	2.26	0.024*
Survey year	-0.51	-1.01; -0.01	0.26	-2.01	0.045*
Age	0.26	-0.24; 0.76	0.25	1.02	0.310
Distance	0.86	0.30; 1.43	0.29	3.00	0.003**
Inter-row: yes	0.43	-0.60; 1.47	0.53	0.82	0.410
Treatments	0.80	0.28; 1.31	0.26	3.01	0.003**
Leaf removal	-0.64	-1.64; 0.36	0.51	-1.26	0.208
Region: Baranya	0.35	-2.06; 2.75	1.23	0.28	0.778
Region: Borsod-Abaúj-Zemplén	1.56	-0.42; 3.55	1.01	1.54	0.123
Region: Budapest	-2.74	-6.07; 0.59	1.70	-1.61	0.107
Region: Csongrád	-30.41	-13778188.26; 13778127.43	7030000	0.00	1.000
Region: Fejér	0.37	-1.84; 2.58	1.13	0.33	0.745
Region: Győr-Moson-Sopron	-3.11	-6.57; 0.35	1.77	-1.76	0.078
Region: Heves	0.15	-1.64; 1.93	0.91	0.16	0.873
Region: Jász-Nagykun-Szolnok	-4.96	-49.04; 39.12	22.49	-0.22	0.825
Region: Komárom-Esztergom	-3.23	-6.75; 0.29	1.80	-1.80	0.072
Region: Nitra (Sk)	-6.59	-18.60; 5.41	6.13	-1.08	0.282
Region: Pest	1.32	-0.82; 3.47	1.10	1.21	0.228
Region: Somogy	1.21	-1.53; 3.96	1.40	0.87	0.386
Region: Szabolcs-Szatmár-Bereg	10.06	-60.08; 80.20	35.79	0.28	0.779
Region: Tolna	0.93	-1.11; 2.97	1.04	0.90	0.371
Region: Vas	-6.32	-13.98; 1.34	3.91	-1.62	0.106
Region: Veszprém	-0.34	-2.26; 1.57	0.98	-0.35	0.726
Region: Vojvodina (Srb)	-65.64	-131531022.12; 131530890.84	67110000	0.00	1.000
Region: Zala	5.96	-1.73; 13.65	3.92	1.52	0.129

TABLE S3. The table summarises the associations between *Plasmopara viticola* infection occurrence and plantation and crop management characteristics (Predictors) fitted by the Generalized Mixed Effect Model with a negative binomial error structure (GLMM-nb).

We report parameter estimates (β) with their standard errors (SE) and 95% Confidence Intervals (CI). Significant results are highlighted in bold. The asterisks indicate the level of significance of the given predictor (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Model statistics: $R^2(\text{fixed}) = 0.98$, $R^2(\text{total}) = 0.99$.

Predictor	β	CI (lower; upper)	SE	z-value	p-value
Intercept	2.14	0.18; 4.09	1.00	2.14	0.033
Inclination	0.53	0.07; 1.00	0.24	2.26	0.024*
Orientation: N-S	-0.90	-2.39; 0.60	0.76	-1.17	0.240
Orientation: NE-SW	1.33	-0.69; 3.35	1.03	1.29	0.197
Orientation: E-W	0.06	-1.55; 1.68	0.83	0.08	0.937
Surrounding vineyards	0.68	0.17; 1.20	0.26	2.63	0.009**
Survey year	-0.77	-1.30; -0.25	0.27	-2.90	0.004**
Age	-0.03	-0.46; 0.41	0.22	-0.12	0.904
Distance	0.27	-0.34; 0.88	0.31	0.88	0.381
Inter-row: yes	0.95	-0.02; 1.92	0.49	1.92	0.054
Treatments	-0.28	-0.74; 0.18	0.24	-1.18	0.237
Leaf removal	0.04	-0.93; 1.01	0.50	0.08	0.935
Region: Baranya	-2.07	-4.39; 0.26	1.19	-1.74	0.082
Region: Borsod-Abaúj-Zemplén	-1.98	-3.87; -0.10	0.96	-2.06	0.039*
Region: Budapest	-3.70	-6.94; -0.46	1.65	-2.24	0.025*
Region: Csongrád	50.84	-169805683.82; 169805785.49	86640000.00	0.00	1.000
Region: Fejér	72.19	-49713956.46; 49714100.85	25360000.00	0.00	1.000
Region: Győr-Moson-Sopron	-1.10	-4.19; 1.99	1.58	-0.70	0.486
Region: Heves	-1.11	-3.00; 0.79	0.97	-1.15	0.252
Region: Jász-Nagykun-Szolnok	37.36	-131530919.12; 131530993.85	67110000.00	0.00	1.000
Region: Komárom-Esztergom	-4.75	-8.37; -1.12	1.85	-2.57	0.010*
Region: Nitra (Sk)	-5.55	-10.80; -0.31	2.68	-2.07	0.038*
Region: Pest	0.88	-1.77; 3.52	1.35	0.65	0.516
Region: Somogy	-0.87	-3.45; 1.71	1.32	-0.66	0.510
Region: Szabolcs-Szatmár-Bereg	25.34	-502207.29; 502257.97	256200.00	0.00	1.000
Region: Tolna	-0.31	-2.63; 44958	1.18	-0.26	0.793
Region: Vas	-7.27	-15.37; 0.82	4.13	-1.76	0.078
Region: Veszprém	-1.83	-3.84; 0.17	1.02	-1.79	0.073
Region: Vojvodina (Srb)	6.09	-68.92; 29860	38.27	0.16	0.874
Region: Zala	-1.75	-4.42; 0.92	1.36	-1.29	0.198

TABLE S4. The table summarises the associations between *Erysiphe necator* infection occurrence and plantation and crop management characteristics (Predictors) fitted by the Generalized Mixed Effect Model with a negative binomial error structure (GLMM-nb).

We report parameter estimates (β) with their standard errors (SE) and 95% Confidence Intervals (CI). Significant results are highlighted in bold. The asterisks indicate the level of significance of the given predictor (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Model statistics: $R^2(\text{fixed}) = 0.87$, $R^2(\text{total}) = 0.87$.

Predictor	β	CI (lower; upper)	SE	z-value	p-value
Intercept	-0.08	-1.57; 1.41	0.76	-0.11	0.916
Inclination	0.25	-0.15; 0.65	0.20	1.21	0.227
Orientation: N-S	-0.36	-1.56; 0.83	0.61	-0.60	0.549
Orientation: NE-SW	1.07	-0.40; 2.54	0.75	1.42	0.155
Orientation: E-W	-0.49	-1.74; 0.77	0.64	-0.76	0.449
Surrounding vineyards	0.33	-0.09; 0.74	0.21	1.55	0.121
Survey year	-0.04	-0.42; 0.35	0.20	-0.20	0.843
Age	-0.08	-0.46; 0.30	0.19	-0.41	0.681
Distance	0.47	0.06; 0.87	0.21	2.26	0.024*
Inter-row: yes	0.34	-0.45; 1.13	0.40	0.83	0.404
Treatments	0.26	-0.11; 0.63	0.19	1.37	0.170
Leaf removal	0.77	-0.04; 1.58	0.41	1.87	0.061
Region: Baranya	-0.53	-2.55; 1.49	1.03	-0.52	0.604
Region: Borsod-Abaúj-Zemplén	-0.39	-1.93; 1.15	0.79	-0.49	0.622
Region: Budapest	-1.57	-4.43; 1.29	1.46	-1.07	0.283
Region: Csongrád	-17.67	-10939.16; 10903.82	5572.00	0.00	0.998
Region: Fejér	-1.16	-3.27; 0.96	1.08	-1.07	0.283
Region: Győr-Moson-Sopron	-0.89	-3.46; 1.69	1.31	-0.68	0.499
Region: Heves	0.83	-0.72; 2.38	0.79	1.05	0.293
Region: Jász-Nagykun-Szolnok	22.48	-125656.56; 125701.51	64120.00	0.00	1.000
Region: Komárom-Esztergom	18.28	-12387.82; 12424.39	6330.00	0.00	0.998
Region: Nitra (Sk)	-3.62	-9.93; 2.69	3.22	-1.13	0.261
Region: Pest	0.47	-1.21; 2.15	0.86	0.55	0.585
Region: Somogy	-1.09	-3.32; 1.14	1.14	-0.95	0.340
Region: Szabolcs-Szatmár-Bereg	24.68	-145453.09; 145502.45	74220.00	0.00	1.000
Region: Tolna	0.71	-1.14; 2.57	0.95	0.75	0.452
Region: Vas	-5.38	-19.44; 8.68	7.17	-0.75	0.453
Region: Veszprém	-0.76	-2.35; 0.83	0.81	-0.94	0.350
Region: Vojvodina (Srb)	41.54	-131530914.94; 131530998.03	67110000.00	0.00	1.000
Region: Zala	0.21	-2.15; 2.58	1.21	0.18	0.860

TABLE S5. The table details the fitted General Linear Model summary to test the association (highlighted in bold) of the infection occurrence and the grape variety-specific characteristics (Predictor).

The statistical tests were run separately in each pathogen (*Botrytis cinerea*, *Plasmopara viticola*, *Erysiphe necator*). In *Botrytis cinerea*, we run two models based on the complete database (including all grape varieties) and the reduced database (excluding the noble-rot varieties). We report parameter estimates (β) with their standard errors (SE) and 95% confidence intervals (CI). Significant results are highlighted in bold. The asterisks indicate the level of significance of the given predictor (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Predictor	β	CI (lower; upper)	SE	t-value	p-value
<i>Botrytis cinerea</i> (Complete database)					
Intercept	0.24	0.09; 0.38	0.07	3.53	0.003**
Susceptibility	0.05	0.00; 0.09	0.02	2.32	0.036*
Ripening	0.09	0.05; 0.13	0.02	4.87	<0.001***
Bunch compactness	-0.05	-0.10; -0.01	0.02	-2.38	0.032*
Berry skin thickness	0.08	0.04; 0.12	0.02	3.96	0.001**
Berry colour: noir	-0.18	-0.28; -0.08	0.05	-4.02	0.001**
Berry colour: rouge	0.02	-0.25; 0.28	0.12	0.13	0.902
Utilisation: wine	0.09	-0.06; 0.24	0.07	1.27	0.224
<i>Botrytis cinerea</i> (Reduced database)					
Intercept	0.15	-0.09; 0.39	0.11	1.40	0.188
Susceptibility	0.04	-0.02; 0.10	0.03	1.42	0.184
Ripening	0.07	0.00; 0.14	0.03	2.32	0.041*
Bunch compactness	-0.04	-0.13; 0.05	0.04	-1.07	0.307
Berry skin thickness	0.08	0.02; 0.14	0.03	2.84	0.016*
Berry colour: noir	-0.18	-0.32; -0.05	0.06	-3.10	0.010*
Berry colour: rouge	-0.01	-0.32; 0.30	0.14	-0.05	0.958
Utilisation: wine	0.15	-0.12; 0.41	0.12	1.23	0.243
<i>Plasmopara viticola</i>					
Intercept	0.25	0.05; 0.44	0.09	2.75	0.016
Susceptibility	0.02	-0.04; 0.09	0.03	0.72	0.484
Ripening	-0.01	-0.06; 0.05	0.02	-0.29	0.776
Bunch compactness	0.02	-0.04; 0.08	0.03	0.82	0.426

Berry skin thickness	0.03	-0.02; 0.08	0.02	1.29	0.217
Berry colour: noir	-0.03	-0.14; 0.09	0.05	-0.53	0.606
Berry colour: rouge	0.07	-0.27; 0.40	0.16	0.42	0.682
Utilisation: wine	0.02	-0.18; 0.23	0.10	0.24	0.812
<i>Erysiphe necator</i>					
Intercept	0.32	0.16; 0.48	0.07	4.29	0.001
Susceptibility	0.01	-0.10; 0.11	0.05	0.14	0.893
Ripening	0.01	-0.03; 0.05	0.02	0.55	0.589
Bunch compactness	0.03	-0.03; 0.08	0.03	1.07	0.302
Berry skin thickness	0.02	-0.03; 0.07	0.02	0.84	0.416
Berry colour: noir	-0.04	-0.14; 0.07	0.05	-0.75	0.465
Berry colour: rouge	0.04	-0.47; 0.54	0.24	0.15	0.883
Utilisation: wine	-0.01	-0.19; 0.17	0.08	-0.15	0.883

TABLE S6. The table summarises the formal grape variety name based on the VIVC database, the reference variety number and the common name used in Hungarian.

VIVC name	VIVC number	Hungarian name
Bianca	1321	Bianka
Blauburger	1457	Blauburger
Cabernet franc	1927	Cabernet franc
Chardonnay	2455	Chardonnay
Cserszegi fueszeres	3277	Cserszegi fűszeres
Furmint	4292	Furmint
Harslevelu	5314	Hárslevelű
Irsai oliver	5557	Irsai Olivér
Kekfrankos	1459	Kékfrankos
Kiralyleanyka	4121	Királyleaányka
Olasz rizling	13217	Olaszrizling
Othello	8838	Othello
Sarga muskotaly	8193	Sárgamuskotály
Sauvignon blanc	10790	Sauvignon blanc
Szurkebarat	9275	Szürkebarát
Zalagyoenye	13374	Zalagyöngye
Zweigelt	13484	Zweigelt
Cabernet sauvignon	1929	Cabernet sauvignon
Merlot	7657	Merlot
Ottonel muscotaly	8243	Ottonel muskotály
Zoeld veltelini	12930	Zöld veltelini
Rajnai rizling	0077	Rajnai rizling

SUPPLEMENTARY DATA

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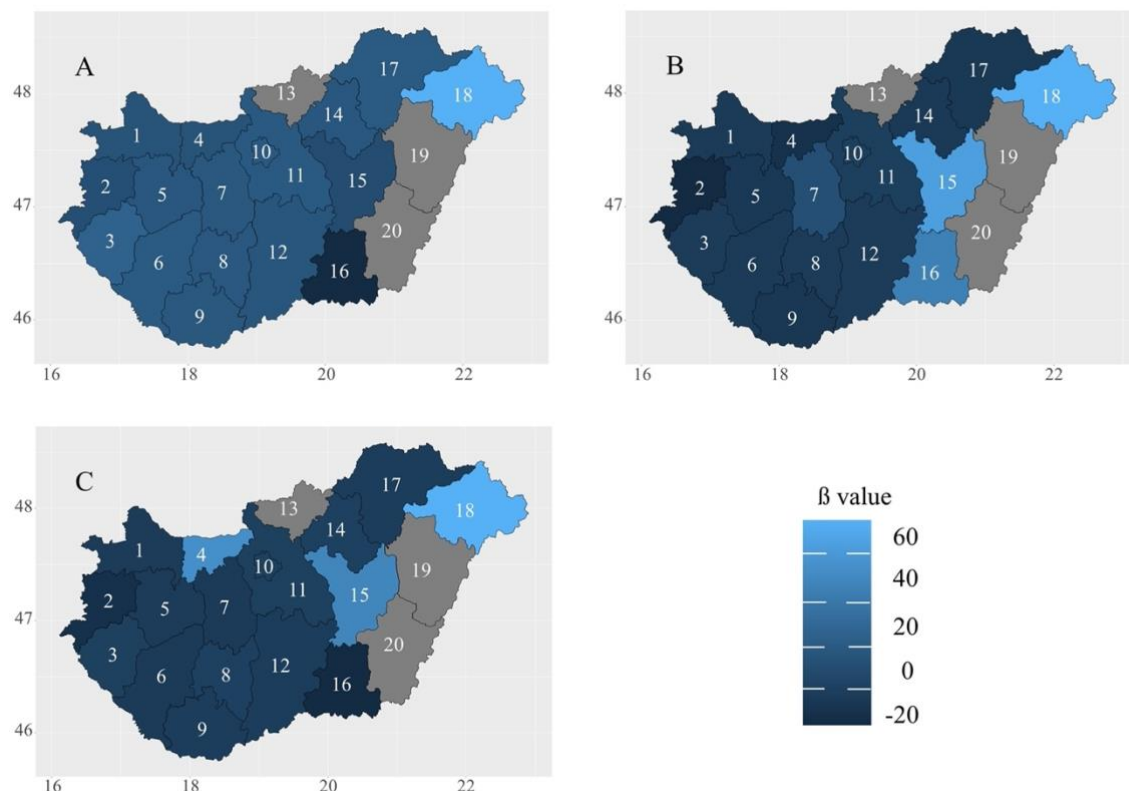


FIGURE S1. The figures show the model estimates (β) in each Hungarian county ('Region'), reflecting the spatial variation among regions in the grape diseases' occurrence, such as *Botrytis cinerea* (A), *Plasmopara viticola* (B) and *Erysiphe necator* (C).

The x and y axes represent the longitude and latitude coordinate scales, respectively. The numbers indicate the following counties: 1: Győr-Moson-Sopron, 2: Vas, 3: Zala, 4: Komárom-Esztergom, 5: Veszprém, 6: Somogy, 7: Fejér, 8: Tolna, 9: Baranya, 10: Budapest, 11: Pest, 12: Bács-Kiskun, 13: Nógrád, 14: Heves, 15: Jász-Nagykun-Szolnok, 16: Csongrád, 17: Borsod-Abaúj-Zemplén, 18: Szabolcs-Szatmár-Bereg, 19: Hajdú-Bihar, 20: Békés. A lighter blue shade indicates higher model estimates (i.e., more likely disease occurrence), while a darker blue shade reflects lower ones (i.e., less likely disease occurrence). The grey colour reflects Counties without relevant information due to a lack of observations. These spatial differences may suggest a possible role of large-scale background mechanisms and their variations related to the macroclimatic, topographic and soil conditions.

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