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Viticultural and oenological characterization of Muscat a Petits Grains Blancs and Muscat giallo clones

Ovrednotenje vinogradniških in enoloških parametrov klonov sort Muscat a Petits Grains Blancs in Muscat giallo

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ABSTRACT

In the present study, viticultural and oenological parameters of six clones of Muscat a Petits Grains Blancs (MPG) and five clones of Muscat giallo were investigated. Differences were found between varieties and clones in the occurrence of the phenological phases: bud break, véraison, and maturity. In the MPG clones (B41-5, FR 94, MPG 154, MPG 454, and MPG 455), all three phenological phases started earlier, resulting in earlier grape maturity and higher total soluble solids content (TSS) in grapes at harvest compared to the M. giallo clones (R1, VCR100, VCR 102, and VCR 5, BEMK 33). The MPG clones also resulted in higher cluster weight, higher yield per vine, and lower must pH compared to the M. giallo clones. The only exception was the MPG clone R2, which showed more similarities with the M. giallo clones. The wines of the MPG clones showed a tendency toward higher values for alcohol, citronellol, total acids, and total dry matter. In contrast, the wines of the M. giallo clones and the R2 clone of MPG showed higher pH and higher levels of linalool, α-terpineol, geraniol, and nerol. Although R2 is classified as a clone of MPG, our results indicate a strong similarity with the M. giallo clones studied. This study has highlighted the differences in phenological development and grape and wine quality characteristics between MPG and M. giallo clones. Therefore, clone selection can be an important tool for winemakers to develop the desired wine style and adapt to climatic changes.

Keywords: climatic changes, clonal selection, monoterpenes, Muscat wine, wine quality

POVZETEK

V raziskavi smo preučili vinogradniške in enološke parametre šestih klonov sorte Muscat a Petits Grains Blancs (MPG) in petih klonov sorte Muscat giallo. Med sortami in kloni so bile ugotovljene naslednje razlike v fenoloških fazah: odganjanje zimskih očes, dozorevanje in zrelost grozdja. Začetek vseh treh fenoloških faz je bil zgodnejši pri klonih sorte MPG (B 41-5, FR 94, MPG 154, MPG 454 in MPG 455), kar se je odrazilo v zgodnejšem dozorevanju grozdja in večji vsebnosti skupne suhe snovi (TSS) v moštu ob trgatvi, v primerjavi s kloni sorte M. giallo (R1, VCR100, VCR 102 in VCR 5, BEMK 33). Kloni sorte MPG so imeli v primerjavi s kloni sorte M. giallo večjo maso grozda, večji pridelek po trsu in nižjo vrednost pH mošta. Edina izjema je bil klon R2 sorte MPG, ki je bil po vinogradniških parametrih bolj podoben skupini klonov sorte M. giallo. V vinih, pridelanih iz grozdja klonov sorte MPG, smo izmerili večje vsebnosti alkohola, citronelola, skupnih kislin in ekstrakta brez sladkorja. V nasprotju pa so imela vina, pridelana iz klonov sorte M. giallo in klona R2 (sorte MPG), izmerjeno višjo vrednost pH in večje vsebnosti linaloola, α-terpineola, geraniola in nerola. Čeprav je bil klon R2 klasificiran kot klon sorte MPG, naši rezultati kažejo veliko podobnost tega klona s kloni sorte M. giallo. Študija je poudarila razlike v fenološkem razvoju in kakovostnih parametrih grozdja in vina med kloni sort MPG in M. giallo. S selekcijo klonov lahko pomembno vplivamo na kakovostne parametre grozdja, kar neposredno vpliva na slog vina. Hkrati lahko s pravilno odbiro klonov vinogradniško prakso prilagajmo spreminjajočim se podnebnim razmeram in ohranjamo tipičnost pridelanih vin.

Ključne besede: podnebne spremembe, klonska selekcija, monoterpeni, muškat, kakovost vina

INTRODUCTION

Muscats are a large group of *Vitis vinifera* L. grape varieties that share not only the common name but also the typical muscat aroma (Crespan and Milani, 2001). Within the Muscat family, there is a high genetic variability, mainly due to spontaneous natural mutations (OIV, 2017; van Leeuwen et al., 2019). In addition, there are a large number of synonyms and homonyms registered in the Vitis International Variety Catalogue (VIVC) (Maul, 2022). One of the most important wine varieties of the Muscat family, Muscat a petits grains blancs (MPG), is listed in the VIVC as Gelber Muskateller, Muscat blanc, Moscato bianco, Rumeni muškat, and other synonyms. The variety Muscato giallo is also listed in the VIVC and Goldmuskateller is mentioned as a synonym. The varieties MPG and M. giallo differ in phenological characteristics (e.g., ripening time), yield, and quality parameters (growth performance, yield, aroma profile, and sensory characteristics). The MPG variety ripens earlier, has larger clusters, and higher sugar and total acidity than M. giallo, as measured in must (Regner et al., 2015; Jaquerod et al., 2016). In addition, an important tool for improving vine parameters is clonal selection (Vujović et al., 2016; OIV, 2017). So far, several clones have been selected in France, Germany, Austria, and Italy for the variety MPG and in Italy and Germany for the variety M. giallo.

The specific and characteristic aroma profile of Muscat grapes and wines has been studied by several authors (Ribéreau-Gayon et al. 1975; Lanaridis et al., 2002), and the terpenes linalool, geraniol, nerol, α-terpineol, two furan oxides and two piran oxides of linalool have been identified as the main aroma compounds responsible for the typical Muscat aroma. Flamini et al. (2001) analysed the content of free and glycosidically bound monoterpenes in grapes of different Muscat varieties and confirmed that 78% of the samples with a similar genetic profile had similar aroma characteristics, although cultivation methods and environmental variables may influence each other. Moreover, among the varieties studied, a particularly high content of monoterpenes was found in those belonging to the M. giallo genetic profile, with the highest total linalool content (about 1.3 mg/kg of grapes) and the highest total diendiol I content (between 2.1 and 3.2 mg/kg of grapes). Monoterpenes also play an important role in the differentiation of wine varieties and their concentrations have a significant influence on the sensory quality of the wines produced (Rapp, 1998; Čuš et al., 2009).

The economic importance of Rumeni muškat (MPG variety) in Slovenia is significant, as it is grown on about 650 ha (RPGV, 2020). According to the literature, the different clones of Muscat varieties in Slovenia were not compared under the same experimental conditions. The choice of a suitable clone of a particular grape variety is definitely one of the prerequisites for producing high-quality grapes (Vujović et al., 2016) and wines with the desired chemical and sensory characteristics (van Leeuwen et al., 2013; Regner et al., 2021) and adaptation to climatic changes (van Leeuwen et al., 2019). Therefore, six MPG and five M. giallo clones originating from clonal selections in Austria, France, Germany and Italy were examined in the present study. The aim was to evaluate the viticultural and oenological characteristics of these clones and their potential use in different regions of Slovenia in the context of changing climatic conditions.

MATERIALS AND METHODS

Vineyard location and experimental design

Grapevine material of Muscat a Petits Grains Blancs (MPG) and Muscat giallo (Table 1) varieties was planted in a vineyard in the Vipava Valley in the Primorska wine region of western Slovenia with a sub-Mediterranean climate

- Lože village, Pouzelce site (45°50'01'N, 13°56'19'E, elevation 170 m). The vineyard consists of euteric brown soil on flysch. The organic matter content was 2% and the soil pH was 6.1. The texture class of the soil is silty clay loam. The vines were planted in two consecutive years, 2012 and 2013 (Table 1), at a spacing of 2.5 x 1.0 m (row in row x vine), with the rows facing west-east. Clones of both varieties were randomly planted in four consecutive rows in one repetition with 25 vines per clone. Given the location of the vineyard and the short length of the rows, we assumed that there would be no differences in terrain, i.e., exposure, drainage, and soil type and depth, between rows and within each row. The terrain is almost flat with a slope of 8%. The vines were trellised to a single Guyot and were not irrigated during the season. The experiment was carried out in the 2015, 2016 and 2017 vintages.

Grapevine material

Six clones of MPG and five clones of M. giallo were grafted onto three different rootstocks, all of which were crosses of *V. berlandieri* x *V. riparia* (Table 1). Vine phenology was monitored during the experiment using the BBCH scale (Lorenz et al., 1995).

Meteorological data

Meteorological data were collected by the Agrometeorological Portal of Slovenia (UVHVVR, Agrometeorološki portal Slovenije, http://agromet.mko.gov.si/APP/Tag/Export/155, March 14, 2022) from the Slap weather station (49193), located 500 m from the experimental vineyard, to calculate average temperatures and precipitation for the period from April 1 to September 30 for the 2015 to 2017 vintages. The growing degree days (GDD) index was calculated using 10 °C as the baseline temperature for the vine, which was subtracted from the average temperature recorded from April 1 to September 30 (Jones et al., 2010).

Yield and grape parameters

Average yield and number of clusters per vine were determined at harvest of each vintage on 10 representative vines per clone. The average weight of cluster was calculated from the recorded yield per vine divided by the number of clusters per vine.

Table 1. The list of clones for M. a Petits Grains Blancs (MPG) and M. giallo varieties planted in the Vipava Valley, the country and place of selection, the rootstock used and the year of planting

Muscat variety	Synonym	Clone	Country and place of origin	Grafted on rootstock	Year of planting
M. a Petits Grains Blancs	Gelber Muskateller	B 41-5	Austria, Rebveredler	SO4	2012
	Gelber Muskateller	FR 94	Germany, Freiburg	SO4	2012
	Muscat à petit grains blancs	MPG 154	France, Lot-et-Garonne	SO4	2013
	Muscat à petit grains blancs	MPG 454	France, Drome	SO4	2013
	Muscat à petit grains blancs	MPG 455	France, Drome	R110	2013
	Moscato bianco	R2	Italy, Asti	/[a]	2013
M. giallo	Gold Muskateller	BEMK 33	Germany, Obersülzen	SO4	2012
	Moscato giallo	R1	Italy, Rauscedo (PN)	Kober 5BB	2012
	Moscato giallo	VCR 5	Italy, Grave di Rauscedo	Kober 5BB	2012
	Moscato giallo	VCR 100	Italy, Campodarsego (PD)	SO4	2012
	Moscato giallo	VCR 102	Italy, Grave di Rauscedo	Kober 5BB	2012

Grape harvest and microvinifications

In the 2015, 2016 and 2017 vintages, approximately 25 kg of grapes per clone were harvested at the time of technical ripeness of the grapes, which was determined by measurements of total soluble solids (TSS) and total acids (TA). Grapes were destemmed using an Inox destemmer (Enoop, Vipava, Slovenia) and 0.25 g/L Suprarom product (25% ascorbic acid, 50% potassium metabisulfite, 25% tannins; Laffort, Bordeaux, France) was added to prevent oxidation of mash and must. The mash from each clone was pressed immediately after destemming using a 55-litre water bladder press with a maximum pressure of 1.5 bar (Lancman VSX 55, Gomark d.o.o., Vransko, Slovenia). The pressed must was collected in a 15-litre glass container/clone, and 50 mL of must was taken for analysis of total soluble solids (TSS), total acidity (TA), and pH. The must was left overnight at +4 °C for cold settling. The next day, the clear must was racked into 10-litre containers in the presence of N2 gas. After tempering to 18 °C, the must was inoculated with ADY *Saccharomyces cerevisiae* Uvaferm 228 (Lallemand, Montreal, QC, Canada) at a rate of 0.3 g/L without prior dehydration of the yeast. Fermentations were performed in a temperature-controlled room at 16 to 18 °C in one replicate per clone. The fermenting must was supplemented with the yeast nutrient Nutri start Org (0.3 g/L), corresponding to the addition of 30 mg yeast assimilable nitrogen (YAN)/L of must (Laffort, Bordeaux, France) at about 1/3 of fermentation, as determined by refractometric TSS measurements. The progress of fermentation was monitored by refractometric measurements of density in degrees Oechsle. All treatments fermented to a residual sugar content of 1.1-3.5 g/L as measured by an enzymatic robot (Mindray, BS -200, China). At the end of fermentation, a 5 to 6% aqueous solution of sulphurous anhydride was added at a level of 50 mg/L SO_2, and the wine was racked. The wines were bottled in 0.75-litre screw-cap bottles 8 to 10 weeks after the first racking and stored in the wine cellar at 12 °C.

Grape must and wine analysis

The TSS (Brix) in the must was determined using a digital refractometer WM -7 (Atago, Saitama, Japan). The pH value of must and wine were measured using MeterLab PHM 210 (Radiometer Analytical, Lyon, France). TA was determined by sodium hydroxide titration and the indicator bromothymol for colorimetric modification and expressed as g/L tartaric acid. Reducing sugars were quantified using an enzymatic robot (BS -200, Mindray, Nanshan, Shenzhen, China) and total dry matter using the method OIV-MA -AS2-03B (OIV, 2022). Alcohol content was measured using an Alcolyser Wine M alcohol meter (Anton Paar, Graz, Austria). Since the wines of the selected clones differ in the concentration of reducing sugars, their concentration was included in the calculation of potential (theoretical) alcohol.

Analyses of monoterpene alcohols

Analyses were performed by headspace solid-phase microextraction (HS-SPME) as described by Bavčar et al. (2011) using a gas chromatograph (GC, Agilent Technologies 7890A, Palo Alto, Santa Clara, CA, USA) coupled to MS (Agilent Technologies 5975C, Palo Alto, Santa Clara, CA, USA) and equipped with a Gerstel MPS autosampler (Gerstel, Mulhein an der Ruhr, Germany). Wine samples were diluted 1:4 with ultrapure MilliQ water. 4-nonanol was added to 5 ml of the diluted wine in an SPME vial, followed by the addition of 1.7 g NaCl. Compounds were separated on an INNOWax column (30 m x 0.25 mm, 0.25 µm film thickness; Agilent Technologies) connected to a deactivated 2 m x 0.25 mm fused silica guard column (Agilent Technologies). The ions used for the quantification of monoterpene alcohols and the method validation parameters are described elsewhere (Bavčar, 2011; Bavčar and Česnik, 2011).

Statistical analysis

Because there were not enough grapes to perform three replicates for each clone in each year, comparisons of viticultural and oenological parameters between clones were made with the combined sample of three years to form n = 3. Since vintage variation is accounted for, vintage is not separated as a separate variable. Therefore, all reported uncertainties of must and wine parameters are the standard deviation of three vintages for one clone. Analysis of variance (ANOVA) was performed using Statistica, version 12 (StatSoft, Tulsa, OK, USA). Means were separated and compared for significant differences at $P < 0.05$ using Fisher's LSD test. Principal component analysis (PCA) was performed using Statistica, version 12 (StatSoft, Tulsa, OK, USA) for data with scaled unit variance.

RESULTS AND DISCUSSION

Climatic conditions and phenological stages

Samples were collected in three growing seasons (from 2015 to 2017) that differed in GDD, average daily temperature and precipitation (Figures 1, 2), making our comparisons between clones and varieties robust. The average climatic parameters for the period from April 1 to September 30 for all three years were as follows: mean daily temperature 20.0 ± 0.9 °C, precipitation 624 ± 184 mm, and GDD value 1885 ± 92.

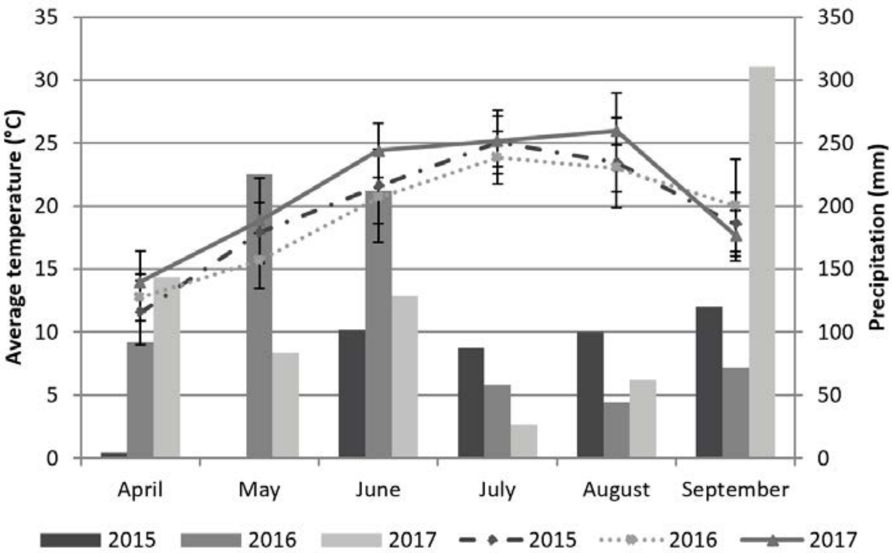

Figure 1. Average monthly precipitation (mm) - histograms and average temperatures (°C) from April 1 to September 30 at the Slap - Vipava Valley site for the 2015, 2016 and 2017 vintages

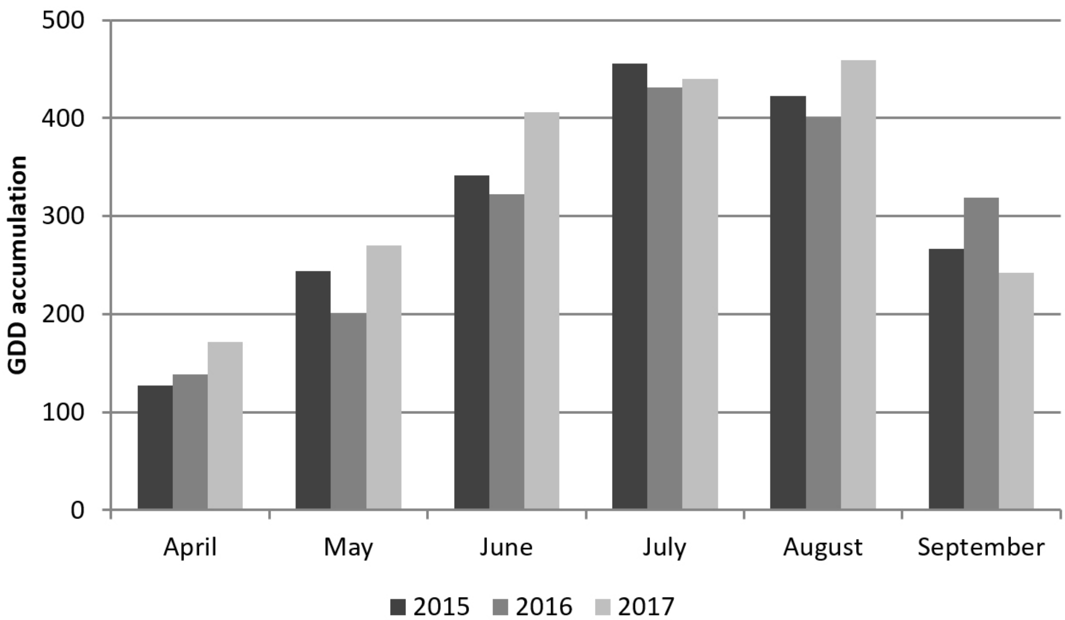

Figure 2. Growing degree days (GDD) by month for the vegetation periods 2015, 2016 and 2017 at the Slap - Vipava valley site

Consistent with the variation in temperature and precipitation among the three vintages, differences in the occurrence of phenological stages of up to 9, 11, 16, and 11 days, respectively, were observed for sprouting-bud development, inflorescence emergence and anthesis, berry softening, and harvest (Table 2). Variations of several days in the onset of phenological stages between vintages can be attributed primarily to inter annual variations in average temperatures rather than to changes in precipitation (Ramos and de Toda, 2022). Results of phenological stages onset, calculated as the average of three seasons in which different weather conditions prevailed, show that clones of MPG, with the exception of clone R2, began bud development (BBCH 05-09) on average 1-3 days earlier than M. giallo clones (Table 2).

Despite the small difference, this may be important due to the increased frequency of late spring frosts (de Rosa et al., 2021), which pose a greater risk in colder areas (Meier et al., 2018). At the onset of the inflorescence emergence and flowering phenological stages (BBCH 55-68), there were no major differences between the clones of the two varieties, except for the Italian clone R2 (MPG variety), where inflorescence emergence and anthesis started 1-2 days later than in the other clones (Table 2). However, the differences between the clones of the two varieties increased with the onset of berry softening (BBCH 85-88) and were even greater at the onset of grape maturity (BBCH 89; Table 2). Ripening and sugar accumulation were faster for MPG clones compared to M. giallo clones, with the exception of R2, resulting in an earlier harvest date. In 2015, MPG clones MPG 154, MPG 454, and MPG 455 were harvested on August 20, clones B 41-5 and FR 94 on August 27, and clone R2 on September 21. In the subsequent 2016 and 2017 vintages, the MPG clones, with the exception of clone R2, were harvested at the same time, on September 8 in 2016 and August 23 in 2017. Clone R2 was harvested on September 23 in 2016 and September 4 in 2017. All Muscat giallo clones were harvested on September 10 in 2015, September 23 in 2016, and September 4 in 2017.

The results show that the MPG clones, with the exception of the Italian clone R2, have a shorter vegetative cycle than the M. giallo clones, as previously observed by Jaquerod et al. (2016). Interestingly, the Italian MPG

Table 2. Average day of year and date ± standard deviation for phenological stages of M. a Petits Grains Blancs (MPG) and M. giallo clones from 2015 to 2017

		Phenological stage			
Muscat variety	Clone	Sprouting-Bud development (BBCH 05-09)	Inflorescence emerge and Anthesis (BBCH 55-68)	Softening of the berries (BBCH 85-88)	Harvest (BBCH 89)
M. a Petits Grains Blancs	B 41-5	95(5.4.) ± 9	146(25.5.) ± 10	231(18.8.) ± 12	241(28.8.) ± 9
	FR 94	95(5.4.) ± 9	145(24.5.) ± 11	231(18.8.) ± 12	241(28.8.) ± 9
	MPG 154	97(7.4.) ± 6	146(25.5.) ± 10	233(20.8.) ± 16	239(26.8.) ± 11
	MPG 454	97(7.4.) ± 6	146(25.5.) ± 10	233(20.8.) ± 16	239(26.8.) ± 11
	MPG 455	97(7.4.)±6	146(25.5.) ± 10	233(20.8.) ± 16	239(26.8.) ± 11
	R2	98(8.4.) ± 6	148(27.5.) ± 10	238(25.8.) ± 8	258(14.9.) ± 11
M. giallo	BEMK 33	97(7.4.) ± 6	145(24.5.) ± 11	237(24.8.) ± 8	255(11.9.) ± 10
	R1	98(8.4.) ± 6	146(25.5.) ± 10	237(24.8.) ± 8	255(11.9.) ± 10
	VCR 5	98(8.4.) ± 6	146(25.5.) ± 11	237(24.8.) ± 8	255(11.9.) ± 10
	VCR 100	98(8.4.) ± 6	146(25.5.) ± 10	237(24.8.) ± 8	255(11.9.) ± 10
	VCR 102	98(8.4.) ± 6	146(25.5.) ± 10	237(24.8.) ± 8	255(11.9.) ± 10

The values in the red cells represent the maximum value, in the yellow cells the median and in the green cells the minimum value.

clone R2 shows strong similarities with the M. giallo clones in terms of the timing of vegetative development. Shortening the vegetative cycle and ripening of grapes, as well as shifting ripening and harvest dates to the warmer summer months, can significantly affect the quality of grapes produced, resulting in high sugar content and low acidity (Vršič et al., 2014; van Leeuwen and Darriet, 2016; van Leeuwen et al., 2019) and negatively affecting terpenoids in wine (Marais 1983, Šuklje et al., 2019). Therefore, in the face of climate change, the cultivation of late-ripening varieties and clones with lower sugar accumulation will be beneficial in the future to produce high-quality wines under elevated temperatures and maintain their typicity according to their origin (Duchêne et al., 2010; van Leeuwen and Darriet, 2016; van Leeuwen et al., 2019).

Viticultural parameters

The values of the different viticultural parameters were calculated as the average of three vintages for each clone per variety (Table 3). No significant differences were found in the number of clusters per vine between the different clones of the two varieties. The differences between cluster weight and yield per vine of the different clones of the two varieties were statistically significant (Table 3). The tendency to higher cluster weight and yield per vine was observed in the MPG clones (B 41-5, FR 94, MPG 154, MPG 455, and R2) compared to the M. giallo clones (R2, VCR 5, VCR 100, and VCR 102). The exception was the French clone MPG 454, which had the lowest yield per vine among the MPG clones tested and was comparable to the values of the M. giallo clones (Table 3). Among the M. giallo clones, BEMK 33 had an above-average yield per vine, similar to the MPG clones (Table 3). The highest cluster weight (215.5 ± 24.9 g) was measured for the Austrian MPG clone B 41-5, and the lowest (138.0 ± 22.8 g) for the Italian M. giallo clone R1 (Table 3). The highest-yielding clone (2.63 ± 0.53 kg per vine or 1.22 ± 0.25 kg per m^2) was the French MPG clone MPG 455, and the lowest-yielding (1.45 kg/vine or 0.67 kg per m^2) was the French MPG clone MPG 454 (Table 3). The results are somewhat consistent with the descriptions of the clones (UMT Géno-Vigne et al., 2021), except that the clone MPG 454 was less productive in our experiment.

Table 3. Grapevine yield parameters were calculated as the average of three vintages

Muscat variety	Clone	Clusters/vine	Cluster weight (g)	Yield per vine (kg)
M. a Petits Grains Blancs	B 41-5	10.3 ± 3.4	215.5 ± 24.9 ^{a}	2.17 ± 0.59 ^{ab}
	FR 94	12.3 ± 3.7	200.6 ± 11.9 ^{ab}	2.45 ± 0.68 ^{ab}
	MPG 154	12.0 ± 1.4	184.9 ± 5.7 ^{abc}	2.22 ± 0.33 ^{ab}
	MPG 454	9.9 ± 0.8	145.8 ± 12.7 ^{bc}	1.45 ± 0.00 ^{b}
	MPG 455	13.1 ± 0.6	204.0 ± 46.1 ^{ab}	2.63 ± 0.53 ^{a}
	R2	15.0 ± 2.2	150.9 ± 2.7 ^{bc}	2.15 ± 0.40 ^{ab}
M. giallo	BEMK 33	11.8 ± 2.8	200.3 ± 34.9 ^{ab}	2.28 ± 0.81 ^{ab}
	R1	11.5 ± 2.8	138.0 ± 22.8 ^{c}	1.56 ± 0.52 ^{b}
	VCR 5	11.0 ± 1.7	176.3 ± 23.6 ^{abc}	1.88 ± 0.03 ^{ab}
	VCR 100	12.1 ± 2.4	155.7 ± 36.4 ^{bc}	1.83 ± 0.53 ^{ab}
	VCR 102	11.8 ± 2.4	171.9 ± 52.7 ^{abc}	1.95 ± 0.42 ^{ab}

Data are given as mean ± standard deviation. Letters next to values indicate statistically significant differences between clones of two Muscat varieties as determined by one-way ANOVA and Fisher LSD test at *P*<0.05. The values in the red cells represent the maximum value, in the yellow cells the median and in the green cells the minimum value.

In general, our experiment showed a trend toward lower yields in the group of Italian M. giallo clones.

Must parameters

In general, musts from MPG clones (B 41-5, FR 94, MPG 154, MPG 454, MPG 455), with the exception of the Italian clone R2, had significantly lower pH and higher TSS content than M. giallo clones (BEMK 33, R1, VCR 5, VCR 100, VCR 102) (Table 4).

The differences at TA were not significant. The highest pH (3.62 ± 0.13) was measured in must of the Italian clone R2 of MPG and in two clones of M. giallo, VCR 100 and VCR 102, (3.62 ± 0.06) and (3.62 ± 0.08), respectively. The lowest pH (3.43 ± 0.14) was measured in must of the Austrian clone B 41-5 of the variety MPG. Conversely, the highest TA (5.76 ± 1.54 g/L) was measured in must of Austrian clone B 41-5 and the lowest in must of Italian clones VCR 100 and VCR 102 (4.34 ± 0.23 g/L and 4.34 ± 0.13 g/L, respectively). The highest TSS content was measured in the must of the French MPG clone MPG 454 (22.6 ± 1.1 Brix), and the lowest values of TSS content were measured in the must of the German M. giallo clone BEMK 33 and the Italian clone R1, (19.0 ± 2.0 Brix) and (19.0 ± 1.8 Brix), respectively. It can also be seen that the French MPG clones are ranked by yield, from low (MPG 454) to medium (MPG 154) to higher yields per vine (MPG 455) and, consequently, in reverse order in terms of TSS content in the must (Table 4).

Wine parameters

Notwithstanding the fact that the quantities of grapes harvested did not allow us to work with sufficiently large quantities of must to carry out repetitions of fermentation, we consider that three repetitions of vintage are relevant enough for each clone to draw reliable conclusions.

Comparing differences between wines from clones of two varieties, there was a tendency toward higher levels of alcohol, total dry matter, TA, and citronellol in wines from French (MPG 154, MPG 454, MPG 455), German (FR 94), and Austrian (B 41-5) clones of the MPG variety (Table 5).

Table 4. Must parameters were calculated as the average of three vintages

Variety	Clone	pH	TA (g/L)	TSS (Brix)
M. a Petits Grains Blancs	B 41-5	3.43 ± 0.14 [d]	5.76 ± 1.54	20.1 ± 1.4 [bc]
	FR 94	3.49 ± 0.08 [abcd]	5.65 ± 1.11	21.0 ± 1.2 [abc]
	MPG 154	3.47 ± 0.08 [cd]	4.94 ± 0.85	21.8 ± 0.6 [ab]
	MPG 454	3.47 ± 0.05 [cd]	4.93 ± 1.0	22.6 ± 1.1 [a]
	MPG 455	3.50 ± 0.04 [abcd]	4.67 ± 0.98	20.3 ± 0.4 [abc]
	R2	3.62 ± 0.13 [ab]	4.79 ± 0.47	20.4 ± 0.7 [abc]
M. giallo	BEMK 33	3.48 ± 0.07 [bcd]	4.94 ± 0.45	19.0 ± 2.0 [c]
	R1	3.56 ± 0.06 [abcd]	4.74 ± 0.37	19.0 ± 1.8 [c]
	VCR 5	3.59 ± 0.09 [abc]	4.60 ± 0.22	19.6 ± 2.0 [bc]
	VCR 100	3.62 ± 0.06 [a]	4.34 ± 0.23	20.4 ± 1.3 [abc]
	VCR 102	3.62 ± 0.08 [a]	4.34 ± 0.13	20.4 ± 1.1 [abc]

Data are given as mean ± standard deviation. Letters next to values indicate statistically significant differences between clones of two Muscat varieties as determined by one-way ANOVA and Fisher LSD test at $P<0.05$. The values in the red cells represent the maximum value, in the yellow cells the median and in the green cells the minimum value.

Table 5. Wine parameters were calculated as the average of three vintages

Variety	Clone	Total alcohol (% vol.)	Total dry matter (g/L)	TA (g/L)	pH	α-terpineol (μg/L)	Linalool (μg/L)	Geraniol (μg/L)	Nerol (μg/L)	Citronellol (μg/L)
M. a Petits Grains Blancs	B 41-5	12.63 ± 0.84	21.77 ± 2.06	6.23 ± 0.68 ^{a}	3.40 ± 0.15 ^{d}	867 ± 149 ^{bcd}	483 ± 372 ^{bc}	219 ± 151 ^{bc}	74 ± 87	59 ± 56
	FR 94	13.15 ± 0.59	21.83 ± 1.11	6.13 ± 0.40 ^{ab}	3.51 ± 0.08 ^{bcd}	732 ± 144 ^{cd}	516 ± 273 ^{bc}	204 ± 65 ^{bc}	67 ± 65	70 ± 36
	MPG 154	13.65 ± 0.44	20.83 ± 1.21	5.57 ± 0.49 ^{bc}	3.49 ± 0.14 ^{cd}	792 ± 91 ^{bcd}	380 ± 103 ^{c}	189 ± 49 ^{c}	63 ± 60	53 ± 29
	MPG 454	15.04 ± 0.44	21.43 ± 1.48	5.43 ± 0.49 ^{cd}	3.51 ± 0.12 ^{bcd}	701 ± 268 ^{d}	467 ± 246 ^{bc}	211 ± 71 ^{bc}	80 ± 30	70 ± 28
	MPG 455	12.60 ± 0.23	20.30 ± 0.95	5.60 ± 0.17 ^{bc}	3.48 ± 0.08 ^{cd}	819 ± 265 ^{bcd}	528 ± 332 ^{bc}	218 ± 108 ^{bc}	69 ± 76	78 ± 63
	R2	12.72 ± 1.21	19.40 ± 1.08	4.73 ± 0.15 ^{ef}	3.72 ± 0.18 ^{ab}	1114 ± 127 ^{abcd}	887 ± 323 ^{abc}	390 ± 145 ^{abc}	87 ± 72	29 ± 17
M. giallo	BEMK 33	11.51 ± 1.51	19.2 ± 1.37	5.23 ± 0.35 ^{cde}	3.55 ± 0.14 ^{abcd}	1392 ± 275 ^{a}	823 ± 346 ^{abc}	394 ± 131 ^{abc}	76 ± 57	20 ± 16
	R1	11.46 ± 1.34	18.87 ± 1.27	4.93 ± 0.15 ^{def}	3.64 ± 0.11 ^{abc}	1355 ± 366 ^{a}	1037 ± 529 ^{abc}	469 ± 172 ^{a}	94 ± 70	22 ± 16
	VCR 5	12.03 ± 1.39	19.37 ± 2.19	4.73 ± 0.29 ^{ef}	3.69 ± 0.17 ^{abc}	1198 ± 182 ^{ab}	1220 ± 617 ^{a}	466 ± 175 ^{a}	94 ± 69	27 ± 22
	VCR 100	12.58 ± 0.94	19.6 ± 2.00	4.57 ± 0.15 ^{f}	3.74 ± 0.13 ^{a}	1116 ± 260 ^{abc}	1057 ± 487 ^{abc}	448 ± 153 ^{a}	91 ± 70	35 ± 36
	VCR 102	12.86 ± 0.68	19.37 ± 2.44	4.63 ± 0.21 ^{f}	3.73 ± 0.16 ^{ab}	1130 ± 285 ^{abc}	1078 ± 578 ^{ab}	426 ± 162 ^{ab}	85 ± 60	41 ± 38

Data are given as mean ± standard deviation (n = 3). Letters next to values indicate statistically significant differences between clones of the two Muscat varieties as determined by one-way ANOVA and Fisher LSD test at $P<0.05$. The values in the red cells represent the maximum value, in the yellow cells the median and in the green cells the minimum value.

In contrast, the wines of the Italian clones (BEMK 33, R1, VCR 5, VCR 100, VCR 102) of the M. giallo variety and the Italian clone R2 of the M. a Petits Grains Blancs variety had higher pH and higher levels of monoterpene alcohols, namely α-terpineol, linalool, geraniol ($P<0.05$), and nerol (Table 5).

The odor detection thresholds for monoterpene alcohols are as follows: α-terpineol 250 μg/L, linalool 15 to 25 μg/L, geraniol 30 μg/L, nerol 300 μg/L, and citronellol 100 μg/L (Fereira et al., 2000; Guth, 1997). Geraniol and linalool are the major aroma compounds in Muscat grapes (Ribéreau-Gayon et al., 1975). Their concentrations and those of α-terpineol exceeded the reported thresholds for odor detection in the wines of all Muscat clones.

To summarize the results, two PCAs (Figure 3 (A, B); Figure 4 (A, B)) were applied to the measured yield, must, and wine parameters, averaged over three years, separately for the MPG and M. giallo clones. A clear separation of the MPG clones MPG 454, 154, 455, FR -94, B-41-5 and R2 was observed according to the principal component (PC) 1, which explained 56.86% of the variance in the data set (Figure 3A). The French clones MPG 154 and MPG 455 grouped with the German clone FR 94 and the Austrian clone B 41-5 (Figure 3B), which showed higher cluster weight, yield per vine, TA and TSS in must and wine, and higher concentrations of citronellol in wine (Figure 3 (A, B); Tables 3, 4 and 5).

The Italian clone R2 was in the negative dimension of PC1 (Figure 3A) and was associated with higher pH in must and wine and higher concentrations of nerol, geraniol, linalool, and alfa-terpineol in wine (Figure 3A; Tables 4 and 5), which made it closer to the M. giallo clones (Table 5). The French clone MPG 454 was separated from the other clones along PC2 (Figure 3 (A, B)). It had lower cluster weight and consequently lower yield, as well as higher TSS content in must and higher alcohol content in wine (Figure 3A; Tables 3, 4, and 5).

The first two principal components for the Muscat giallo data set explain 90.87% of the variance. PC 1 explains 61.83% of the variance and separates the M. giallo VCR clones from clone R1 and BEMK 33 (Figure 4A). Clones VCR 5, 100, and 102 were associated with higher terpene concentrations in the wines, but also with higher pH, alcohol, and TSS levels in the must (Figure 4B). The VCR 100, VCR 102, and BEMK 33 clones were separated from the VCR 5 and R1 clones after PC2. The VCR 100 and VCR 102 clones were most similar in terms of yield characteristics, must and wine parameters (Figure 4 (A, B)).

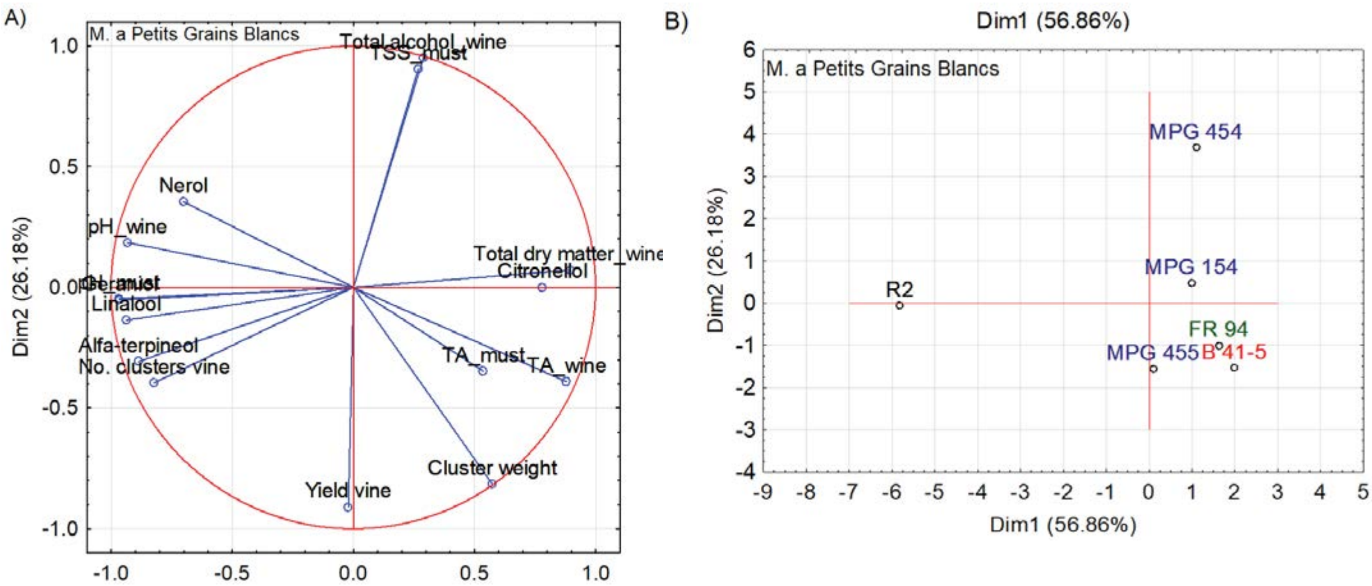

Figure 3. Principal component analyses (PCA) for the first two principal components performed on measured vine yield, must, and wine parameters of clones of M. a Petits Grains Blancs (MPG) variety in three consecutive vintages (2015, 2016, and 2017); (A) loadings, (B) score plot for the first two components. French clones are marked in blue, Austrian in red, German in green, and Italian in black

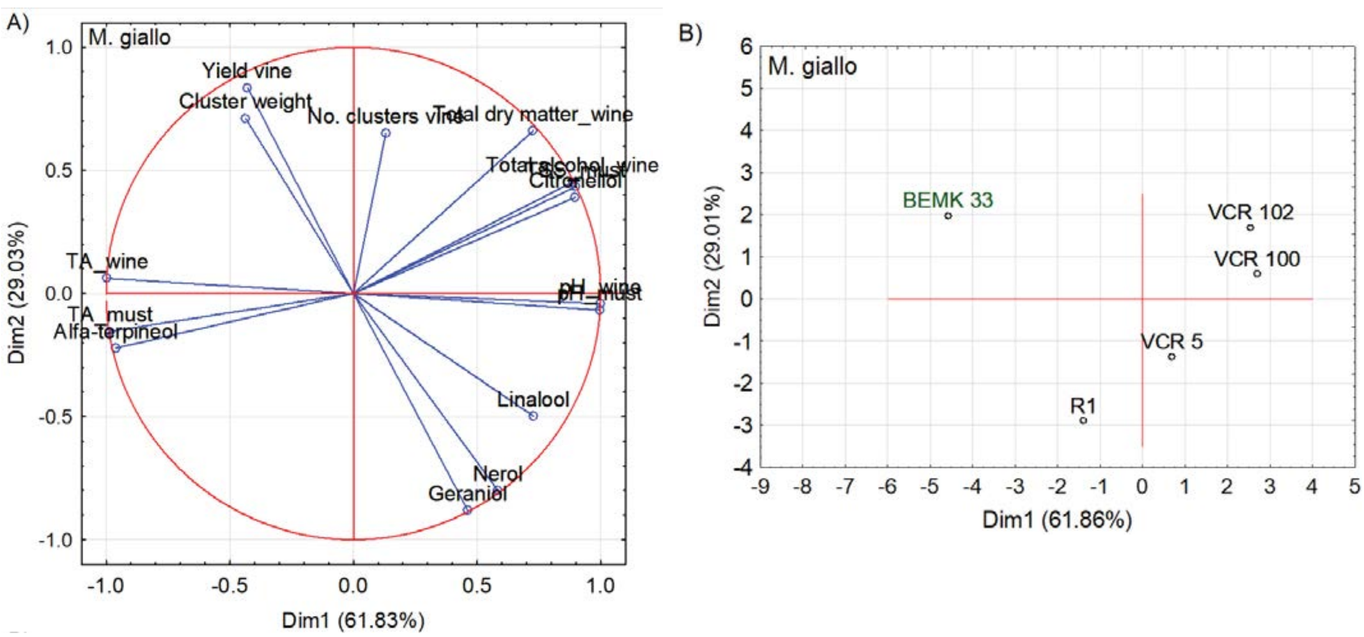

Figure 4. Principal component analyses (PCA) for the first two principal components performed on measured vine yield, must, and wine parameters of clones of M. giallo variety in three consecutive vintages (2015, 2016, and 2017); (A) loadings, (B) score plot for the first two components. The German clone is marked in green and the Italian clones in black

CONCLUSIONS

The climatic differences between the three vintages studied make our comparison of the clones of Muscat a Petits Grains Blancs (MPG) and Muscat giallo meaningful and allow us to draw the following conclusions. (1) The MPG clones (the Austrian clone B 41-5, the French clones MPG 154, MP 454, and MPG 455, and the German clone FR 94) have a shorter growth cycle, resulting in earlier grape ripening, higher cluster weight, and higher yield per vine compared to the M. giallo clones (the Italian clones R1, VCR100, VCR 102, and VCR 5, and the German clone BEMK 33). (2) Musts from clones that matured earlier had higher levels of TSS and TA and lower pH value than musts from clones with longer maturation period (M. giallo clones and R2). (3) Consequently, wines from clones of the MPG variety were characterized by higher TA, higher alcohol content and higher total dry matter, and lower levels of monoterpenes. (4) The clones of the M. giallo variety were characterized by a significantly higher content of α-terpineol, linalool and geraniol in the wine. (5) In terms of viticultural and wine parameters, the Italian clone R2 showed greater similarity to the M. giallo variety than the clones from MPG.

In conclusion, we can say that the clones of the two Muscat varieties tested in our experiment proved their suitability for use in different climates: the MPG clones show good potential for cultivation in cooler climates (i.e. in the continental part of Slovenia) and the group of M. giallo for warmer regions (i.e. in the coastal part of Slovenia), resulting in wines with different chemical and sensory characteristics. The results of the experiment confirm the importance of clonal selection in times of climate change and call for similar studies with other economically important grape varieties.

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