

Article

Varietal Response to Sour Bunch Rot in Polish Grapevine Genetic Resources

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Abstract: The aim of this study was to assess the resistance to sour rot of twenty-eight valuable cultivars of grapevine for wine production and twenty-five cultivars of table grapevine with diverse geographic and genetic origins, and to explain the causes of varied resistance based on the features related to the morphology, biology and ecology of assessed genotypes. The study was conducted for six years in the grapevine field collection of the National Institute of Horticultural Research in Skierniewice (Poland, latitude 51.9627 N, longitude 20.1666 E). Sour rot was severe in three seasons with abundant rainfall during the berry ripening stage. The number of wine and table cultivars in particular classes of resistance (mean value for three years) was as follows: very little or little—9 (wine) and 9 (table), medium—9 (wine) and 3 (table), high or very high—10 (wine) and 13 (table). The severity of bunch sour rot was positively correlated with single berry weight (moderate or weak correlation), bunch density and single bunch weight (very weak or weak correlation), and negatively correlated with thickness of berry skin (strong correlation) and the time of the beginning of veraison (weak correlation). Cultivars that were characterized by such agrobiological and ecological features as easy detachment of the berry from the pedicel, sensitivity to berry skin cracking, frequent damage to the skin by insects, and sensitivity to sunburn, were more heavily exposed to sour rot.



Citation: Lisek, J.; Lisek, A. Varietal Response to Sour Bunch Rot in Polish Grapevine Genetic Resources.

Agronomy **2021**, *11*, 1537. <https://doi.org/10.3390/agronomy11081537>

Academic Editors: Nikolaos Nikoloudakis and Iakovos Pantelides

Received: 17 June 2021

Accepted: 29 July 2021

Published: 31 July 2021

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Keywords: assessment; central europe; cluster; collection; field; resistance; rotting; *Vitis* spp.

1. Introduction

Climate change is widening the grapevine-growing zone in Europe and North America further north, compared to traditional wine-growing regions [1,2]. The area above latitude 50° N is described in viticulture as the cool climate zone. Poland, located in Central Europe, belongs to this zone. The vines are threatened by unfavorable climatic conditions—a relatively short frost-free period, low winter temperatures, frosts during the growing season, extreme weather phenomena (hail, prolonged rain, heat) and harmful organisms, including plant pathogens and pests. The assessment of genetic resources has shown that over the past decades, the frequency of grapevine infection by sour rot has increased in Poland.

Berries infected with sour rot turn pinky-brown in white varieties and purple-brown in red varieties [3]. Sour rot is a wet-type rot. The pulp is leaks from infected berries, which remain hollow, and some berries detach from the pedicel [4]. It is distinguished from other types of rot by the distinct smell of vinegar or acetone emitted by the infected fruit and the absence of fungal spores (the gray, velvety fuzz in the case of *Botrytis cinerea*) on the surface of the berries. Although in later stages it may be associated with rot caused by fungi, double (secondary) infection of sour rot and botrytis are rarely observed together [5,6]. Sour rot causes a spike in volatile acidity, which can lead to off-tasting wine [7,8]. Sour rot is caused by yeasts, acetic acid bacteria and *Drosophila* sp. flies [3,6,9–11]. Various species of yeast have been identified on the grapevine berries affected by sour rot (*Hanseniaspora uvarum*, *Aureobasidium pullulans*, *Rhodotorula*, *Cryptococcus*, *Metschnikowia*, *Pichia*, *Zygosaccharomyces* genus [12–15] among others), as well as acetic acid bacteria from *Acetobacter* spp. and

Gluconobacter spp. [16,17]. *Drosophila melanogaster* is always associated with sour rot [3,4,9] and is an important vector of the disease [6,7,11,17]. The yeasts and bacteria associated with sour rot cannot penetrate intact skin and must come in contact with the pulp through wounds [3,7,10]. Sour rot also begins at the place where the berry is attached to the pedicel [3]. Skin damage is caused by biotic factors, including fungal pathogens such as *Botrytis cinerea* [9] and *Erisiphe necator* [18]; birds and insects, including berry moths, honey bees, wasps [5–7,11], *Drosophila suzukii* [19] and abiotic factors, including hail, sunburn, water stress, and wet weather, all of which lead to microfissures and cracking of berry skin [3,16].

Berries become highly susceptible to infections when the extract reaches 15°Brix. Sour rot develops rapidly and severely at temperatures between 20 and 25 °C, moderately at 15 to 20 °C, and barely develops at temperature of 10 to 15 °C [5]. Sour rot incidence and severity in *V. vinifera* cv. ‘Riesling’ increased with mean air temperature and with total rainfall during the period of ripening, between veraison and harvest [17]. This disease is particularly widespread in wet, humid areas such as the Ontario region in Canada [17] and the Eastern United States [20].

Varietal differences in susceptibility of grapes to bunch rots may arise from either morphological, anatomical or physiological sources. The mechanism of resistance has been studied mainly in the rotting of clusters caused by fungal pathogens. Resistance to *Rhizopus stolonifer*, one of the pathogens causing grape rot, is related to the thickness of the skin, which depends on the number of cell layers and cell density in the epidermis and hypodermis; the angle formed between the fruit and the pedicel; and tannin and phytoalexin content [21]. Resistance to *Botrytis cinerea*, which causes causing gray mold, depends on the density of berries within a cluster, number of pores and lenticels on the berry surface, thickness and number of cell layers in the epidermis and external hypodermis; amount of cuticle and wax, berry skin protein content, total phenolic content of the skin before and after *B. cinerea* inoculation, and catechin and *trans*- and *cis*-resveratrol contents [22]. The degree of sensitivity to gray mold is related to the architecture of the bunch, where tight clusters are more affected than loose ones. They are determined by the following characteristics, ranked in order of importance: weight of clusters, the ratio of interior to exterior berries, and the number of berries per centimeter of rachis [23]. One of the 14 clones of cultivar Albariño that were studied, with the shortest pedicels and the smallest berries, was clearly more resistant to *B. cinerea* [24].

Thin-skinned, tight-clustered cultivars, such as ‘Riesling’ [5,25], ‘Baco Noir’, ‘Pinot Noir’, ‘Pinot Gris’, ‘Gamay’ and ‘Gewürztraminer’ [5] are considered particularly susceptible to sour rot. Hybrid cultivars ‘Seyval’, ‘Valvin Muscat’, ‘Traminette’, and ‘Chardonnay’ are also known to be susceptible [26]. Field observations of ‘Chardonnay’, classified as sensitive [5], suggest that clones can vary in their susceptibility to sour rot, possibly related to cluster morphology [20]. Thin-skinned, tightly packed cultivars such as ‘Vignoles’, ‘Sauvignon blanc’, ‘Blanc du Bois’, ‘Muscat Ottonel’, and ‘Vidal Blanc’ have been observed to be more susceptible to sour rot compared to cultivars that are thick skinned and loose clustered like *vinifera* cultivars ‘Petit Manseng’, ‘Petit Verdot’ and ‘Cabernet Sauvignon’ and hybrid cultivars ‘Chambourcin’, ‘Chardonnay’, ‘Norton’ and ‘Lomanto’ [20].

The aim of the present research was to assess the resistance to sour rot of newly introduced and traditionally grown wine and table cultivars and to verify data on the resistance of commonly grown cultivars, obtained in other, distant viticulture regions. Due to different ecological conditions in different growing regions, an important aspect of the research was to establish relations in the level of resistance between cultivars, including reference cultivar, as which can be considered ‘Pinot Noir’ and ‘Riesling’, both defined as sensitive to sour rot. The purpose of the research was to obtain results useful in practical recommendations for grapevine growers regarding the choice of varieties for planting and to explain the reasons of varied resistance to sour rot based on features related to the morphology, biology and ecology of assessed genotypes.

2. Materials and Methods

2.1. Site, Grapevines and Cultivars Characteristics

The assessment of bunch sour rot was carried out in years 2015–2020 in the grapevine field collection of the National Institute of Horticultural Research in Skierniewice (Poland, latitude 51.9627° N, longitude 20.1666° E), located on a luvisol soil, which was slightly acidic (pH 6.3) and containing 1.3% of organic matter. Each genotype under research was represented by three, at least 5 years old (in 2015) vines, planted at the spacing of 2.5×1 m and maintained in the form of a low head with a trunk 0.15–0.2 m high and 3–5 spurs pruned into 2–3 buds (6–10 young shoots per vine). In July, young shoots were pruned above the 10th–12th leaf past the last cluster of grapes. Lateral shoots were removed or shortened regularly. Fertilization and plant protection were carried out according to current recommendations for commercial vineyards. Mineral fertilization was carried out with ‘Azofoska’, a multi-component fertilizer containing macronutrients N, P, K, Mg and micronutrients Cu, Zn, Mn, B, Mo; and triple superphosphate (P); this was applied in spring, at the beginning of April. Half of the necessary nitrogen dose was applied in the first half of June in the form of calcium nitrate. The annual dose of macronutrients was N: 40 kg ha⁻¹, P: 30 kg ha⁻¹, K: 100 kg ha⁻¹. Chemical protection against fungal diseases was carried out with the use of fungicides containing active ingredients belonging to different chemical groups and with a different mode of action: copper, sulphur (2 treatments per season by each agent), mancozeb+metalaxyl, pyraclostrobin+boscalid, cyprodynil+fludioxonil and penconazole (optionally, 1–2 treatments per season by product, depending on the weather). No insecticides limiting insects, including *Drosophila* flies, or antimicrobials limiting yeasts and acetic acid bacteria were used in the collection. Vines were covered for winter (December) with cereal straw (mounds of 0.4 m). Sour rot severity was assessed in years characterized by weather conditions in the period June–October, specified in the Table 1.

Table 1. Climatic conditions in Skierniewice in the period June–October.

Year	Average Monthly Air Temperature at the Height of 2.0 m (°C)					Monthly Sum of Rainfall (mm)				
	Jun	Jul	Aug	Sept	Oct	Jun	Jul	Aug	Sept	Oct
2015	16.4	19.2	21.3	14.6	6.8	40.0	45.4	4.2	2.8	64.4
2016	18.2	18.7	17.9	14.9	7.1	150.9	103.8	0.2	0.8	32.6
2017	17.5	18.2	18.9	13.3	9.6	149.8	51.8	71.8	249.4	77.6
2018	18.2	20.1	19.9	14.9	9.5	39.4	118.8	60.6	76.0	0.4
2019	21.6	18.2	19.7	13.8	10.2	46.2	55.4	77.8	82.8	21.6
2020	17.9	18.2	19.1	14.4	9.9	105.2	0.0	0.0	0.0	127.6
Average 1991–2010	16.8	19.2	18.2	13.9	8.2	67.3	68.2	54.2	46.5	37.6

Twenty-eight valuable cultivars of grapevine for wine production and twenty-five cultivars of table grapevine with diverse geographic and genetic origins and different resistances to bunch sour rot were selected for the presentation of the study results out of the overall 350 genotypes represented in the collection. From among wine cultivars, eleven belonged to *Vitis vinifera*, three to interspecific hybrids and fourteen to inter-intraspecific hybrids. Inter-intraspecific (intra-interspecific) hybrids were isolated into a separate group [27] or classified as *Vitis vinifera* cultivars [28]. Table cultivars belonged to interspecific hybrids, except for one—‘Chasselas Dore’, classified as *V. vinifera*. Information on wine and table cultivars, such as origin and skin colour of the berries, is given in Tables 2 and 3, which also contain the results of the study.

2.2. Assessment of Infestation and Cultivar Features

The results from the three years when sour rot caused severe bunch injuries were analyzed in detail. In years with severe rot, three grape samples (each with at least ten

bunches representative of the cultivar) were taken from each of the plots (cultivars), from the three plants being assessed. Degree of infestation by sour rot, expressed as percentage of cluster area with sour rot, was estimated on all bunches, at full maturity of the berries. To determine the level of infestation, the ratio of the number of external infested berries to the total number of external berries in the cluster was calculated. Cultivar resistance was evaluated using percentage of cluster area with sour rot, obtained in present study, and an adapted, 9-point scale published in the OIV Descriptor List, characteristic 459, which was originally used to describe bunch resistance to *Botrytis* [29]. Cultivars were divided into classes, where values characterize resistance to bunch sour rot, on a scale of 1–9, as given below:

- very little and little resistance (1–4 = many wilted or rotten berries on all clusters, all clusters are attacked, some of them can be slightly affected);
- medium (5–6 = large percentage of wilted or rotten clusters (up to 20%)—most clusters are moderately attacked, only a few clusters are attacked more severely);
- high and very high (7–9 = only a few wilted or rotten berries on all clusters, only single clusters are slightly attacked).

During the research, selected features related to the morphology, phenology and ecology of the grapevine cultivars were evaluated, which, according to the literature data, may affect the degree of sour rot infestation. Five features were assessed according to the OIV Descriptor List (called further OIV) on 9-point scales [29]:

- density of bunch (OIV, character 204)—1 (very loose) = berries clearly separated, many visible pedicels; 3 (loose) = berries in loose contact with each other with some visible pedicels; 5 (medium) = densely distributed berries, pedicels not visible, berries are movable; 7 (dense) = berries not readily movable; 9 (very dense) = berries deformed by compression;
- thickness of berry skin (OIV, character 228)—1 (very thin); 3 (thin); 5 (medium); 7 (thick); 9 (very thick). The evaluation was carried out in relation to reference cultivars;
- time of beginning of berry ripening (veraison) (OIV, character 303)—1 (very early); 3 (early); 5 (medium); 7 (late); 9 (very late);
- single bunch weight (OIV, character 502) 1 (very low) = up to about 100 g; 3 (low); 5 (medium) = about 500 g; 7 (high); 9 (very high) = about 900 g and more;
- single berry weight (OIV, character 503)—1 (very low) = up to about 1 g; 3 (low); 5 (medium) = about 5 g; 7 (high); 9 (very high) = about 9 g and more.

Density of bunch, thickness of berry skin, single bunch weight and single berry weight were assessed at maturity. The time of the beginning of veraison for each cultivar was considered to be reached when about 50% of the plants reached this stage. During the berry ripening stage (veraison–maturity), additional features of berries were also assessed, such as: easy detachment of the berry from pedicel or berry drop, sensitivity to skin cracking, frequent insect damages, and sensitivity to sunburn. These traits were attributed to cultivars if they occurred at least twice in the 2017–2019 period, when the sour rot was severe.

2.3. Statistical Analysis

Data concerning infestation by sour rot, expressed as percentage of cluster area with sour rot, were analyzed statistically with the use of the variance analysis method which was applied to the values after Bliss' transformation. The significance of the means was evaluated using Student's *t*-test at the 5% level. The correlation between infestation by sour rot, expressed as percentage of cluster area with sour rot and selected varietal traits (density of bunch, thickness of berry skin, time of beginning of veraison, single bunch weight, single berry weight), expressed as numbers from 1 to 9, was assessed through the Pearson's linear correlation coefficient (*r*). The strength of Pearson's linear correlation coefficient was rated as follows: $|r|$: 0.0–0.2—very weak; 0.2–0.4—weak; 0.4–0.6—moderate; 0.6–0.8—strong; 0.8–1—very strong.

3. Results

In 2017, 2018 and 2019, the infestation by sour rot was assessed as severe. In the remaining seasons (2015, 2016 and 2020), the infestation was marginal or absent and the data relating to these years were not included in the presentation of the results. The mean infestation of bunches from the three selected years, together with the standard deviation, are presented separately for wine (Table 2) and table (Table 3) cultivars. The severity of infestation, expressed as a percentage of cluster area with sour rot, was used to divide the varieties according to the resistance class to sour rot. Among 28 wine cultivars, the number of cultivars in particular classes of resistance was as follows: very little or little—9, medium—9, high or very high—10. The cultivar ‘Siegerrebe’ was characterized by a very little resistance, and the cultivars ‘Phoenix’, ‘Pinot Noir’, ‘Silvaner’, ‘Riesling’, ‘Calandro’, ‘Seyval’, ‘Reberger’, ‘Veltliner Frührot’, by a little resistance. The wine cultivars with very high resistance were ‘Bianca’, ‘Regent’, ‘Prior’, ‘Souvignier Gris’, ‘Marechal Foch’, and ‘Cabernet Cantor’. Among 25 table cultivars, the number of cultivars in particular classes of resistance was as follows: very little or little—9, medium—3, high or very high—13. ‘Rusven’, ‘Piesnia’, and ‘Krasotka’ belonged to table cultivars with very low resistance, whereas ‘Festivee’, ‘Alden’, and ‘NY Muscat’ belonged to cultivars with very high resistance.

Table 2. Severity of infestation and resistance of wine cultivars to sour bunch rot.

Cultivar	Colour of Berry Skin *	Origin **	Country of Breeding	Mean Severity of Sour Rot—Cluster Area with Sour Rot (%)	Class of Resistance to Bunch Sour Rot ***
Siegerrebe	R	Vin	Germany	53.0 ± 8.54 t ¹	VL (1)
Phoenix	B	IIH	Germany	40.6 ± 9.61 s	L (2)
Pinot Noir	N	Vin	France	31.2 ± 7.57 r	L (3)
Silvaner	B	Vin	Austria	28.2 ± 6.81 qr	L (3)
Riesling	B	Vin	Germany	25.2 ± 5.13 pq	L (3)
Calandro	N	IIH	Germany	23.5 ± 5.03 op	L (4)
Seyval	B	IH	France	22.2 ± 5.13 n-p	L (4)
Reberger	N	IIH	Germany	21.2 ± 5.69 m-o	L (4)
Veltliner Frührot	R	Vin	Austria	20.4 ± 6.43 l-o	L (4)
Domina	N	Vin	Germany	19.8 ± 5.00 l-n	M (5)
Pinot Blanc	B	Vin	France	18.6 ± 3.51 lm	M (5)
Villaris	B	IIH	Germany	17.3 ± 5.57 kl	M (5)
Tauberscharz	N	Vin	Germany	17.2 ± 3.06 kl	M (5)
Cabernet Cortis	N	IIH	Germany	15.4 ± 5.03 jk	M (5)
Solaris	B	IIH	Germany	14.7 ± 5.57 i-k	M (6)
Rondo	N	IIH	Germany	13.2 ± 4.16 h-j	M (6)
Johanniter	B	IIH	Germany	12.1 ± 4.58 hi	M (6)
Pinot Gris	R	Vin	France	11.5 ± 4.04 gh	M (6)
Pinot Meunier	N	Vin	France	9.5 ± 3.06 fg	H (7)
Hibernal	B	IIH	Germany	8.8 ± 3.00 f	H (7)
Felicia	B	IIH	Germany	4.6 ± 1.53 e	H (7)
Traminer Rot	R	Vin	France	2.9 ± 1.00 d	H (7)
Bianca	B	IH	Hungary	1.9 ± 1.00 cd	VH (8)
Regent	N	IIH	Germany	1.5 ± 1.15 c	VH (8)
Prior	N	IIH	Germany	0.4 ± 0.58 b	VH (8)
Souvignier Gris	R	IIH	Germany	0.1 ± 0.58 ab	VH (8)
Marechal Foch	N	IH	France	0.1 ± 0.58 ab	VH (8)
Cabernet Cantor	N	IIH	Germany	0.0 ± 0.00 a	VH (9)

¹ Means followed by the same letter do not differ significantly at $p = 0.05$. Values with the prefix \pm represent standard deviation. * Colour of berry skin: B (blanc)—green-yellow, R—rose, N (noir)—blue-black. ** Origin: Vin—*V. vinifera*; IH—interspecific hybrid from crossing *V. vinifera* and species from among *V. riparia*, *V. rupestris*, *V. lincecumii*, *V. amurensis*, *V. labrusca*; IIH—inter-intraspecific (intra- interspecific) hybrid from crossing interspecific hybrid and *V. vinifera*. *** Class of bunch sour rot resistance, with values on a scale of 1–9 in the brackets: VL—very little and L—little (1–4 = many wilted or rotten berries on all clusters (all clusters are attacked, some of them can be slightly affected); M—medium (5–6 = large percentage of wilted or rotten clusters (up to 20%)—most clusters are moderately attacked, only few clusters are attacked more severely); H—high and VH—very high (7–9 = only a few wilted or rotten berries on all clusters, only single clusters are slightly attacked).

Table 3. Severity of infestation and resistance of table cultivars to sour bunch rot.

Cultivar	Colour of Berry Skin *	Origin **	Country of Breeding	Mean Severity of Sour Rot—Cluster Area with Sour Rot (%)	Class of Sour Rot Resistance ***
Rusven	B	IH	Russia	62.2 ±10.5 n ¹	VL (1)
Piesnia	B	IH	Russia	55.8 ±13.0 mn	VL (1)
Krasotka	R	IH	Russia	54.1 ±9.54 lm	VL (1)
Argo	R	IH	Ukraine	49.7 ±11.6 lm	L (2)
Galbena Nou	B	IH	Russia	48.0 ±10.4 l	L (2)
Reliance	R	IH	USA	39.6 ±8.62 k	L (3)
Galanth	N	IH	Germany	37.9 ±9.17 k	L (3)
Aron	B	IH	Hungary	26.2 ±11.6 j	L (3)
Evita	B	IH	Austria	22.8 ±7.00 ij	L (4)
Sophie	B	IH	Hungary	19.5 ±5.03 hi	M (5)
Garantos	B	IH	Germany	16.5 ±4.51 gh	M (5)
Antracyt	N	IH	Russia	12.3 ±2.52 fg	M (6)
Palatina	B	IH	Hungary	9.9 ±1.53 f	H (7)
Nero	N	IH	Hungary	8.6 ±2.08 ef	H (7)
Arkadia	B	IH	Ukraine	8.3 ±1.53 ef	H (7)
Price	N	IH	USA	5.6 ±1.53 de	H (7)
Muscat Bleu	N	IH	Switzerland	4.9 ±1.00 cd	H (7)
Vostorg	B	IH	Russia	4.6 ±1.53 cd	H (7)
Jupiter	R-N	IH	USA	3.6 ±1.53 b-d	H (7)
Chasselas Dore	B	Vin	France	3.3 ±0.58 b-d	H (7)
Suzi	B	IH	Hungary	2.9 ±1.00 bc	H (7)
Somerset Sdl	R	IH	USA	2.6 ±1.15 bc	H (7)
Festivee	N	IH	Canada	1.5 ±1.15 b	VH (8)
Alden	N	IH	USA	0.2 ±1.15 a	VH (9)
NY Muscat	R-N	IH	USA	0.0 ±0.00 a	VH (9)

¹ Means followed by the same letter do not differ significantly at $p = 0.05$. Values with the prefix \pm represent standard deviation. * Colour of berry skin: B (blanc)—green-yellow, R—rose, N (noir)—blue-black; ** Origin: Vin—*V. vinifera*; IH—interspecific hybrid from crossing *V. vinifera* and species from among *V. riparia*, *V. rupestris*, *V. lincecumii*, *V. amurensis*, *V. labrusca*; *** Class of bunch sour rot resistance, with values on a scale of 1–9 in the brackets: VL—very little and L—little (1–4 = many wilted or rotten berries on all clusters (all clusters are attacked, some of them can be slightly affected); M—medium (5–6 = large percentage of wilted or rotten clusters (up to 20%)—most clusters are moderately attacked, only few clusters are attacked more severely); H—high and VH—very high (7–9 = only a few wilted or rotten berries on all clusters, only single clusters are slightly attacked).

The differentiation of selected features related to morphology, biology and ecology are presented separately for wine (Table 4) and table (Table 5) cultivars. The assessed wine cultivars were characterized by a significant variation in the density of grapes, from loose ('Cabernet Cantor', 'Marechal Foch') to very dense ('Silvaner', 'Johanniter'); skin thickness, from thin ('Siegerrebe', 'Phoenix', 'Pinot Noir') to thick ('Souvignier Gris') and the time of the beginning of veraison, from very early ('Siegerrebe') to medium ('Silvaner', 'Riesling', 'Johanniter', 'Traminer Rot', 'Souvignier Gris'). The diversity of wine cultivars in terms of weight of single bunch was small, from very low ('Pinot Noir', 'Riesling', 'Pinot Meunier', 'Traminer Rot', 'Marechal Foch'), to low ('Phoenix', 'Souvignier Gris'), as was the weight variation of single berry, from very low ('Marechal Foch') to low ('Phoenix'). Table cultivars were clearly differentiated in terms of the density of the grapes, from very loose-loose ('NY Muscat') to dense ('Aron'); thickness of skin, from very thin-thin ('Rusven') to medium-thick ('Festivee', 'Alden', 'NY Muscat') and the time of the beginning of veraison, from very early ('Krasotka', 'Galbena Nou', 'Nero', 'Somerset Sdl') to medium ('Aron', 'Sophie', 'Festivee', 'Alden'). In terms of a weight of single bunch, which rated from very low ('Somerset Sdl') to medium-high ('Aron'), and weight a of single berry, which ranged from very small ('Somerset Sdl') to medium-large ('Piesnia'), table cultivars were more varied than wine varieties.

Both wine and table cultivars were clearly differentiated in terms of the presence of such features as easy detachment of the berry from the pedicel or berry drop, sensitivity to berry skin cracking, frequent insect damage, and sensitivity to sunburn (Tables 4 and 5).

The skin of berries cracked in humid weather, especially when it followed a period of drought. Damage to the fruit was caused by insects such as wasps, hornets and bees. In the clusters of the ‘Antracyt’ cultivar, hornets were the first and most dangerous pests. *Drosophila suzuki* is not yet common in Poland and has not been found in the location where the present research was conducted. In the cultivars ‘Reliance Sdl’ and ‘Price’, an accumulation of as many as three unfavorable features was observed (easy detachment of berry from pedicel or berry drop, sensitivity to berry skin cracking, frequent damage to the skin by insects), while in others (e.g., ‘Souvignier Gris’, ‘Cabernet Cantor’, ‘Chasselas Dore’, ‘Alden’), no such threats were observed.

The values obtained by Pearson’s linear correlation coefficient showed a relationship between the severity of infestation, expressed as percentage of cluster area with sour rot and the selected varietal traits (Table 6). These relationships were similar for wine and table cultivars. Severity of bunch sour rot was positively correlated with bunch density and single bunch weight (very weak correlation for wine cultivars and weak correlation for table cultivars) and with single berry weight (moderate correlation for wine cultivars and weak correlation for table cultivars). Severity of sour rot was negatively correlated with thickness of berry skin (strong correlation) and the time of the beginning of veraison (weak correlation).

Table 4. Morphological, agrobiological and ecological features of wine cultivars.

Cultivar	Bunch Density	Thickness of Berry Skin	Time of Veraison Beginning	Single Bunch Weight	Single Berry Weight	Additional Features
Siegerrebe	5	3	1	1.4	2.4	c
Phoenix	5	3	2	1.9	2.9	c, d
Pinot Noir	7	3	3	1.0	1.3	d
Silvaner	9	6	5	1.5	1.6	-
Riesling	7	5	5	1.0	1.5	d
Calandro	7	4	4	1.1	1.5	-
Seyval	7	3	4	1.5	1.6	b, d
Reberger	5	5	3	1.7	1.6	d
Veltliner Frührot	7	5	3	1.1	1.4	c
Domina	8	4	3	1.2	1.2	d
Pinot Blanc	7	4	3	1.4	1.5	d
Villaris	5	4	4	1.1	2.2	c, d
Tauberschwartz	5	5	4	1.2	2.3	d
Cabernet Cortis	6	5	4	1.8	1.3	d
Solaris	6	4	2	1.2	1.4	c, d
Rondo	6	5	2	1.2	1.7	d
Johanniter	9	5	5	1.1	1.2	d
Pinot Gris	7	5	3	1.1	1.2	-
Pinot Meunier	9	5	4	1.0	1.1	-
Hibernal	7	5	4	1.2	1.1	d
Felicia	6	4	2	1.3	2.1	c, d
Traminer Rot	6	6	5	1.0	1.4	-
Bianca	5	6	4	1.3	1.9	d
Regent	4	6	4	1.2	1.8	-
Prior	7	6	4	1.6	1.6	-
Souvignier Gris	7	7	5	1.9	1.5	-
Marechal Foch	3	4	2	1.0	1.0	-
Cabernet Cantor	2	6	4	1.2	1.3	-

Density of bunch: 1—very loose, 3—loose, 5—medium, 7—dense, 9—very dense. Thickness of berry skin: 1—very thin, 3—thin, 5—medium, 7—thick, 9—very thick. Time of veraison beginning: 1—very early, 3—early, 5—medium, 7—late, 9—very late. Single bunch weight: 1 (very low)—up to about 100 g, 3 (low)—about 300 g; 5 (medium), 7 (high), 9 (very high)—about 900 g and more. Single berry weight: 1 (very low)—up to about 1 g, 3 (low)—about 3 g, 5 (medium), 7 (high), 9 (very high)—about 9 g and more. Additional features of berries: b—sensitivity to skin cracking; c—frequent damage to the skin by insects; d—sensitivity to sunburn.

Table 5. Morphological, agrobiological and ecological features of table cultivars.

Cultivar	Bunch Density	Thickness of Berry Skin	Time of Veraison Beginning	Single Bunch Weight	Single Berry Weight	Additional Features
Rusven	6	2	2	2.5	5.0	b, c
Piesnia	5	3	2	3.5	6.0	c
Krasotka	3	2	1	2.5	5.1	b
Argo	3	2	2	2.8	5.9	b, c
Galbena Nou	5	3	1	3.5	5.5	c, d
Reliance	5	3	2	1.4	2.5	a, b, c
Galanth	6	3	2	2.9	2.6	c, d
Aron	7	4	5	5.4	4.5	-
Evita	5	3	3	3.5	3.7	c, d
Sophie	6	3	5	4.5	4.7	-
Garantos	6	3	2	2.3	3.1	c, d
Antracyt	5	3	3	3.8	5.2	c
Palatina	5	3	2	2.2	2.5	c, d
Nero	5	3	1	1.8	2.6	c
Arkadia	4	3	2	3.5	5.4	d
Price	5	3	2	1.0	3.1	a, b, c
Muscat Bleu	3	4	2	3.2	4.9	c
Vostorg	4	4	2	3.5	4.9	d
Jupiter	4	4	2	2.0	4.5	a
Chasselas Dore	5	3	3	1.5	3.0	-
Suzi	5	4	4	3.5	4.3	-
Somerset Sdl	5	4	1	1.0	1.5	-
Festivee	3	6	5	1.9	5.5	-
Alden	4	6	5	2.8	4.7	-
NY Muscat	2	6	3	1.6	3.4	-

Density of bunch: 1—very loose, 3—loose, 5—medium, 7—dense, 9—very dense. Thickness of berry skin: 1—very thin, 3—thin, 5—medium, 7—thick, 9—very thick. Time of veraison beginning: 1—very early, 3—early, 5—medium, 7—late, 9—very late. Single bunch weight: 1 (very low)—up to about 100 g, 3 (low)—about 300 g; 5 (medium), 7 (high), 9 (very high)—about 900 g and more. Single berry weight: 1 (very low)—up to about 1 g, 3 (low)—about 3 g, 5 (medium), 7 (high), 9 (very high)—about 9 g and more. Additional features: a—easy detachment of berry from pedicel or berry drop; b—sensitivity to berry skin cracking; c—frequent damage to the skin by insects; d—sensitivity to sunburn.

Table 6. Correlation between severity of bunch sour rot and selected varietal traits.

Varietal Trait	Pearson's Linear Correlation Coefficient (<i>r</i>)	
	Wine Cultivars	Table Cultivars
Bunch density	0.18	0.23
Thickness of berry skin	−0.67	−0.65
Time of beginning of veraison	−0.37	−0.33
Single bunch weight	0.17	0.23
Single berry weight	0.46	0.34

Strength of Pearson's linear correlation coefficient $|r|$: 0.0–0.2—very weak; 0.2–0.4—weak; 0.4–0.6—moderate; 0.6–0.8—strong; 0.8–1—very strong.

4. Discussion

The degree of infestation of grapes by sour rot varied between years and was high in the years with heavy rainfall, falling between veraison and fruit maturity, which is consistent with the reports of other authors [17,20,26]. In the present research, the clusters were more severely infected in the years 2017, 2018, and 2019, which were characterized by abundant rainfall in the August–September period (in 2018, also in July), greater than both the long-term average and rainfall in 2015, 2016 and 2020 in which the sour rot infestation was marginal. A comparison of varieties with diverse geographic and genetic origins showed the differences in the resistance of assessed genotypes to sour rot. The sensitive wine cultivars included the *V. vinifera* genotypes, interspecific hybrids, and inter-intraspecific (intra-interspecific) hybrids. The present study confirmed the reports of other

authors that the basic factor determining the resistance to sour rot are the morphological and anatomical features of bunches and berries. The cultivars with dense clusters and thin skin should be considered the most sensitive [5], while the cultivars with loose clusters and thick skin of berries are characterized by greater resistance [20]. The present results, as well as previous reports, showed the low resistance of 'Riesling' [5,25], 'Pinot Noir' [5] and 'Seyval' [26]. On the other hand, the cultivars 'Pinot Gris' and 'Gewürztraminer' ('Traminer Rot'), also considered very sensitive [5], turned out to be significantly more resistant to sour rot than 'Riesling' and 'Pinot Noir' in the present research. 'Pinot Gris' and 'Traminer Rot' have slightly thicker berry skin (5, 6 respectively) compared to 'Pinot Noir' and 'Riesling' (3 and 5 respectively), slightly lower single berry weight, and were not prone to any skin damage (such as sunburn in the case of both, 'Pinot Noir' and 'Riesling'). Additionally, most of the other wine cultivars assessed, with the exception of 'Siegerrebe', 'Phoenix', and 'Silvaner', were more resistant to sour rot than 'Riesling' and 'Pinot Noir', and the resistance of 'Calandro' and 'Seyval' did not differ significantly from that of 'Riesling'. Cultivars such as 'Phoenix', 'Calandro', 'Seyval', and 'Reberger' have resistance gene loci for powdery and/or downy mildew and proved to be susceptible to sour rot [28]. 'Regent', 'Prior', 'Souvernignier Gris', 'Cabernet Cantor' also have resistance loci and were highly resistant to sour rot in the present study. This indicates that cultivars selected for resistance to powdery and downy mildew may have other drawbacks and might be interesting for future studies related to climate change and site-specific pathogens.

Five table cultivars with the lowest resistance to sour rot originated from Russia or Ukraine, countries where a continental climate with dry summer prevails. The results concerning the resistance of table cultivars are difficult to relate to the data from the literature, which are sparse. The berries of the table cultivar 'Red Globe' (*V. vinifera*) were solely used as experimental material and were infected with sour rot [6].

The severity of bunch sour rot for wine and table cultivars was positively, very weakly or weakly correlated with bunch density and single bunch weight. The correlation between severity of sour rot and single berry weight was positive, with moderate strength for wine cultivars and with little strength for table cultivars. These data are consistent with the earlier reports that the sensitivity of bunches to rot caused by *Botrytis cinerea* increases with their density and weight [23] and with the weight of berries [24]. Severity of sour rot was negatively and strongly correlated with thickness of berry skin. Among the examined features, this parameter was probably the most decisive in determining the resistance to sour rot. Resistance to grape rot caused by fungal pathogens *Rhizopus stolonifer* and *Botrytis cinerea* is related to the thickness of the skin [21,22]. The mechanism of resistance to rotting of bunches, regardless of its cause, seems to be similar.

Severity of sour rot was negatively, although weakly, correlated with the time of the beginning of veraison. This is in line with reports that early maturing cultivars are more sensitive to sour rot than late ones [5]. The main reason for this relationship is probably that the early beginning of veraison and the associated increase in extract content above 15°Brix, occurs in the second half of July or at the beginning of August (northern hemisphere), when temperatures are high, which favors the rapid development of sour rot [5].

Morphological and anatomical features should not be the only determinant of resistance to sour rot. One should agree with the statement that sour rot may also appear on cultivars that are not early maturing and do not have dense clusters and thin skin [5]. This is due to the complex etiology of the disease, since organisms associated with sour rot (yeasts, bacteria, and *D. melanogaster* flies) must come in contact with the pulp through wounds [3,7,10] or through the place where the berry is attached to the pedicel [3]. The obtained results indicate, according to the literature data, that infestation by sour rot is favored by such agrobiological and ecological characteristics of the cultivars as easy detachment of berry from pedicel, sensitivity to skin cracking, frequent damage to the skin by insects, and sensitivity to sunburn [3,7,11,16]. Cultivars that did not exhibit these features were more resistant to sour rot in the conditions of the present research. Under the conditions of the present study, effective chemical control of downy and powdery mildew

made it impossible to establish a correlation between the degree of the mentioned fungal infections of the assessed cultivars and the degree of sour rot.

It is advisable to recommend varieties resistant to sour rot for cultivation in regions where it occurs frequently. This can reduce the losses caused by this type of rot and facilitate the integrated protection against sour rot, which consists of using microbials limiting the development of yeasts and bacteria and combating *Drosophila* flies and other insects control, which is preferable over fungal control, when it comes to sour rot symptom development [5,6,17,20,30], using indirect methods such as management of excessive vine vigor and leaf removal [31], loosening tight clusters with growth regulators [5,17,30] and employing calcium and other supplements to increase skin toughness [31], although calcium is not always effective [32]. Data concerning sour rot resistance can be obtained during the methodical evaluation of cultivars in places of future cultivation and can be included in the descriptions of varieties, as now are data on resistance to the most important fungal diseases, physiological disorders and low temperatures.

5. Conclusions

Sour rot was severe in years with abundant rainfall during the berry ripening stage. The cultivars differed significantly in their resistance to sour rot. Severity of bunch sour rot was positively, very weakly or weakly correlated with bunch density and single bunch weight. The correlation between severity of sour rot and single berry weight was positive, with moderate strength for wine cultivars and with little strength for table cultivars. Severity of sour rot was negatively correlated with thickness of berry skin (strong correlation) and the time of the beginning of veraison—early maturing cultivars were more susceptible (weak correlation). Such agrobiological and ecological characteristics of the cultivars as easy detachment of berry from pedicel, sensitivity to berry skin cracking, frequent damage to the skin by insects, and sensitivity to sunburn, favoured sour rot infestation.

Author Contributions: Conceptualization, methodology, formal Analysis, investigation, resources, data curation, writing—original draft preparation, writing—review & editing—J.L.; review & editing, funding acquisition—A.L. Both authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Polish Ministry of Agriculture and Rural Development in the frame of the programme on protection of genetic resources of horticultural crops.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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