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Agronomic evaluation and adaptability of Pinot gris to an environment with high grey mould disease pressure: a comparative analysis on 17 clones

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ABSTRACT

The grapevine (*Vitis vinifera* L.) cultivar Pinot gris is an international variety that has spread world wide and is oneof the most important in Italy, especially in the northern regions where almost half of the world's total is grown. Over a three-year period (2019–2021), a comparative study was conducted on 17 clones to evaluate their agronomic aptitudes, susceptibility of grapes to *Botrytis cinerea*, fertility of buds, vigour, and oenological characteristics. We aimed to provide local viticulture with agronomic, sanitary status, and oenological indications that help to choose the genotype that best fits and enhances the clone/environment synergy. This is important given climate change, one of the most significant factors affecting viticulture. Hence, productive, qualitative, and health surveys were conducted on grapes during harvest. Vigour and vegetative/productive balance were also evaluated regarding the weight of the pruned wood. The Ravaz index and fertility of buds were studied when the inflorescences were separated and clearly visible (between DOY 131 and DOY 141 each year). The confirmation of the bunch was also evaluated (shape and number of wings) according to the Organisation Internationale de la Vigne et du Vin (OIV) descriptors. Through the use of digital photogrammetry, some descriptors of the cluster that most correlate with the severity of *Botrytis cinerea* were identified. In 2020 and 2021, microvinifications were carried out in white and with maceration of skins, respectively, following tested protocols. Sensory analysis of the wines was performed with a trained panel of experts. The study revealed interesting differences between clones concerning grapes' qualitative, productive, and sanitary aspects. Some clones stood out for their sugar accumulation, yield and resistance to *Botrytis cinerea*, as well as for the oenological olfactory profile. Statistical analysis highlighted that the severity of *Botrytis cinerea* and bunch rot was not correlated with the vigour of the plant but rather with the hardness of skin, content of soluble solids, soluble solids/total acidity ratio, pH, and total acidity. From the sensory analysis, several clones had a higher score for some descriptors in both study years and were more appreciated than others.

KEYWORDS: clones, grapevine, yield, mould, olfactory profile, tolerance

INTRODUCTION

Kim and Signe (2020) reported that Italy, the United States, Germany, Australia, France, and New Zealand produce Pinot gris. Most of the plantings are found in North-Eastern Italy, which accounts for 40.4 % of the global plantings and equates to 1.8 million hectolitres of wine. The data demonstrates the importance of Pinot gris for the territory's economy. Therefore, production, quality, and grape health must be protected. These data makes it clear that Pinot grisis essential to the local economy. As such, the production, quality, and health of grapes must be protected. The ascomycete fungus *Botrytis cinerea* is one of the main pathogens agents responsible for serious production and economic losses worldwide (Kassemeyer and Berkelmann-Löhnertz, 2009; Wilcox *et al*., 2015). Indeed, according to Elmer and Michailides (2007), the economic loss caused by this pathogen amounts to about two billion dollars a year. For this reason, it is essential to employ every means possible to counteract the development of grey mould.

As is known, this pathogen causes serious damage to the inflorescences and grapes, where it can also cause widespread rot, especially during the ripening phase and even more so, in particular, rainy vintages and in compact cluster varieties like the Pinot family. The severity of the disease is often associated with the architecture of the cluster, as the compactness determines the reduction of the production of epicuticular waxes at the point of contact with the berries (Dry and Gregory, 1988; Marois *et al*., 1992; Winkler *et al*., 1975). Consequently, the surface tension increases, and both the evaporative capacity of water (Marois *et al*., 1986), which determines a prolongation of the drying times of the berries (Vail and Marois, 1991), and the hydrophobic capacity of the berry decrease. The prolonged wetting of the berries promotes the development of fungal mycelium (Carre, 1984) and the production of plant exudates, accelerating the germination of the pathogen's conidia (Kosuge and Hewitt, 1964). Further confirmation also comes from a study conducted on clones of Pinot noir, which confirmed that the severity of berry rot depends on the compactness of the grapes (Bernard and Leguay, 1985). Genetic and phenotypic factors also play a significant role in susceptibility to the disease, including the chemical characteristics of the grape skin (Latorre *et al*., 2015), the number and thickness of cellular layers in the skin (Gabler *et al.*, 2003; Comménil *et al.*, 1997), and the susceptibility of the cultivar (La Fuente *et al*., 2017), as well as numerous other agronomic, cultural, climatic, and microclimatic factors (Broome *et al*., 1995b; Molitor *et al*., 2011; Deytieux-Belleau *et al.*, 2009).

The danger of *Botrytis cinerea* requires targeted fungicidal treatments as a preventative measurementto avoid or reduce damages, which can result in significant losses in the production and quality of grapes (Ribéreau-Gayon *et al*., 1979; Ribéreau-Gayon *et al*., 1980; Pallotta *et al*., 1998). A study conducted in France in the late 1990s on Bordeaux varieties demonstrated that 35 % of rotted berries at harvest resulted in a 28.5 % reduction in wine production (Dubos, 1999). Negative effects on wine sensory aspects such as colour, aroma, and taste are already evident when the grapes have reached a 5 % infection threshold, as evidenced by phenol oxidation, colour alteration, unpleasant appearance, and problematic ageing (Ky *et al*., 2012). The use of anti-*Botrytis cinerea* products is increasingly being resorted to control disease (Rosslenbroich and Stuebler, 2000), but this leads to the generation of resistant strains on the one hand (Hahn, 2014) and, on the other hand, a more massive use of pesticides with serious repercussions on the environment and human health (Damalas and Eleftherohorinos, 2011). Therefore, new agronomic strategies are needed because several studies have shown that controlling the disease using only anti-*Botrytis cinerea* products may not be enough to contain its spread and severity (Travis and Hed, 2002; Shtienberg, 2007).

Instead, combined control methods (chemical/agronomic cultivation) are needed, as they are much more effective. In this context, widespread agronomic practices are used, such as the early defoliation of the productive belt in pre-flowering (Poni *et al*., 2006; Poni *et al*., 2008; Molitor *et al*., 2011) and the delay in carrying out the first topping (Molitor *et al*., 2014). The evaluation of intra-varietal variability represents another valid tool that helps to mitigate various problems (phenological, productive, qualitative, and sanitary). In this context, the search for biotypes characterised by more scattered grape clusters is essential.

To illustrate the importance of clonal selection in Italy, it is worth noting that of the 642 wine grape varieties registered in the National Register of Vine Varieties, 1532 clones are officially recognised and homologated (source: www. catalogoviti.politicheagricole.it; Ministry of Agriculture, Food Sovereignty and Forestry - Masaf – Accessed on 27th March 2024). The same trend is observed in all the other wine-producing countries of the European Union.

In Italy, 21 clones of Pinotgrisare registered in the National Register of Grape Varieties (source: National Register of Grape Varieties 2022, Ministry of Agricultural, Food, and Forestry Policies). Some of these clones are widely cultivated, while others are less common. However, Italian vineyards also cultivate clones of foreign origin, primarily of French and German descent, which have found suitable environmental conditions and showed interesting oenological properties.

The purpose of this study was to evaluate 17 Pinot gris clones, which have never been compared and studied simultaneously in a single environment, to obtain objective and scientific information on agronomic, oenological, and sanitary traits to identify the most suitable clone/s for the environmental conditions of the study area. The study applied innovative technology based on digital photogrammetry, through which three-dimensional models of the cluster were processed. The numerous indices obtained from this analysis (perimeter, area, diameter, major axis) were related to the shape of the grapes, which allowed for the determination of descriptors

most correlated with grey mould severity and the identification of clones with morphological characteristics that favour a lower incidence.

MATERIALS AND METHODS

1. Experimental setup

The trial was conducted from 2019 to 2021 in a vineyard containing 17 Pinot gris clones located in the flat territory of the "delleVenezie" PDO (Protected designation of origin) in Cimadolmo (Treviso), North-East Italy (45°78' 06" N;12° 37' 56" E). The vineyard was planted in the spring of 2016, is without an irrigation system and is located at an altitude of 50 metersa.s.l. The rows are oriented east–west. The study was conducted following a completely randomised experimental design, with 3 replicates of 5 vines for each clone.

The vines are grafted onto the Kober 5BB rootstock (*Vitis Berlandieri* x *Vitis Riparia*) and trained to a vertical shoot position with a trellis system using three fruiting canes with 12 or 13 buds each. The permanent cordon is positioned 1.3 meters above ground, and the row spacing is 2.85 meters, while the vine spacing is 1.25 meters, resulting in a density of 2440 vines per hectare. The soil is classified as loamy (44 % sand, 35 % silt, 20 % clay) according to the USDA (United States Department of Agriculture) with a high total nitrogen content (0.15 %), organic matter (2.7 %), and total calcium (21 %), while the active lime content is considered moderate (9 %). The agronomic management of the vineyard involves spontaneous interrow vegetation with mowing during the spring-summer period, under-vine weed control, two hedging interventions between the end of flowering and véraison to improve the microclimate around the grapes, and defoliation of the productive zone before harvest to facilitate mechanical harvesting. Fertilisationwasbased on applying 80 units of N and K and 40 units of P per hectare per year, distributed after bud break and harvest.

Grey mould—*Botrytis cinerea*—was controlled using Amylo-x, a fungicide based on *Bacillus amyloliquefaciens* (1 treatment in June after flowering, 2 kg/ha), and Switch, a fungicide based on ciprodinil and fludioxonil (1 treatment in July before véraison, 0.8 kg/ha). Treatments were applied using tunnel atomisers with drift recovery. The 17 tested clones listed in Table 1 have different origins and come fromfour different European countries (Italy, France, Germany, and Hungary).

2. Meteorological data

The climatic data for the three-year trial at the experimental site, provided by the meteorological centre of ARPAV in Teolo-Padova, Italy (https://wwwold.arpa.veneto.it/previsioni), was recorded by a weather station located 200 meters from the vineyard. The sensors were positioned two meters above the ground, and the average, minimum, and maximum temperatures, as well as the daily average relative humidity and rainfall, were monitored. However, the minimum and maximum temperatures were not reported.

3. Yield measurements

At harvest of each year, 15 healthy and representative plants/clones(three replicates offiveplants)were chosen to determine the average production per vine (kg), the number of clusters per vine, and the average weight of the cluster (kg). The average weight of the berry (g) was calculated on 150 berries taken from the grapes of the same 15 plants.

4. Qualitative analysis

Each year, the berry composition was evaluated when grapes had reached the technological maturity defined based on the value of the soluble solids/total acidity (SS/TA) ratio. The minimum value of this parameter has been set at 2.5, the same value established by the production discipline of the Pinot gris PDO.

From the same 15 plants/clones, random parts of the grape bunches were taken to compose three samples/clones of approximately 1.5 kg, which were then transported to the laboratory in freezer containers and pressed with a roller crusher with opposite rotation.

The soluble solids determined in the resulting clear must by refractometry at 20 °C with the digital Refractometer

TABLE 1. List of investigated clones and their origin.

Italy	Germany	France	Hungary
R6	1 GM	ENTAV 52	B10
VCR 5	2-15 GM	ENTAV 53	
SMA 505	HAUSER 1 (H1)	ENTAV 457	
SMA 514	FR 49-207		
IsmaAvit 513			
ERSA FVG 151			
ERSA FVG 152*			
ISV F1 Toppani			
F 13 CSG			

*CRAVIT ERSA FVG 152.

ATAGO PR-32 (0–32 %) (Eastgate Way Suite 450 Bellevue, WA 98007 U.S.A) and expressed in refractometric Brix degrees (%). Total acidity (expressed as g/L of tartaric acid equivalents) was determined on 20 mL of clear must by titration with 1N NaOH (ACS reagent Honeywell Fluka 30620) using a Micro TT 2022 automatic titrator (Crison, Barcelona, Spain) equipped with a pH probe Hamilton FlushTrode P/N 238060/08.

Total anthocyanins and flavonoids were determined by separating the skins of 30 berries from the pulp and seeds and placing them in a tartaric buffer at pH=3.2. The polyphenolic substances were extracted in approximately four hours under conditions of excess sulphur dioxide. Tosimulatethe extraction that occurs during alcoholic fermentation, 48 hours passed (Di Stefano *et al*., 2008). Then, the skins were homogenised and separated from the extract, which was analysed by spectrophotometric assays following protocols already reported (Di Stefano *et al*., 2008).

5. Vigour, vegetative-productive balance, and fertility of buds

The vigour, vegetative-productive balance, and bud fertility were assessed. Vigour was defined by measuring the weight of pruned wood from 15 plants/clones, while the vegetative-productive balance Ravaz index (Ravaz, 1911) was evaluated by comparing grape yield to the weight of winter pruned wood. The actual fertility was calculated as the ratio of the number of grape clusters observed when the inflorescences were well separated (BBCH 62-63) (Biologische Bundesanstalt, Bundessortenamt and Chemical industry) from the number of buds left after winter pruning.

6. Morphometry and shape of the grape cluster

For grape bunch morphology and shape, six grape clusters per clone (a total of 105 clusters) were captured using a Nikon D5100 camera (Nikon Corporation, Tokyo, Japan). The grape clusters were suspended from the ceiling of an LED-illuminated room, and the camera, mounted on a rotating arc device, was positioned 0.45 m away from the cluster. For each complete rotation, 33 photos were taken from three different positions: perpendicular to the axis of the cluster, at +45°, and at -45°, fora total of 99 images per cluster. Photogrammetry techniques and Metashape 1.7.2 software (Agisoft LLC) were used to process the images of individual grape clusters and construct a virtual 3D model for each clone. CloudCompare and AutoCAD 2022.1 (Autodesk^{tm}) software were used for cross-sectional and vertical sectioning of the grape clusters, respectively, and to measure the perimeter, area, and length of the sections. These parameters were employed to study the morphological characteristics of the grape clusters. The shape and number of wings were defined using OIV 208 and 209 descriptors (OIV, 2009),respectively, while compactness was determined according to the 204/9 descriptor, which classified all clones as “very compact”.

7. Hardness of the skin

The breaking point of the skin was determined at harvest on 100 randomly chosen berries per clone/per year (three replicates of approximately 33 berries) on the cluster using the Fruit Texture Analyzer, Guss Manufacturing (PTY) Ltd, Strand—South Africa—equipped with FTAwin software, fitted with a cylindrical steel probe 50 mm long and 1 mm in diameter. The test was performed on the equatorial part of berries with a pedicelwith a similar diameter (about 10 mm) and a soluble solids content of approximately 18 to 20 °Brix. The instrument was calibrated by setting the probe speed to 6 mm s^{-1}, the return speed to 10 mm s^{-1}, the sample penetration depth to 4.5 mm, and the minimum activation threshold to 0.19N.

8. Sanitary evaluation

The sanitary evaluation of grapes (grey mould and bunch rot) wasvisually performed every year at harvest on 150 bunches per clone taken from 15 plants (three replicates of five vines each), classifying the extent of damage into four classes: 0 = healthy cluster (0 %); 1 = 1–25 % damage; 2 = 26–50 % damage; 3 = >50 % damage. The severity (or spread) on the same clusters was calculated using the Townsend-Heuberger formula (Townsend and Heuberger, 1943):

$$\text{ID (\%)} = \Sigma i\ (ni \times vi)/N \times V,$$

where ID = infection rate; I = number of classes; ni = number in a class; vi = damage class; N = total number; V = highest class.

The incidence (Ic) of the disease, expressed as a percentage, was calculated as the ratio between the number of infected clusters (NI) and the total number of clusters (TN) 100.

$$Ic = \frac{NI}{TN} * 100$$

The range of severity values was divided, using Sturges’ rule (Sturges, 1926), into five successive classes of infection with a common limit: 1 = very low; 2 = low; 3 = medium; 4 = high; 5 = very high.

Sturges’rule :

C=1+(10/3)*log10(n), where C is the number of classes and n is the number of observations.

9. Micro-vinification and sensory analysis of wines

At the harvest, 150 kg of grapes per clone were collected, divided into three replicates of 50 kg each, mixed, and taken to the cellar for micro-vinification. The grapes were harvested from the 15 selected vines for the trial and other plants of the same clone.

The grapes were stored overnight at 6 °*C crushed* and pressed, using a membrane press operating at 1.2 bar, the following day. From the micro-vinification, approximately 100 L of wine per clone was obtained without replicates and following the protocol outlined below.

In 2020, the pulp was separated from the skins. In steel tanks, musts were inoculated with 20 g hL^{-1} of *Saccharomyces*

cerevisiae (Zymaflore FX10, Laffort, Bordeaux, France). Next, sulfur dioxide was added at a 1.5 g hL^{-1} dose as $Na_2S_2O_5$. On the second day, 40 g hL^{-1} of $(NH_4)_3PO_4$ was added. Alcoholic fermentation lasted ten days at room temperature (18–20 °C); wine was gravity-settled. Wines were bottled in February.In 2021, the same protocol was used, but winemaking was performed after maceration of the skins for 24 hours.Sensory evaluation was conducted at the Interdepartmental Centre for Research in Viticulture and Enology (CIRVE) at the University of Padua in Conegliano (TV) by a trained panel of 12 testers (the evaluation of each judge was considered a biological replica) following the criteria of agreement and repeatability (Piccini, 2008).

Before being evaluated, the wine samples (one for each clone) were coded with a three-digit number and randomised, including a replicate sample whose identity is known only to the panel leader.

The repeatability criterion was assessed by statistical analysis of the scores assigned by each judge to the descriptors in the sample, and the judge whose score differed significantly from the others was excluded from the panel.

The wines of the 2020 vintage were tested on July 22, 2021–DOY 334 after harvest–while the wines of the 2021 vintage were tested on July 12, 2022–DOY 306 after harvest.A point test with an unstructured scale (0–10) was performed, and the sensory profile was defined using typical descriptors of Pinot gris that are commonly used, such as white flowers (hawthorn, broom, acacia), citrus (lemon or yellow grapefruit), pineapple/melon, apple/pear, peach/apricot, fresh vegetables, mineral, acidity, and sapidity. Furthermore, colour intensity, aroma intensity, taste intensity, hue, and overall judgment were evaluated.

10. Statistical analysis

The data for all studied parameters were normalised. First, a two-way fixed effects ANOVA with interaction (clone × year) was performed for all traits (Table S1). A one-way ANOVA was then performed on the average of years for each clone, followed by multiple comparisons of means (Tukey's test, $p \leq 0.05$) using STATISTICA v.7 software (StatSoft Inc., Tulsa, OK, USA).

Normal distribution of the data was verified using Shapiro-Wilk tests, rejecting the null hypothesis (H0) whenever the calculated p-value was below the significance level of alpha = 0.05.

RStudio (version 1.2.1335 © 2009–2019 RStudio) was the software chosen for the statistical analysis of the cluster morphology part. The Pearson linear correlation coefficient was used to define the significance of correlations between variables, rejecting the null hypothesis whenever the calculated p-value was below the significance level of alpha = 0.05. Correlation plots were created using XLSTAT 22 software. For all analyses, the sample size was n = 153 (3 replicates × 3 years × 17 clones).The sensory analysis scores were first normalised and then subjected to ANOVA, and the Tukey test ($p < 0.05$) was used to test for statistically significant differences in the means for all descriptors.

RESULTS

1. Meteorological characterisation of the study site

The greatest danger for grapes is represented by rainy events that can occur near harvest, which normally falls in the last part of August. In 2019, the year with the highest rainfall,

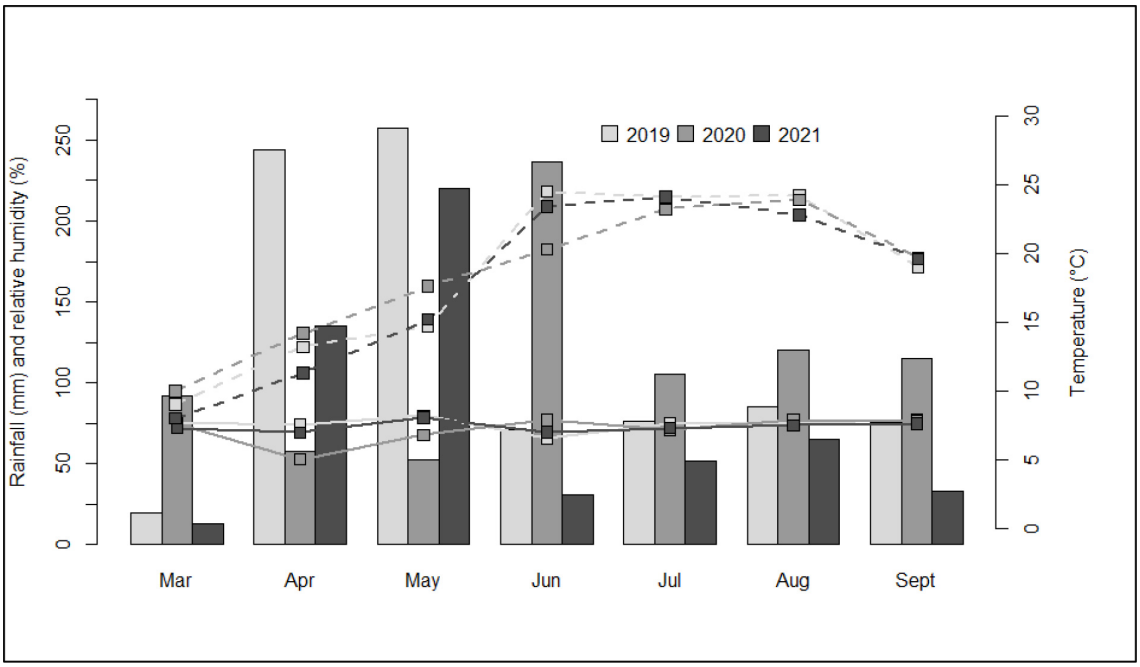


FIGURE 1. Climatic characterisation of the site during the three years of the study. The dashed lines indicate the average temperature, while the solid lines represent the relative humidity. The bars indicate the amount of precipitation.

830 mm of cumulative precipitation was recorded from March to September, 63 % of which was concentrated from March to May. In 2021, the least rainy year (548 mm), the rainiest months were still April and May. In 2020 (690 mm), June was the month most affected by rainfall, with almost 240 mm of precipitation, making it the rainiest year if the last three months of the vegetative cycle are considered. The average temperature during the observation period in each of the three years was very similar at around 18 °C. Despite June being 3–4 °C cooler, 2020 was the hottest year due to the higher maximum temperatures of April and May, as confirmed by the Huglin index (2440 °C), which was slightly higher than in 2019 (2400 °C) and significantly higher than in 2021 (2350 °C). From July onwards, the three years had a very similar thermal trend. The relative humidityover the three years, excluding April and May 2020, was also very similar, with values completely overlapping throughout the vegetative period (Figure 1).

2. Quality of grapes

The black line in Figure 2A represents the three-year average (19.0 °*Brix) of the sugar content for all the clones studied. Looking solely at the numerical outcome, the graph highlights that compared to this value, 10* clones have a higher sugar content (as the three-year average), and six clones have a lower content. However, statistically, the differences are limited to only a few clones. Specifically, clone ERSA FVG 151 (20.1 °Brix) shows good tendencies to accumulate soluble solids, but as seen from the figure, it is statistically different only from clones 1 GM, FR 49-207, SMA 505, and B10. The latter, which has consistently performed the worst, differs from 14 clones and is similar only to FR 49-207 and 1 GM. The qualitative parameters of individual clones for each year of the study are reported in Supplementary Tables S2, S3 and S4.

Considering the total acidity (Figure 2B), it can be observed that there is a high homogeneity of values, and statistically significant differences were observed only among a few clones. In particular, differences were found between F13 CSG and H1 compared to Entav 52 and F13 CSG (with the former having the highest value) and between clones ERSA FVG 152 and H1, with the latter having the lower value. All the other clones have values close to the mean value of the entire group.

The effects of clone, year, and the interaction between clone and year for these two traits are reported in Table S1; it can be inferred that there is a significant clone effect on both parameters, while the year effect had no impact on total acidity but is evident on soluble solids, with the content being significantly lower in 2020 (–1.1 °Brix compared to 2019 and –1.4 °Brix compared to 2021), likely due to the abundant rainfall (about 41 mm) in the two days preceding the harvest (probable dilution effect). There is no clone × year interaction on either soluble solids or titratable acidity. No significant differences were observed in values, anthocyanin content, and flavonoid content (Table S5).

3. Yield results

Over the three-year average, the production per strain was quite homogeneous, with statistically significant differences found only between clones 1 GM and B10, whose productions

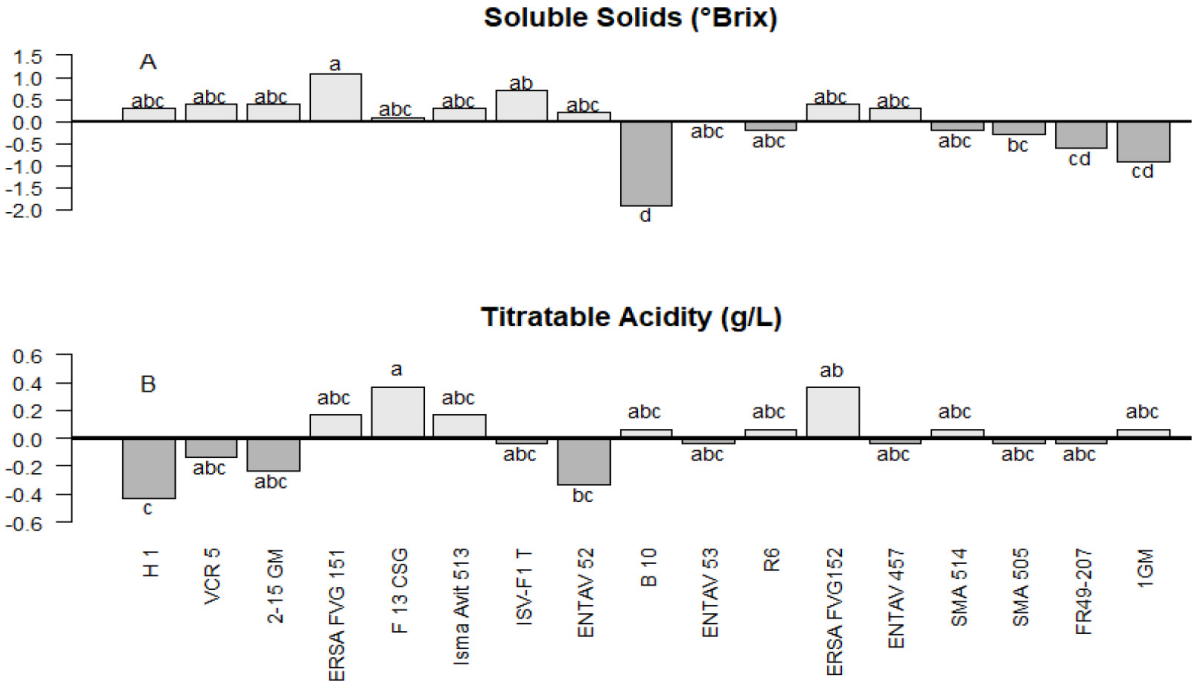


FIGURE 2. The black line in panels A and B represents the three-year average of the soluble solid content (19.1°Brix) and total acidity (6.96 g/L, expressed as g/L of tartaric acid) of the 17 clones. The vertical bars indicate the deviation of each individual clone from the group mean. The means of the clones with the same letter are not significantly different per $p > 0.05$ (Tukey test).

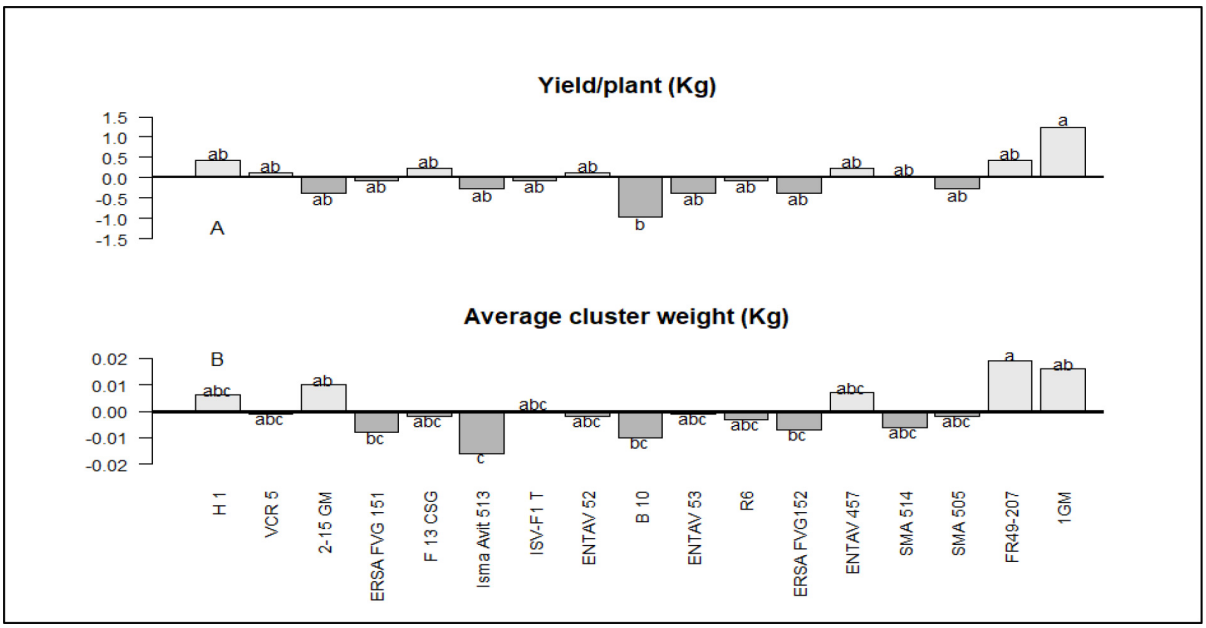


FIGURE 3. The black line in panels A and B represents the three-year average production per vine (6.5 kg) and the average weight of the cluster (0.145 kg) of the 17 clones, respectively. The vertical bars indicate the deviation of each individual clone from the group mean. The means of the clones with the same letter are not significantly different per $p > 0.05$ (Tukey test).

were 7.7 and 5.5 kg/vine, respectively, while the mean value of the entire group was 6.5 kg/vine, as represented by the black line in Figure 3A.

The three-year average grape weight of the grape cluster for all clones studied, represented by the black line in Fig. 3B, was 0.145 kg, and except for the extremes, weight fluctuations did not exceed ± 10 grams.Clone FR 49-207 tended to have the heaviest cluster (0.165 kg), but statistically, it differed only from clones ERSA FVG 151, CRAVIT ERSA FVG 152, B10, and ISMA-AVIT 513. The latter had the cluster weighing 0.128 kg but was statistically only different from clones 2-15 GM, FR 49-207, and 1 GM.

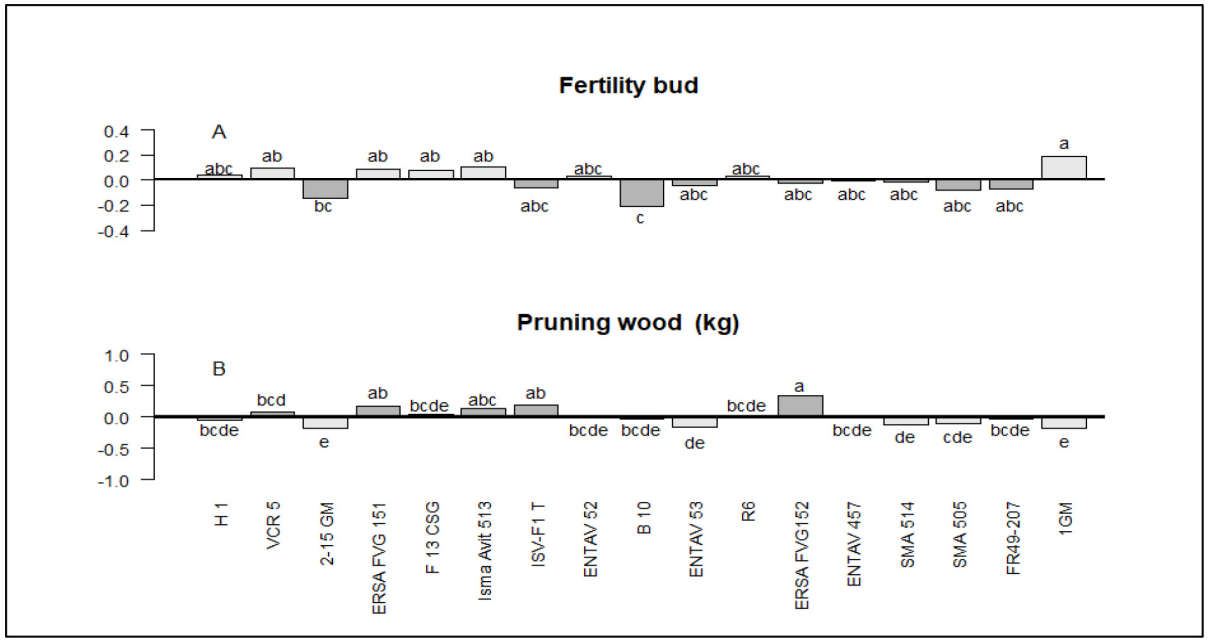


FIGURE 4. The black line in Figures A and B indicates the three-year average of bud fertility (1.1) and plant vigour (0.62 kg) of the 17 clones, respectively. The vertical bars indicate the deviation of each single clone with respect to the mean value of the group.The means of the clones with the same letter are not significantly different per $p > 0.05$ (Tukey test).

There were also a few significant differences in the average weight of the grape berry (Table S5), which differed only among clones CRAVIT ERSA FVG 152 (1.5 g), 1 GM, and H1 (1.3 g). The agronomic responses of the single clones for each year of study are reported in Supplementary Tables S2, S3 and S4.

The effects of clone, year, and the interaction between clone and year for these two traits are reported in Table S1; the cluster weight is influenced by both the clone and the year (with clusters significantly lighter in 2019), while the year has a statistically significant effect on production (which in turn is influenced by bud fertility and the number of clusters per plant). Specifically, 2021 was statistically the least productive year (5.5 kg/vine on average) due to significantly lower fertility and the number of clusters compared to 2019 and 2020 (Table S4 A). Year ×clone interaction effects for these traits were not significant.

4. Vegetative-productive balance and bud fertility

Figure 4A shows the average bud fertility, which is 1.1. The highest fertility was observed in clone 1 GM (1.3), but it is statistically different only from 2-15 GM and B10 (0.8), while the latter differs from VCR 5, ERSA FVG 151, F 13 CSG, ISMA Avit 513, and 1 GM.

Figure 4B shows the vine vigour expressed through pruning wood weight. The black line represents the three-year average of the entire group, which is 0.62 kg, and the graph reveals high similarity among the clones. CRAVIT ERSA FVG152 appears to be the most vigorous (0.95 kg), but statistically, it is similar to other clones such as ISV-F1 T, IsmaAvit 513, and ERSA FVG 151. The effects of clone, year, and the interaction between clone and year for these two traits are reported in Table S1, from which it is evident that the clone has a significant impact on vigour, while the year affects both parameters indeed, in 2021, fertility and vigour had statistically lower values compared to the other two years (Table S4 A). The year × clone interaction effects for these traits were not significant.

The Ravaz index values are reported in Table S5. The values range from 6.2 for CRAVIT ERSA FVG 152 to 16.7 for 1 GM, with only four clones being statistically similar to each of these two. Three groups can be identified: one with values ranging from 6.2 to 9.6, a slightly more numerous group with values between 10.1 and 11.8, and a third group with an interval of 13.4 to 16.7. For this parameter, the clone factor has a very significant impact, while the year effect and the interaction between clone and year are null.

5. Grape cluster morphology

The grape cluster morphology study involved dividing the cluster into two vertical sections and five equidistant and perpendicular transverse sections along the longitudinal axis of the cluster, with each section representing 16.67 % of the cluster's height (Figure 5).

A total of 185 measurements were obtained for each cluster, including 82 native measurements and 103 indices derived from relevant international literature (Bribiesca, 2008; Li *et al.*, 2013; OIV, 2009; Cubero *et al.*, 2015; Zhang and Lu, 2004; Yang *et al.*, 2011b) as well as some proposed and evaluated in this study. From the numerous indices obtained through various models, six were selected based on linear regression analysis, as they showed the highest correlation with the severity of *Botrytis cinerea* infections. These selected indices are presented in Table 2, while Table 3 summarises the indices grouped by *Botrytis cinerea* class severity. With the exception of some middle classes, the trend from the lowest to the highest class is clear.

This table shows the indexes most associated with the severity of *Botrytis cinerea*. EF: Empty fraction; $S*H^{-1}$: surface and height ratio; S*TotB-1: Surface and total berries number ratio; $P*B^{-1}$: middle section perimeter and berries number ratio; Mja max width of the sections number 1 and 4.



FIGURE 5. Horizontal and vertical sections of the grape clusters, as well as a graphic representation of the sections.

TABLE 2. Definitions of the indexes. The reference column aims to specify which authors proposed the measurement or the indexes."Authors" means the measurement or the indexes that wereproposed in this manuscript.

Measurements	Definition	Reference
EF	Ratio between the empty volume and computed volume	Authors
$S*H^{-1}$	Ratio between the 3D model's surface and height	Authors
$S*TotB^{-1}$	Ratio between the 3D model's surface and total berries	Authors
$P*B^{-1}$	Ratio between the perimeter of the middle section and the Number of berries crossed by the same section	Authors
Mja	Major axis is the longest line that can be drawn inside a horizontal section	(Zhang and Lu, 2004)

TABLE 3. Indices grouped by *Botrytis cinerea* class severity.

Class	EF	$S*H^{-1}$ (mm)	$S*TotB^{-1}$ ($mm^2*Berry^{-1}$)	$P*B^{-1}$ ($mm*Berry^{-1}$)	Mja4 (mm)	Mja1 (mm)
Very Low	0.2418	34.4401	4.0116	2.0838	4.9882	8.0549
Low	0.1945	30.8453	4.0761	1.8954	5.3457	7.3946
Medium	0.1863	29.7217	3.6535	1.9372	5.1708	6.6222
High	0.2146	27.9296	3.4351	0.875	5.0544	6.5251
Very High	0.1256	27.4031	3.698	1.3434	5.7029	5.9675

The term Empty Fraction (EF) refers to the proportion of space inside a grapevine bunch compared to the total volume of the entire 3D mesh. Higher EF values indicate more empty spaces within and between the berries (Tello *et al*., 2014). The $S*H^{-1}$ index can be considered a measure of surface density. While grape height depends solely on the grape size, surface density considers the number, size, arrangement, and proximity of the berries. $S*TotB^{-1}$ and $P*B^{-1}$ are two indices used to estimate berry density. $S*TotB^{-1}$ measures the average surface area per berry, while $P*B^{-1}$ indicates the average perimeter occupied by a berry in the horizontal midsection. Finally, Mja refers to the length of the longest axis of the horizontal sections. In particular, Mja1 and Mja4 represent the projection of the bunch cut at 16.33 % and 66.33 % of the bunch's height from the peduncle, respectively. High values for Mja1 and small values for Mja4 may describe funnel or conic-shaped bunches, which are typically wider at the top and narrower at the bottom.

Figure 6 provides an example of bunch renderings from each *Botrytis cinerea* class. The first bunch on the left represents clone 1-GM, which has a typical funnel shape. The second bunch is clone ISV-F1-TOPPANI, which has a cylindrical shape and large berries. The central bunch and the following one have two wings representing the SMA 514 and ERSA-FVG 151 clones, respectively. Finally, the last clone, H1, has a cylindrical shape and several small berries.

Figure 7 shows five examples of horizontal middle sections of bunches from the five severity classes. Clone 1-GM and ISV-F1-TOPPANI have 10 and 9 berries, respectively, and their perimeter measures 20.0837cm and 18.7827cm, respectively. The first two clones show the highest perimeter-to-berries ratio. SMA-514 is in the middle severity class and



FIGURE 6. The pictures refigure five examples of Pinot gris virtual model grapes per class. Clones are listed from the left as clone 1 GM, clone ISV F1 Toppani, clone SMA 514, clone ERSA FVG 151, and clone H1.

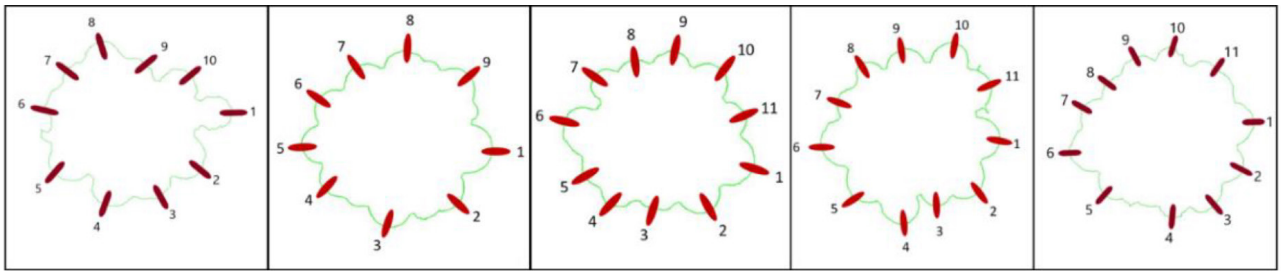


FIGURE 7. The picture shows an example of five horizontal middle sections and the berries counting method. The clones are listed from the left as clone 1 GM, clone ISV F1 Toppani clone SMA 514, clone ERSA FVG 151, and clone H1.

has 11 berries, with a perimeter measuring 21.0827cm. ERSA FVG 151 and H1 could be considered the most compact bunches, each with 11 berries and perimeters measuring 19.8562cm and 19.6397cm, respectively. The last two clones show the smallest perimeter-to-berries ratio. The perimeter-to-berries ratio is significant as it indicates compactness: the higher the ratio value, the lower the compactness.

In Table S6, the number of wings and the shape of the bunch are reported, and the latter is obtained according to the OIV technical protocol (descriptor 208).

The prevailing shape is cylindrical (10 clones), only three clones (FR 49-208, 52F, and 1-GM) have a funnel-shaped bunch, and four clones (CRAVIT ERSA FVG152, ISMA-AVIT 513, SMA 514, and ENTAV 457) have a bunch that can be attributed to both shapes. All bunches have only one wing. According to the OIV descriptor 204, all clones are classified with code 9, "highly compact".

6. Skin hardness

The skin resistance, expressed in N (Newton), indicates the force the metal probe must exert to break the skin tissues and complete the penetration. Figure 8 shows the average resistance value (0.69 N) of the 17 clones—indicated by the black line—and the deviation of the values of the individual clones from the same average: from the graph, some variability emerges only among some clones, and it is evident that as the negative difference increases, the resistance of the skin to penetration decreases and vice versa. The skin-breaking values range from 0.61 N for clone H1 to 0.82 N for clone 1 GM.

Clone 1 GM has the highest value, but statistically, it is the same as two other clones (FR 49-207 and SMA 505), while H1, which ranks among the lowest values, is different from all except VCR 5 and 2-15 GM; clone VCR 5 is different from all clones that have a positive difference compared to the mean (except for ERSA FVG 151).

The effects of clone, year, and the interaction clone x year for these traits are reported in Table S1. As can be seen from Table S4 A, in 2019 and 2020, the skin resistance values are statistically lower than in 2021, which may explain the higher degree of *Botrytis cinerea* infection. However, the clone effect is even more pronounced (confirming the role

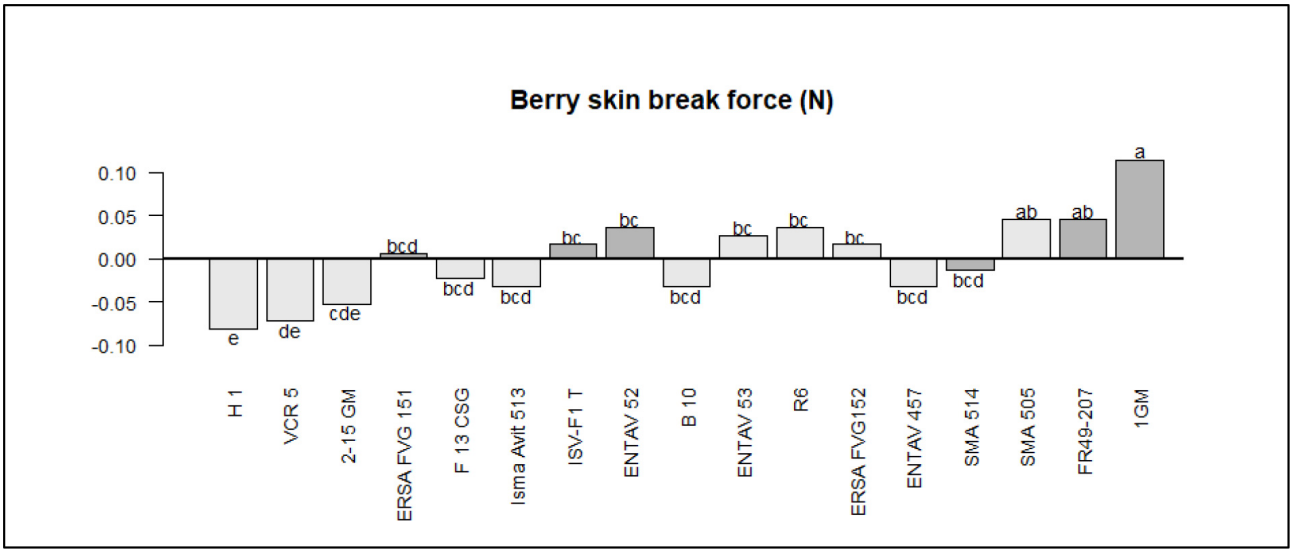


FIGURE 8. Resistance of grape skin to penetration, with the black line indicating the mean value (0.69N) of the 17 clones. Vertical bars indicate the deviation of each single clone with respect to the mean value of the group. The means of the clones with the same letter are not significantly different per $p > 0.05$ (Tukey test).

of genetics), while year × clone interaction effects for these traits were not significant.

The correlation between skin hardness and *Botrytis cinerea* infections (three years average) is represented by the negative correlation in Figure 9, which clearly highlights how grape health improves significantly as skin hardness increases, while the correlation between the two variables for each single year is reported in Figure S1.The skin hardness is influenced by various factors, such as the grapevine genetics and ripeness level at harvest, which, in our study, was carried out when the ratio of soluble solids to total acidity was greater than 2.5 (Table S7). In summary, clones with the highest mechanical resistance of the skin (SMA 505, FR 49-207, 1 GM) are also the healthiest, and vice versa (H1, VCR 5, 2-15 GM), and this trend is very clear.

The equation represents the linear regression model. The error bars indicate the standard error of the mean.

7. Berry health status

The Sturges formula created five infection classes with subsequent and common limits, arbitrarily defined as very low, low, medium, high, and very high.

Figure 10 shows the placement of individual clones within different classesconcerning their susceptibility to *Botrytis cinerea* infections.

Clones 1 GM, 2-15 GM, and H1 are placed at the extremes of the scale, with the former being the least and the latter being the most susceptible. Only five clones are positioned in the high class, and the remaining nine have infection levels classified as medium-low.

The analytical description of the three-year data highlights that the average degree of grape infection, evaluated every year at harvest, was higher in 2019 and 2020. The incidence of the disease in both years was around 24 %, which was significantly higher than the value observed in 2021, which was 19.3 %. The severity showed statistically significant differences among the three years, with the highest and lowest values recorded in 2019 and 2021, respectively (Table 4). As a consequence of these two measures, the highest value of healthy clusters was detected in 2021 (80.8 %).

In more detail, the data reveals significant differences observed among individual clones for each of the three years (see Table S8).

Figure 11A,B shows the three-year average of *Botrytis cinerea* and bunch rot infections, highlighting the tendency of clones H1 and 1 GM to be, respectively, the most and least susceptible to *Botrytis cinerea* and bunch rot. While clone H1 had the highest severity (and falls in the "very high" infection class of Figure 10), it was statistically similar to clones up to ENTAV 52 starting from the left of the figure and was different from all others. Clone 1 GM (the only clone falling in the "very low" infection class of Figure 10) had the lowest value but was statistically similar to three others located to the right of the figure and different from all others.The severity

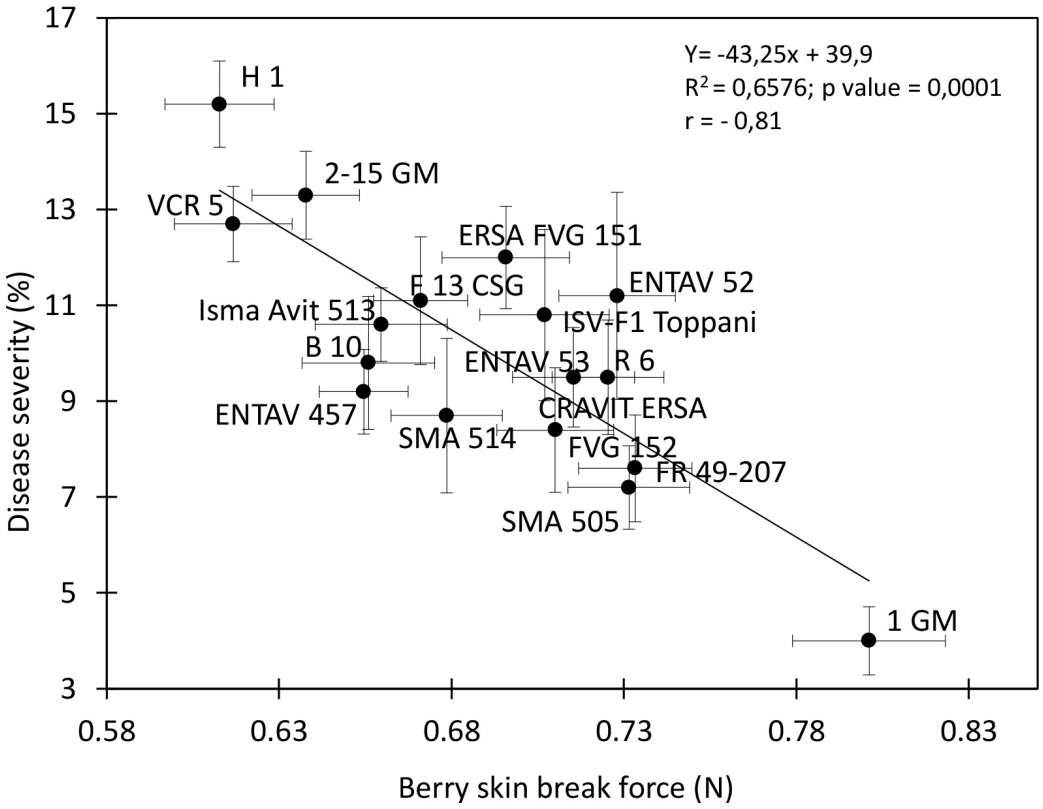


FIGURE 9. Correlation between disease severity and skin resistance (three-year average). Each point on the graph represents the mean value of three years of data (n = 9).

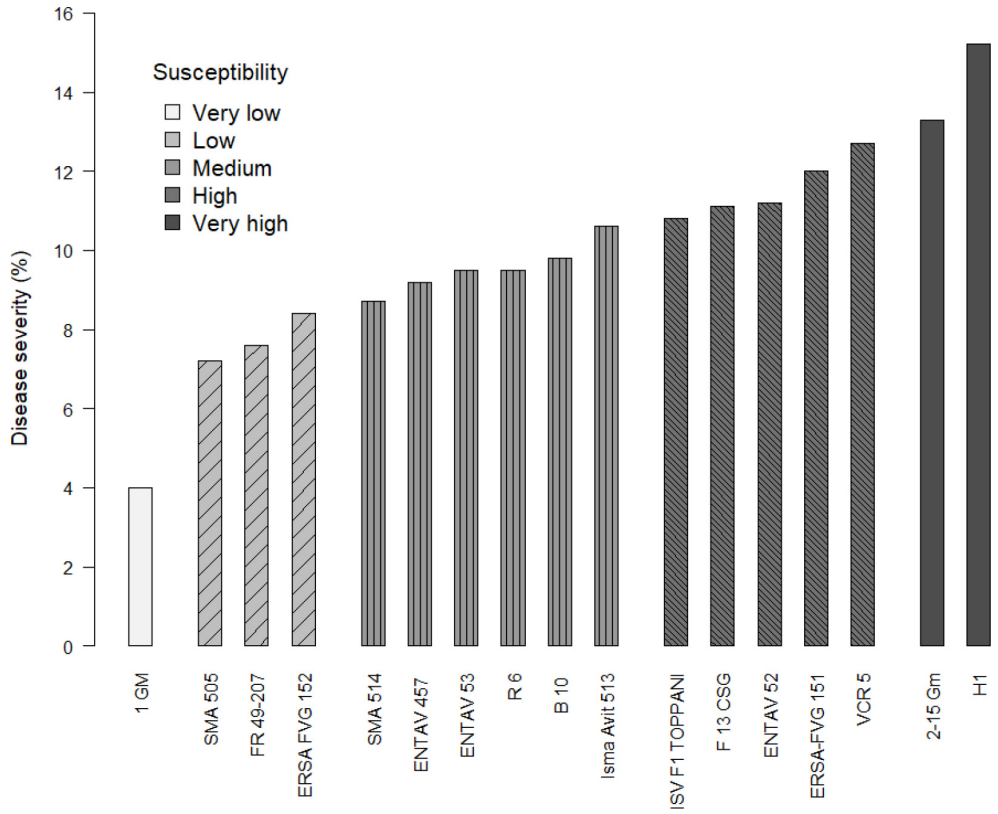


FIGURE 10. The grouping of clones into five infection classes was constructed using the Sturges rule and based on the three-year average value.

values show a deviation of ±5 % from the mean (10.1 %). Excluding the six clones positioned at the extremes of the Figure (H1, VCR 5, and 2-15 GM among the highest values and 1 GM, FR 49-207, and SMA 505 among the lowest), a similar behaviour was observed among the clones.Regarding the incidence of the disease (Figure 11B), whose three-year average is 22.4 %, the health picture did not change, and the order of Figure 11A was essentially maintained. However, unlike the production and quality parameters, which remained consistent across different clones over the three years, the health data showed significant variability, as highlighted by the two-way analysis of variance, which revealed not only the clone effect and the year effect but also a significant "clone x year" interaction (Table S1).

The year effect has already been shown in Table 4 and can be attributed to the different rainfall patterns characterising the months of August and September in the three study years. The cloning effect is reported in Table S8: clones reacted differently to their ripening stage and the rainfall preceding the harvest. Specifically, the data show a decrease in soluble solids content in 2020 across all clones, resulting in many of them concurrently experiencing a reduction in *Botrytis cinerea* infection incidence and severity values (see positive correlation reported in Table S9). Additionally, the abundant rainfall in August 2020, occurring in the two weeks before harvest time (100 mm), and the higher vine vigour confirmed in the same year created an ideal environment for disease development, which manifested in some clones with increased incidence and/or severity values compared to 2019 (F13 CSG, VCR 5, B10, ERSA FVG 152, ENTAV 53, ERSA FVG 151). However, in the same year (2020), other clones such as H1, 2-15 GM, Entav 52, Entav 457, SMA 514, and ISV F1 T showed lower sensitivity to rainfall patterns, resulting in healthier grapes compared to 2019.

Correlations between the severity of grey mouldand various variables were analysed, showing how each variable had

TABLE 4. The effect of different vintages on the health status of grapes is expressed through the percentage of *Botrytis cinerea* attack and bunch rot. Values assigned by different letters are statistically significant at $p \leq 0.05$ (Tukey test).

Year	Disease severity (%)	Disease incidence (%)	Bunch healthy (%)
2019	12.1 a	23.8 a	76.2 b
2020	10.1 b	24.2 a	75.4 b
2021	7.9 c	19.3 b	80.8 a

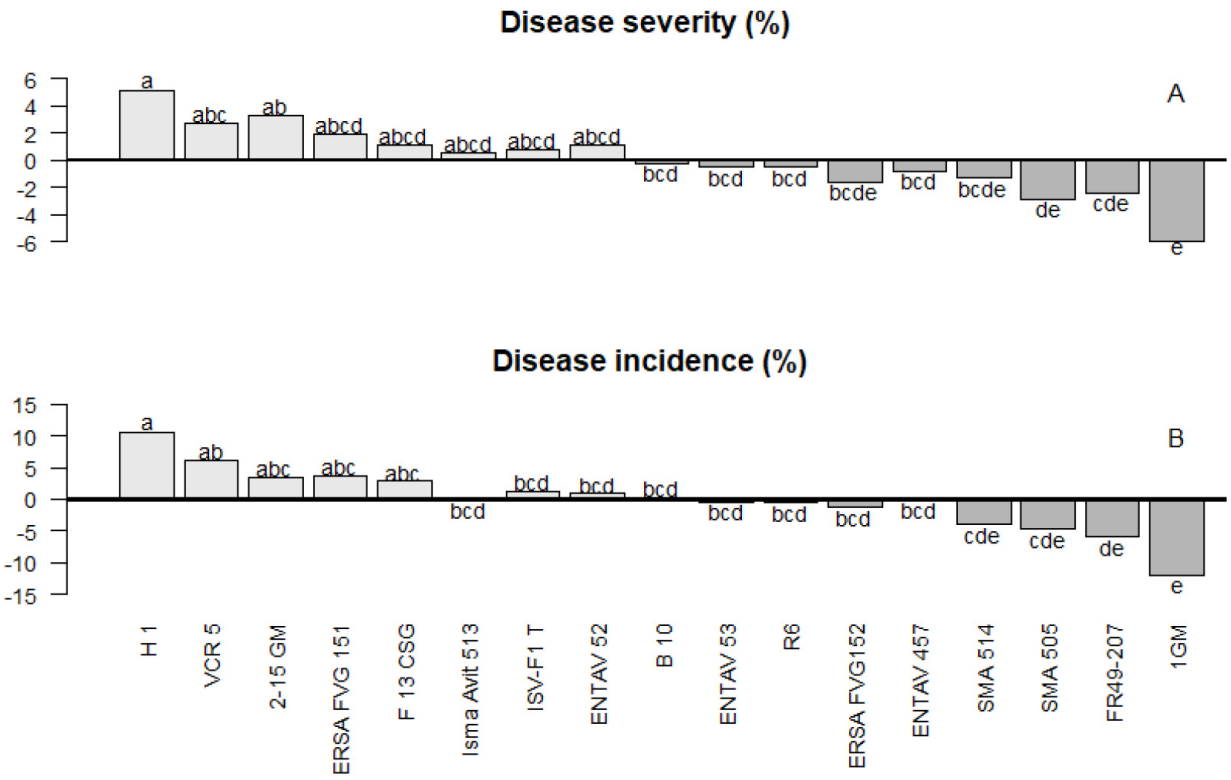


FIGURE 11. The three-year average severity (10.1 %) and incidence (22.4 %) of disease for the 17 clones, respectively, are represented by the black line in panels A and B. The vertical bars indicate the deviation of each individual clone from the group mean. The means of the clones with the same letter are not significantly different per $p > 0.05$ (Tukey test).

TABLE 5. Descriptors for which statistically significant differences were found between wines from the two vintages (Tukey test; for each descriptor, n = 12x17).

2020 wines	p-value	2021 wines	p-value
Olfactory intensity	0.006	Hue	<0.001
White flowers	0.004	Colour intensity	<0.001
Fresh vegetable	0.02	Taste intensity	0.007
Taste intensity	<0.001	Overall evaluation	0.036
Overall evaluation	<0.001	————	——

a different impact on the severity of the disease. From Table S9,it can be seen that the severity of the disease is positively correlated with the SS/TA ratio, soluble solids, vigour and content of anthocyanins and negatively correlated with total acidity, Ravaz index, content offlavonoids and yield per plant.

8. Sensorial analysis

As mentioned in the materials and methods section, a panel of 12 judges evaluated the wines from individual clones obtained from microvinifications (2020 and 2021). In Table 5, only the descriptors for which the analysis of variance revealed statistically significant differences among all clones in the two years are reported (see the *p*-values), briefly describing in the text (here and later on) some characteristics of a few clones, without reporting the data.

In particular, in 2020, the R 6 and 1 GM clones stood out for their greater olfactory intensity, with the former also obtaining the highest score for the "white flowers" descriptor and the latter for the "citrus" descriptor. The R 6 clone, together with the ENTAV 52 and F 13 CSG clones, was also awarded for "gustatory intensity," while for the same descriptors, the SMA 514 clone was the least appreciated. In the overall evaluation, once again, the R 6 clone was preferred to all others. In 2021,the visual evaluation parameters (hue and colouring intensity) showed statistically significant differences among samples as the grapes, in this year, were vinified into rosé. The colour obtained naturally can prove to be interesting in today's market, where such

types of wine are highly appreciated. In particular, the VCR5 clone stood out not only for its greater colouring intensity but also for its greater gustatory intensity. Overall, the ERSA FVG 151 clone was the most appreciated and evaluated by judges as a balanced wine in terms of olfaction and taste.

DISCUSSION

The higher temperature during the first part of the 2020 vegetative season led to an advancement of both budbreak and flowering by about two weeks compared to 2019 and 2021. This advancement persisted until harvest, resulting in the grapes having the lowest sugar content (18.2°Brix) despite intermediate production compared to the other two years. However, despite the advancement, the acidity of the grapes was comparable to that of the other two years (around 7 g/L).

At harvest (SS/TA ≥ 2.5), clone ERSA FVG 151 had the highest absolute concentration of soluble solids (20.1°Brix) despite being a moderately productive clone, but, statistically, ERSA FVG 151 was different only fromfour clones (B10, SMA 505, FR 49-207, and 1 GM). Conversely, B10 had the lowest sugar content (17.1 °Brix) compared to 14 clones and was similar only to FR 49-207 and 1 GM.

The tendency of B10 and, to a lesser extent, of 1 GM and FR49-207 clones to accumulate fewer sugars is a constant observed over the three years. This behaviour affected the potential alcohol content of the future wine, which never reached the minimum value (11 % vol.) required by the PDO disciplinary. In fact, 1 GM e FR 49-207 showed values justbelow the threshold, whereas B10 never exceeded 9.5–10 % vol. of potential alcohol content. For these clones, delaying the harvest to promote higher sugar accumulation could reduce the healthy status of grapes and also subject the production to more severe climatic risks.

Overall, the content in soluble solids is quite similar since the three-yearly mean of every clone is close to the mean of the whole group. The exception is represented by B10 and 1 GM, among the less productive and statistically equal, and ERSA FVG 151, among the most productive, which tend to deviate from the average value. Concerning the total acidity, the only statistically significant differences were found in F13 CSG and H1 clones,but all exceeded the minimum value required by the production regulations (4.5 and 5 g/L), and this aspect is very positive considering its importance for wine quality. In 2021, post-flowering problems significantly reduced the number of bunches, which in turn reduced production. For this reason, both parameters were the lowest of the three years and looking at the three-year average number of clusters (Table S5), statistically significant differences can only be seen between clones 1 GM (48) and B10 (34).

On the other hand, considering the yield, statistically significant differences were only found between clone 1 GM (7.7 kg/vine) and B10 (5.5 kg/vine). Although B10 consistently ranked among the least productive in absolute terms, its grapes consistently had a lower sugar content of 0.5–3.3 °Brix compared to the other clones.

Excludingthese two extreme cases, no clones stand out as particularly productive or unproductive, as the difference within the of all the clones studied fluctuates within a range of ± 400 grams compared to the mean, indicating substantially similar productivity.

As expected, the linear correlation between average production per plant and the sugar content of the musts (Table 9) was negative and significant (r= –0.53; p = 0.034).

The cluster weight, despite the different genetic backgrounds, is very similar, and only in a few clones does it deviate by more than 10 grams from the average, positively (1 GM, FR 49-207) or negatively (IsmaAvit 513) and is positively and significantly correlated (r = 0.65; p = 0.004) with production per plant (Table S9).

Regarding the health status comparison between the three vintages, 2021 was the best due to the lower rainfall in the last 40 days preceding the harvest. In general, without distinction of clones and considering the average value of each year, the severity of the disease in 2021 was 7.9 % compared to 10.1 % in 2020 and 12.1 % in 2019.

In our case, infections were of a late type (from véraison) since precipitation was low before and during flowering. Additionally, immediately after flowering, we used pneumatic leaf strippers to remove the dehiscent floral residues. It has been demonstrated that their accumulation significantly contributes to increasing the severity of early *Botrytis cinerea* infections on grape clusters (Hed *et al*., 2009).

Visual monitoring during the season confirmed that *Botrytis cinerea* infections were absent until the end of the green berry stage (BBCH 79), and the first infections appeared immediately after the onset of véraison, which occurred on DOY 220 in 2019 and 2021, and DOY 208 in 2020. The disease progressed as the grapes matured, with the peak of infections occurring at harvest because, at this stage, the berries have the highest sugar content, and the skin becomes thinner as the number of layers decreases (Lee and Bourne, 1980). Numerous hypodermal cells are also transformed into pulp tissues (Kretschmer *et al*., 2007). This behaviour was also demonstrated in a study by Deytieux-Belleau *et al*., 2009 on Sauvignon Blanc. Through controlled environment inoculation with three *Botrytis cinerea* strains (II-transposa), the level of infection was evaluated during seven berry growth stages (from herbaceous to maturity). The study revealed that berry susceptibility to *Botritis cinerea* increased sigmoidally from the onset of colour change and that the responsible macrostructures were positively or negatively correlated with the severity of *Botritis cinerea.*

The strong relationship between grey mould susceptibility and soluble solids content is also confirmed by Mundy and Beresford (2007) and Kretschmer *et al* . (2007). They studied the evolution of *Botrytis cinerea* by inoculating healthy berries with fungal conidia, showing that susceptibility

to *Botrytis cinerea* increases with the progress of berry maturation.

Our research confirms almost all the results obtained by the study conducted by Deytieux-Belleau, highlighting how disease severity is closely linked to the content of soluble solids, as clearly indicated by the values of the positivecorrelation in Table S9.This result is partially confirmed by Figures 2A and 11, and it is especially clear when considering the extreme values of the two figures.

Indeed,the clones that tend to accumulate more sugars (H1, VCR5, 2-15 GM, F1 Toppani, ERSA FVG 151) and those that have the opposite tendency (1 GM, FR 49-207, SMA 505, SMA 514) are positioned, respectively, on the left side (higher susceptibility) and the right side (lower susceptibility) of Figure 11.

An anomaly is represented by clone B10: despite being the clone with the lowest sugar content, it should theoretically be among the most resistant to *Botrytis cinerea*, yet it falls within the moderate infection class depicted in Figure 10. The values of the correlations between the severity of the infections and the variables studied are mentioned in cited Table S9. The negative correlation between total acidity and susceptibility to *Botrytis cinerea* is in line with the findings of Pezet *et al*. (2004), Vercesi *et al*. (1997), and Donèche (1986), who demonstrated that organic acids could be inhibitors for the pathogen, thus representing a natural barrier that slows down its spread and colonisation of tissues.

In our research, the result is confirmed in a few cases: H1, VCR5, and 2-15 GM are clones that present the lowest total acidity values and the highest *Botrytis cinerea* infection values. The opposite is evident only for ERSA FVG 152, whose total acidity value is among the highest, and its severity value is among the lowest.

The severity of *Botrytis cinerea* is negatively correlated with the Ravaz index (Table S5). For this parameter, the calculated average values range between 6.2 and 16.7 (in Sylvoz-trained Pinot gris, it should oscillate between 6 and 8), and it appears that all the clones have reduced canopy density to properly ripe the production, especially those with a value above 10. At any rate, it is not advisable to intervene specifically to increase its volume as it would risk worsening the internal microclimate of the canopy with negative consequences on grape health (production per hectare and sugar content of grapes, however, are compatible with the provisions of the production regulations).

The correlation between skin hardness and *Botrytis cinerea* infections is highly significant (r=–0.81; p=0.0001), showing a negative relationship. We emphasise that the resistance to breakage was measured on berries collected from different parts of the cluster since it has been shown that the position does not influence the mechanical properties of the skin (Letaief *et al*., 2006). However, for the characteristics of the clones in relation to this relationship, more detailed evaluations should be made by analysing Figures 8 and 10.

Figure 8 revealsthat the first three clones positioned to the left (H1, VCR5, 2-15 GM) and the last three positioned to the right (SMA 505, FR 49-207, and 1 GM) tend to have the lowest and highest skin hardness, respectively. The clones from the two subgroups are statistically different.

The first three are in the higher infection classes, and the other three are in the lower ones in Figure 10, and they are the same clones that exhibit the lowest and highest susceptibility to *Botrytis cinerea* and bunch rot, respectively, as depicted in Figure 11. F13 CSG behaves similarly.

However, this rule is not always respected. For example, clones such as ENTAV 52 and R6, which have resistance values among the highest in the group, are placed in the middle and high infection classes. The same can be said for clones ENTAV 457 and IsmaAvit 513, which, despite having among the lowest breaking points, do not belong to the highest infection classes. Furthermore, B10, which probably has a lower level of maturation and theoretically should have a more resistant skin, is among the clones with the lowest mechanical resistance but good resistance to *Botrytis cinerea* and is placed in the middle infection class of Figure 10. This could be explained by the genetic background of the vine, which could influence the physicochemical composition, structure, and intrinsic properties of the skin (Rolle *et al.*, 2006).

Therefore, skin hardness is certainly a very important aspect from an agronomic and phytopathological point of view (Considine, 1981; Lang and During, 1990; Bišof *et al*., 1994) to be taken into consideration when choosing the clone that offers the highest guarantees regarding resistance to *Botrytis cinerea.*

Numerous studies conducted on different varieties have shown a strong relationship between cluster compactness and susceptibility to decay (Hed *et al*., 2009; Tello *et al*., 2014; Molitor *et al*., 2014). However, this postulate is not always valid. For instance, Vail *et al*. (1998) demonstrated on a population of six Chardonnay clones that susceptibility to *Botrytis cinerea* does not always depend on cluster compactness but can be related to numerous other factors, as already indicated in the introductory part of the text.

Although our study did not define a compactness index, some aspects of the cluster related to its structure were studied through morphometric analyses based on a series of indices regarding the morphological characteristics of the cluster (see Table 4). These indices were the most appropriate as they consider the empty spaces essential to ensure consistent air exchange to limit humidity and water deposits both inside the bunch and on the berries' surface (Hed *et al*., 2009).

Specifically, the surface-to-height ratio of the grape clusters (S/H) can be considered as an index of surface density, reflecting the relationship between the height and surface area of the cluster (number, size, arrangement, and proximity of the berries): the higher the value of the ratio, the lower the compactness of the cluster, and in our study, this index ranges from 25 to 34. If this compactness scale is to be

associated with the degree of *Botrytis cinerea* infection found in the clones under study, it is observed that the relationship between compactness and susceptibility to *Botrytis cinerea* is only valid for those clones whose index value is above 30 (1 GM, ENTAV 457, FR 49-207, SMA 514, CRAVIT ERSA FVG 152). The ratio of surface area to height seems to be more associated with susceptibility to *Botrytis cinerea* and probably with compactness, as confirmed by Lopes and Cadima, 2021. In contrast to the findings of Tello and Ibáñez (2014), this study showed that the ratio of volume to weight and height was strongly correlated with the degree of compactness of grape clusters of different varieties.

The ratio of the perimeter of the cross-section of the cluster to the number of berries on the section (P/B) is an index that estimates the density of the berries and indicates the "average perimeter" of each berry (Hed *et al*., 2009): large values indicate larger size and, especially, less overlap of the berries, so that as the value of the ratio increases, the empty spaces and the looseness of the cluster increase, and it is possible to classify clones according to their compactness. More open clusters should also show greater variability in the P/B index (Cubero *et al*., 2015)

In our study, the values of this ratio range from 0.33 to 2.22: the clones SMA 514, ENTAV 457, 1 G M, FR 49-207, CRAVIT ERSA FVG 152, IsmaAvit 513, and R 6 have values ranging from 1.8 to 2.2. The clones 2-15 GM, F 13 CSG, H1, ERSA FVG 151 have ratios between 0.33 and 1.31.Let's consider the classification of clones as reported in Figure 10. These values express well the relationship between compactness and *Botrytis cinerea* infection, as the former are located in the classes of medium to very low infection and the latterin the classes of high to very high infection. The remaining six clones do not follow this trend and are scattered.

The ratio between the surface area and the total number of berries (S/TotB) indicates the space occupied by each berry per unit of surface area. Therefore, the higher the value of this index, the lower the compactness, as each berry will occupy a larger surface area, which means that the berries are very large or spaced apart. S/TotB represents a more significant "density" index than others, such as the ratio of volume to height or weight to height proposed by Tello and Ibáñez (2014) and Tello *et al.* (2016).

However, it only partially explains the susceptibility of clones to *Botrytis cinerea*, as it provides a modest decreasing trend towards the clusters that are more susceptible to infections.

Finally, as expected, a positive correlation was found with plant vigour and a negative correlation with production.

Although it was not possible to evaluate the potential effect of *Botrytis cinerea* severity on wine quality because the grapes used for microvinification were previously cleared of botrytised clusters and, considering that the focus of the research was not on the oenological aspect, some judgments on the oenological characteristics of the 17 clones can be made based on sensory analysis. In general, few significant differences were revealed.

In 2020, the wine from the historically most well-known clone, R 6, was the most appreciated by the panel. This was due not only to the greater aromatic notes attributed to the typical floral scents of the monoterpenes class but also to a general evaluation in line with the aromatic component of this clone in the viticultural areas of northern Italy (Technical sheet from Vivai Cooperativi Rauscedo - Rauscedo (PN), consulted online on April 13, 2023). Good interaction with the pedoclimatic environment was also confirmed for clones ENTAV 52 and F 13 CSG, while the wine from clone B10 was the least appreciated (along with clones SMA 514 and FR 49-207). This confirms that the potential of this genotype is not fully expressed in this viticultural area.

In 2021, with rosé vinified grapes, clone VCR 5 emerged for both colour intensity and taste, but overall, the wine most appreciated by judges was that of clone ERSA-FVG 151. Once again, clone B10, along with clone FR 49-207, received the lowest score.

CONCLUSION

Despite the good plasticity of the grapevine, our study highlighted how not all clones have adapted well to this cultivation area, as some of them, for various reasons, have not fully expressed themselves or have shown negative aspects at harvest.

Clone H1 is among the most susceptible to *Botrytis cinerea* and bunch rot, being the only one to fall into the highest infection class, and this trend was confirmed in two out of three years; it is among the clones with the highest sugar content, the least resistant skin and tends to have the lowest total acidity. 1 GM was among the least susceptible clones to *Botrytis cinerea* and bunch rot in all three years of the trialand is the only clone to fall into the lowest infection class. It is among the clones with the lowest soluble solid content andis among those that have the greatest resistance to skin penetration.

The 1 GM clone is also among the least vigorous yet one of the most productive thanks to its high bud fertility; it has among the heaviest clusters, and its wine exhibits the highest olfactory intensity. CRAVIT ERSA FVG 152 clone is among the least productive and has one of the highest total acidity levels.

The B10 clone is among the less productive, has the lower buds fertility and soluble solids content, shows the lowest alcohol content of its wine, and, finally, is moderately susceptible to *Botrytis cinerea* and bunch rot.

ERSA FVG 151 is one of the clones with the highest soluble solid content but alsohashigh susceptibility to *Botrytis cinerea* and bunch rot and falls into the 'high' infection class together, with VCR 5, ENTAV 52, ISV F1 Toppani, and F 13 CSG, in the "high" infection class. However, the wine was the most appreciated in the sensory analysis.

Regarding susceptibility to *Botrytis cinerea* infections and bunch rot, it is important to highlight that the clones were

affected by the rainfall pattern in the weeks preceding the harvest time, responding differently and showing a certain sensitivity to this factor. In 2020, the wettest year, many clones experienced an increasein incidence and severity of the disease, while in 2021, the least rainy year, the values were significantly lower than in the other years Table 4). This aspect, which influences clone selection, should be carefully evaluated during the planning of a new vineyard.

According to the OIV 204/9 descriptor, visually, all clones have clusters classified as "very compact." However, through morphometry, five indices have been identified as potentially able to explain better than the other ones the compactness of the cluster by eliminating subjectivity from the morphological evaluation and the dominant shape of the cluster is cylindrical, and all clusters are mono-winged.

In 2020, the wines of the ENTAV 52, R 6, 1 GM, and F 13 CSG clones were awarded for their greater olfactory intensity and some taste notes. The wine of B10 was among the least appreciated, while in 2021, the wine of the VCR 5 clone prevailed for greater colour and taste intensity. Overall, the R 6 and ERSA FVG 151 clones were rated with the highest scores in 2020 and 2021, respectively.

For various reasons, the H1, 2-15 GM, and B10 clones (the latter also from an oenological standpoint) appear to be poorly suited to this cultivation area, while the ERSA FVG 151 clone, although probably not yet fully expressed in local viticulture, is recommended by the producer as a basic clone to improve the performance of new plantings of this cultivar, due to its quality and oenological characteristics.

In conclusion, our study shows that there is no perfect clone, and the results obtained should suggest the realisationof vineyards with several clones through which to synergistically enhance and valorise the productive and qualitative potential in a specific terroir.

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