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Article

PHENOLOGY AND YIELD OF 'MOSCATEL' GRAPES IN FOUR LOCALITIES OF THE AREQUIPA REGION IN PERU

FENOLOGIA E PRODUTIVIDADE NA UVA 'MOSCATEL' EM QUATRO LOCALIDADES DA REGIÃO DE AREQUIPA NO PERU

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SUMMARY

The study of phenological stage duration and growing degree days (GDD) is crucial for improving grape yield, particularly as Peru aims to expand its role as a major grape exporter. This study investigated the phenology and yield of 'Moscatel' grape (*Vitis vinifera* L.) grown in four locations in the Arequipa region. To the best of our knowledge, there is no scientific documentation on the use of 'Moscatel' for wine production in Peru. The results showed that the phenological cycle at El Pedregal was longer (222 days) compared to Corire (186 days), a difference that was proportionally reflected in the observed GDD. Vines in El Pedregal exhibited the highest canopy coverage, which was associated with lower porosity and higher yield compared to those in La Joya. An inverse correlation between yield and canopy development was observed in all studied locations. These findings can support vineyard management practices, such as an accurate estimation of production and harvest timing, resource optimization, and targeted use of agrochemicals, with the goal of enhancing the productivity and quality of 'Moscatel' wines.

RESUMO

O estudo da duração do estágio fenológico e dos graus-dia de desenvolvimento (GDD) é crucial para melhorar a produtividade da uva, especialmente porque o Peru pretende expandir o seu papel como um grande exportador de uvas. Este estudo investigou a fenologia e a produtividade da uva 'Moscatel' (*Vitis vinifera* L*)* cultivada em quatro locais da região de Arequipa. De acordo com o nosso conhecimento, não existe documentação científica sobre a utilização do 'Moscatel' na elaboração de vinho no Peru. Os resultados demonstraram que o ciclo fenológico de El Pedregal foi mais longo (222 dias) em comparação com Corire (186 dias), diferença que se refletiu proporcionalmente nos GDD observados. As videiras em El Pedregal apresentaram a maior cobertura de copa, o que foi associado a menor porosidade e maior rendimento em comparação com as de La Joya. Foi encontrada uma correlação inversa entre a produtividade e o desenvolvimento da canópia em todos os locais estudados. As respostas obtidas podem sustentar o planeamento do trabalho na vinha, incluíndo a correta estimativa da produção e colheita, a otimização de recursos, e a utilização de produtos químicos, com o objetivo de melhorar a produtividade e qualidade dos vinhos da casta 'Moscatel'.

Keywords: Canopy development, geographic location, phenology, yield.
Palavras-chave: Desenvolvimento da canópia, localização geográfica, fenologia, produtividade.

INTRODUCTION

The cultivation of grapes (*Vitis vinifera* L.) is of great economic, cultural and religious importance, with 31% of its production used for fresh consumption, 2% for sale as dried fruit, and 67% for the production of wines and other types of beverages (Borja-Bravo *et al.*, 2016; Sandoval and Avila, 2019). Peru is the fourth largest grape producer in Latin America, according to the Ministry of Development Agriculture and Irrigation (Sandoval and Avila, 2019), and grapes are one of the most produced fruits in the country, due to sustained growth ranging from 55431 tons in 1990 to 929000 tons in 2022 (Sandoval and Avila,2019; INEI, 2023), as a result of an increase in agricultural area and yield. According to MIDAGRI (2024), over the last three seasons, the National Agricultural Health Service (SENASA) certified 89186 hectares of vineyards across the country. The regions with the largest production were Ica (44483 ha), Piura (30155 ha), and Lambayeque (7531 ha).

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On the other hand, the regions of La Libertad, Arequipa, Ancash, Lima, Moquegua and Cajamarca, together concentrate more than 7000 hectares of grapes for export. The grapevine has a great varietal diversity according to the different local variety denominations (Bardales *et al.*, 2022) or soil and climatic variables (Romero *et al*., 2022). In the Arequipa region, the main grapevine varieties cultivated by area (in hectares) are as follows: 'Negra Criolla' (652 ha), 'Moscatel' (346 ha), 'Uvina' (108 ha), 'Red Globe' (62 ha), 'Italia' (55 ha), 'Flame Seedless' (39 ha), 'Cardinal' (22 ha), 'Quebranta' (18 ha), 'Alfonso Lavalle' (14 ha), 'Thompsom Seedless' (12 ha) and 'Borgoña' (11 ha) (MIDAGRI, 2008). Therefore, and given the economic significance of grapevine cultivation in Peru, it is important to select varieties that are best adapted to the meteorological conditions of each biogeographic area, since the phenological behavior of the vines depends to a large extent on climatology.

Understanding vine phenology and regional climate conditions enables a more effective vineyard management, by optimizing resource use, improving the accuracy of production estimation and harvest forecasts, and ultimately enhancing the quality and quantity of wine production (Vilca *et al.,* 2024). The grapevine is a particular crop, characterized by three key developmental stages: budbreak to blooming, flowering to veraison and veraison to ripening. The time between phenological stages differs according to the grapevine variety, climate and geographic location (Fraga *et al.*, 2017; Jones and Davis, 2000), season, texture, soil structure and management practice, among others. In Ica, Peru, it was observed that the 'Mollar' variety (21 days) exhibited earlier budbreak than 'Torontel' and 'Italia' (30 days). 'Italia' showed earlier flowering (38 days) than 'Uvina' (43 days). Montes (1990) recommended the application of hydrogen cyanamide to promote and homogenize budbreak among vines of a variety. Soazo and Cristian (1987) indicated that the concentration of cyanamide to be applied depends on the variety. The onset of veraison occured earlier in 'Mollar' in comparison (57 days) to 'Negra Criolla' and 'Uvina' (73 days). Berry physiological maturity occured earlier in 'Uvina' (47 days) than in 'Torontel' (70 days). 'Mollar', 'Albilla' and 'Moscatel' showed a very early onset of fruit set (32 days), whereas 'Torontel' and 'Italia' reach this stage in 40 days (Cáceres *et al.*, 2017). In Spain, a study conducted with the red 'Tempranillo' variety across 17 vineyard plots in La Rioja wine region (with 14 plots located in the municipality Uruñuela and three of them located in Torremontalbo, Huércanos and Cenicero) revealed that budbreak occured with a 4-5 days variation among soil subgroups. Grape harvest across all plots was completed within a 10-day interval. The earliest harvest occurred in the vines planted on soil subgroup HC (calcic Haploxeralfs), while the latest one took place in plots classified as subgroup HF (fluventic Haploxerepts) (Vidaurre, 2017).

Another important factor for the wine industry is the Growing Degrees Days (GDD), an index that measures the accumulation of heat required for a vine to progress from one physiological stage to another. This index explains why the flowering dates can vary between growing seasons. In essence, the GDD represents the vines "thermal clock" or physiological time, which governs the timing of its developmental. Knowledge of the accumulated GDD is pivotal (Santos et al., 2025), because this information allows for the planning of phytosanitary treatments, harvest dates, and even to predict yields. The GDD is based on the observation of the beginning of plant's active growth in spring when the average air temperature reaches 10 °C for five consecutive days, which is considered the baseline or base temperature (Amerine and Winkler ,1944).

In São Joaquim-SC, Brazil, the ripening of 'Cabernet Franc', 'Merlot', 'Sangiovese' and 'Syrah' varieties was monitored through key phenological stages, including budbreak, flowering, fruit set, veraison and harvest dates. The phenological cycle—from budbreak to harvest—was found to range between 191 and 219 days, with accumulated GDD varying between 1161 and 1340 ºC.day (Gris *et al.*, 2010). The earliest variety, which also exhibited the longest phenological cycle, was 'Sangiovese', whereas 'Cabernet Franc' was the latest variety with the shortest phenological cycle. The 'Sangiovese' variety grown in the region of Conegliano, Italy, requires a heat summation of 1803 ºC.day and a phenological cycle lasting 163 days (Falcão *et al.*, 2007). The heat summation requirement for 'Cabernet Sauvignon' grapes varied between approximately 1400 and 2000 ºC.day, depending on growing region (Gris *et al.*, 2010). On the other hand, in the Ribera del Duero appellation, Spain, the relationship between phenology and climate was studied in 'Tempranillo' and 'Cabernet-Sauvignon' varieties. Phenological events observed included budbreak (BB), flowering (BL), veraison (V) and maturity (M). The mean GDD required to reach each phenological stage—calculated using the derived baseline temperatures—were 250±45, 425±51, 398±53 and 410±76, respectively, for 'Tempranillo', and 205±43, 395±73, 386±42 and 372±88, respectively, for 'Cabernet-Sauvignon' (Ramos *et al.*, 2018). Similarly, under the climatic conditions of the La Mancha Denomination of Origin in Spain, the base temperatures required to reach BB, BL, V, M, were 6.6 °C, 6.4 °C, 3.2 °C and 12.5 °C for 'Tempranillo', and 0.0 °C, 5.5 °C, 1.1 °C and 10.5 °C for 'Chardonnay'.

The GDD required to reach the BB, BL, V and M phases were 180 ± 40, 431 ± 38, 1020 ± 55 and 259 ± 68 ºC.day, respectively, for ‘Tempranillo’, and 276 ± 52, 479 ± 33, 1207 ± 49 and 262 ± 72 ºC.day, respectively, for ‘Chardonnay’ (Chacón-Vozmediano *et al.*, 2021). Regarding vine yield, key factors for assessment include the evaluation of tree vines canopy—specifically, the leaf area index (LAI), which is traditionally challenging to measure, mainly due to its variability—as well as canopy architecture, porosity, and the distribution and density of leaf area (Togores, 2006). These factors are critical determinants of productivity as leaves are the primary sites of photosynthesis and transpiration, and regulate the interception of solar radiation. Another important assessment is canopy porosity, which plays a crucial role in determining the amount of radiation intercepted by the system, as well as influencing temperature variation, transpiration and ventilation within the canopy. Traditional methods for estimating leaf area index (LAI) include the Carbonneau (1976) and Lopes and Pinto (2005) methods, along with indirect approaches that estimate LAI based on leaf morphology. However, these methods are not very efficient and are destructive (Martín, 2022). A non-destructive alternative involves the use of remote sensing tools, such as VitiCanopy (University of Adelaide, 2019), which estimate canopy parameters by analyzing transmission light through the plant canopy. The square point method is widely used to assess canopy structure, including leaf layer number and distribution, the percentage of exposed leaves and outer bunches, and the proportion of canopy gaps. This method consists of horizontally inserting a metal rod through the canopy toward the fruiting zone and recording each instance of contact with leaves, berries, or open gaps within the canopy. Trujillo *et al.*, (2001), citing Smart and Robinson (1991), emphasized that all evaluations should be contextualized with respect to temperature and precipitation—the main climatic factors influencing vine yield—in the context of ongoing global warming.

‘Moscatel’ and ‘Negra Criolla’ are varieties genetically related to Listán Prieto. However, they both exhibit phenological differences, despite sharing this same molecular relationship (Almanza Cano *et al.,* 2021). In Arequipa-Peru, grape cultivation covers 416 hectares, with production dedicated exclusively to winemaking. The ‘Moscatel’ grape occupies 346 hectares used for pisco production. Consequently, it is classified as an aromatic pisquera grape in accordance with the Denomination of Origin regulation for Pisco and the National Commission of Pisco (MIDAGRI, 2008). To date, there is no scientific documentation on the use of 'Moscatel' for winemaking in Peru, despite its widespread use for this purpose in Europe. Therefore, this study focuses on the phenology and yield of ‘Moscatel’ grapes across four locations in the Arequipa region: San Isidro, La Joya, Corire and Pedregal. It was evaluated how geographical location influences the timing of each phenological phase, degree days of development, yield, and canopy-related variables in ‘Moscatel’ grapevines. The results obtained provided valuable insights for future studies aimed at advancing wine production from this variety in Peru.

MATERIALS AND METHODS

Plant Material

For this study, 14, 12, 14, and 12 year-old ‘ Moscatel’ grapevine from La Joya, San Isidro, El Pedregal, and Corire, respectively, were used. The study was carried out in four locations in the Arequipa region: Torre de Gala, in the district of La Joya at 16°27'20" S, 71°48'19" W and 1626 m.a.s.l.; Majes Tradición SAC Viticulture Company, in the town of Corire at an altitude of 464 m.a.s.l., Latitude 16°13'36" S, Longitude 72°27'04" W; CIEPA-UNSA - Irrig. Majes, El Pedregal district, at an altitude of 1440 m.a.s.l., Latitude 16°16'28" S, Longitude 72°12'55" W; Mr. Victor Cuadros' farm in Irrig. San Isidro, at an altitude of 1660 m.a.s.l., Latitude 16°34'20.7 S" and Longitude 71°55'45 W". In the Arequipa region, areas located below 2000 m.a.s.l. are characterized by an arid, temperate climate with low humidity throughout the year.

The configuration and management of 'Moscatel' plantations grafted onto ‘Salt Creek’ rootstock at each study location are based on the specific practices and criteria of individual growers. In La Joya, the plots were arranged in 2 rows; in San Isidro, in 9 rows; and in El Pedregal and Corire, in 15 rows each. In terms of experimental design, La Joya’s rows were divided into 3 sections. In San Isidro, each section consisted of 3 rows, while in El Pedregal and Corire, each section included 5 rows. Each section contained 5 replications, resulting in a total of 15 experimental units per studied area. The distance between vines varied by location: 1.5 m in La Joya, 1.2 m in San Isidro, 2 m in El Pedregal, and 1.3 m in Corire. Row spacing was 2.50 m in both La Joya and San Isidro, 3 m in El Pedregal, and 2.20 m in Corire. In all four studied areas, vines were trained using a trellising system. Corire and La Joya use a simple trellis system, while El Pedregal and San Isidro use a double T trellis system. Drip irrigation is used in El Pedregal and Corire whereas La Joya and San Isidro use gravity-based irrigation systems. The first irrigation was applied after pruning at varying intervals: 10 days in La Joya, 6 days in San Isidro, 25 days in El Pedregal, and 3 days in Corire. Hydrogen cyanamide was applied after pruning in El Pedregal and La Joya but not in Corire or San Isidro.

Phenology of ' Moscatel' for different geographical locations of study

The maximum, minimum and average temperature and relative humidity were recorded in the four locations, using sensor-based data to determine daily temperature and humidity (thermihydrometer, Xiomi LYWSD03MMC).

For phenology assessment, 15 vines per evaluation zone were monitored, and the phenological stages budbreak, flowering, veraison and maturity were recorded in accordance with the descriptors of the International Organisation of Vine and Wine (OIV, 2015). Pruning was carried out at different times across the locations, and the cumulative daily temperature calculated from these dates to assess the phenological events (Table I). Vineyard management practices were determined by the respective plot owners, resulting in a lack of uniformity across sites. Considering the specific management conditions at each site, the phenological assessment was conducted using the Baggiolini scale (Baggiolini, 1952) in combination with the BBCH code (Lorenz *et al*.,1994) The budbreak, flowering, veraison and ripening were recorded when 50% had been reached.

$$X(\%/day)=(\%final-\%initial)/(fD-iD) \quad \textbf{Eq. 1}$$

Where: fD= Final date; iD= Initial date.

This formula was applied to determine the duration of the different phenological stages of *Vitis vinifera* 'Moscatel', considering the point at which 50% of the vines exhibited the corresponding phenological state.

Due to specific management conditions at each site, the maximum timeframe for total budbreak was defined as a 60-day period. During this time, vines were evaluated periodically, and budburst was recorded when 50% of the buds had burst.

Flowering. The visible clusters on marked vines were counted, ranging from 5 to 10 per vine. Flowering was monitored in these clusters, with the percentage of open flowers ranging from 0% to 100%. For each vine, flowering was recorded when approximately 50% of the flowers were open.

For veraison, four bunches per vine were randomly selected, two from the external part and two from the internal part of the canopy. Each bunch was divided into four sections: upper-external, upper-internal, lower-external, and lower-internal. Berry softening was assessed by touch rather than visually. Five berries were sampled from each section as follows: upper-internal of one bunch, upper-external of another, lower-internal of a third, and lower-external of the fourth. This evaluation was repeated periodically until approximately 50% of the berries in the bunches had reached veraison.

Maturation was considered when the grape must reached a total soluble solids concentration of 21-23 ºBrix.

Table I

Phenology of 'Moscatel' in La Joya, San Isidro, Pedregal and Corire, Arequipa.

	La Joya	San Isidro	El Pedregal	Corire
Pruning	27/7/2021	16/9/2021	14/8/2021	13/8/2021
budbreak	30	30	44	40
Flowering	82	74	89	83
Veraison	153	147	153	143
Harvest	204	196	222	186

Degree-days of development

Using the temperature data recorded by the sensors, the growing degree-days (GDD) were calculated using the residual method (Arnold, 1959), based on the daily maximum and minimum temperatures during phenological development. The base temperature was assumed to be 10 °C (Macías-Carranza and Cabello-Pasini, 2021).

$$GDD=[(Tmax+ Tmin)/2] - Tb \quad \textbf{Eq. 2}$$

Where: GDD=growing degree-days; Tmax=maximum daily temperature (°C); Tmin=minimum daily temperature (°C); Tb=base temperature (°C).

Measurement of canopy development

Vegetative responses were assessed based on the distribution of leaves and clusters using the point quadrat method (Smart, 1988). The method involved determining the number of clusters, leaves and empty spaces intercepted by a rod inserted perpendicularly to the canopy at the bunch height at half-meter distance, within each production zone. From these data, the percentage of empty spaces, the number of leaf layers, the percentage of outer leaves and the percentage of outer clusters were calculated. In addition, the *VitiCanopy* software (De Bei *et al.*, 2016) was used to estimate the leaf area index and canopy porosity. Nine images were taken for each production zone beneath the canopy (at 80 cm) during the early morning, under diffuse light conditions and without direct sun reflection.

Harvest time

Soluble solids content was used to determine the optimum harvest time. For each treatment, 50 berries were sampled from the 15 vines under observation. Juice was extracted to measure the soluble solids content (ºBrix).

Vine performance

Yield was determined based on bunch weight and the number of bunches per vine (15 vines per production zone), as well as the number of berries per bunch. Berry traits were measured from five bunches per production zone, including berry length and width (using a vernier caliper) and berry weight.

Yield per vine was calculated as the product of the number of bunches and the average bunch weight.

Edaphoclimatic characterization of the four study localities.

The soils of the studied localities are of alluvial and colluvial origin, with slightly flat slopes ranging from 2 to 5%. They have a sandy loam texture, an effective depth greater than 70 cm, neutral to slightly alkaline. The soils are poor in organic matter (OM), optimal in phosphorus, high in potassium, and have a low cation exchange capacity (CEC). The average temperatures and relative humidity for the months covering the phenological stages (September-February) for each geographic location were as follows: La Joya, 20.63 °C and 51.81%; El Pedregal, 22.08 °C and 59.94%; Corire, 24.26 °C and 60.92 %; and San Isidro, 20.38 °C and 63.24%. The CEC, OM, electrical conductivity (EC) and pH of the soils in the studied localities were as follows: La Joya, 7.2 meq/100g, 0.83%, 0.17 mmhos/cm, and pH 7.39; San Isidro, 7.6 meq/100g, 0.81%, 0.11 mmhos/cm and pH 7.58; El Pedregal, 9.2meq/100g, 0.66%, 1.36 mmhos/cm and pH 7.3; and Corire, 6.0 meq/100g, 0.57 %, 3.39 mmhos/cm and pH 7.42. It is also important to note that soil influences vine phenological development through several factors, such as root-zone temperature, which is related to soil color. In all four locations, the soils in the top 40 cm are light brown. Other influential soil properties include albedo, slope, and water and mineral content.

Experimental design

A completely randomized design was used, with four treatments corresponding to the locations San Isidro, La Joya, Corire, and El Pedregal. Each treatment included 15 replicates, resulting in a total of 60 experimental units. Phenology, days from pruning, budbreak, flowering, veraison and harvest, as well as growing degree days (GDD) were evaluated for each of these phenological stages. Canopy development and yield were also measured. For these variables, mean comparisons were performed by t-test in R software (R Core Team, 2013). Values are reported as the mean of five replicates ± standard error. Principal component analysis (PCA) was performed using R software (R Core Team, 2013) to simplify trends and identify potential clusters based on the two Principal Components (dimensions). These components summarize all the variables evaluated in the studied locations, including canopy development and yield, and highlight the most important variables for each cluster (Lever *et al.*, 2017). Factor analysis was also applied to each mixed data set to further explore underlying patterns (Pagès, 2014).

RESULTS AND DISCUSSION

Phenology of 'Moscatel' grapes

The phenological cycle of 'Moscatel', spanning from pruning to harvest, lasted between 186 and 222 days under different agroclimatic conditions (Table I). Table II presents the temperature (°C) and relative humidity (%) at each studied location, corresponding to the different phenological stages of 'Moscatel' grapes.

The pruning-to-budbreak stage occurred at 30 days in La Joya and San Isidro, 44 days in El Pedregal, and 40 days in Corire. Echenique *et al.* (2013) reported that, under Argentine agroclimatic conditions, budbreak of the 'Malbec' cultivar occurred from 34 to 42 days during the 2008-2009 to 2010-2011 growth cycles. On the other hand, Cáceres *et al.* (2017), studying eight Pisco varieties, reported differences in budbreak timing. The earliest budbreak occured in 'Mollar' and 'Moscatel' (21 days and 22 days, respectively), whereas 'Torontel' and 'Italia' reached budbreak at 30 days. Pedro Júnior *et al.* (2020) showed that, in eastern and northeastern São Paulo-Brazil, the pruning-to-budbreak stage of the white grape variety SR 0.501-17 lasted on average 16 days, ranging from 12 to 20 days depending on the growing season. As noted by Keller (2020), the observed variability can be explained by the fact that budbreak occurs more rapidly in regions with mild winters than in those with harsh winters, and by differences in cultivar-specific threshold temperatures.

The budbreak-flowering stage occurred at 52 days in La Joya, at 44 days in San Isidro, 45 days in El Pedregal, and 43 days in Corire. Pedro Júnior *et al.* (2020) reported that the budbreak-flowering period for the white grape variety SR 0.501-17 was longer in Jundiaí, São Paulo, Brazil (35 days) than in Votuporanga, São Paulo, Brazil (31 days). An important factor influencing this period is light, which plays a role in the initiation of inflorescences. Additionally, all factors affecting vine vigor also influence bud fertility. Piña and Bautista (2004), studying 10 *Vitis vinifera* varieties in Tocuyo, Venezuela, reported that flowering occurred on average at 35 days.

The flowering-veraison stage occurred at 71 days in La Joya, at 73 days in San Isidro, at 64 days in El Pedregal, and at 60 days in Corire. In Bordeaux, France, the 'Cabernet Sauvignon' and 'Merlot' varieties showed a similar flowering-to-veraison interval, averaging 67 days ± 3 days (Jones and Davis, 2000). The veraison stage showed considerable variation between 'Regina' and 'Napoleon' varieties, occurring at 71 and 109 days from pruning, respectively. In the same locality, the flowering-to-veraison duration for 'Villanueva', 'Chenin Blanc', 'Sauvignon Blanc', and 'Syrah', all grafted onto 'Criolla Negra' rootstock, ranged from 51 to 66 days, with each variety maintaining its characteristic traits during this period. Reynier (1989), indicates that the main factors influencing this stage include climate (temperature and light), irrigation, variety, berry shape and size, pulp structure, and leaf surface, and all affect directly the translocation of sugars to the bunches.

According to Piña and Bautista (2004), the length of this period was approximately 25, 32 and 41 days for the 'Sultanina', 'Perlón' and 'Alphonse Lavallée' varieties, respectively. The results show that variability during this period is influenced by temperature, as well as by management factors, such as the training system, and by light and temperature conditions at the cluster level (Reynier, 1989).

The veraison-to-ripening period in La Joya occurred at 51 days, at 49 days in San Isidro, at 69 days in El Pedregal, and at 43 days in Corire. Similar results were reported in Nobsa, Boyacá, Colombia, where the ripening stage of the 'Pinot Noir' variety lasted 42 days, corresponding to 77 days after anthesis and 119 days until ripening (Almanza-Merchán,2009; Balaguera-López,2009). On the other hand, Hernández (2000) refers that the ripening stage can last from 40 to 60 days in the 'Merlot' variety and in France, Bordeaux, the time from veraison to harvest averaged 45 days ± 5 days and decreased by almost 6 days between 1952 and 1997 (Jones and Davis, 2000).

Table II

Relative humidity and average temperature for each phenological stage of *Vitis vinifera*, 'Moscatel' in La Joya, San Isidro, El Pedregal and Corire, Arequipa.

Stages	La Joya		San Isidro		El Pedregal		Corire	
	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
Pruning	17.6	-	17.7	-	18.7	-	16.9	-
budbreak	17.7	58	18.7	50	18.4	47	18.1	66
Flowering	18.6	45	19.6	55	18.9	55	21.0	66
Veraison	19.1	50	20.1	68	19.3	64	21.5	66
Maturation	20.3	63	20.6	71	19.5	71	23.2	70

Canopy development

One method to determine this parameter is the square point method proposed by Smart (1987), evaluating the percentage of canopy gaps, leaf layers, percentage of external leaves and external clusters, as shown in Table III. La Joya showed a significantly (p<0.05) higher percentage of canopy gaps and percentage of external leaves. La Joya presented the lowest value in external leaves significantly (p<0.05) in relation to Corire and San Isidro, presenting no differences (p<0.05) with Pedregal.

Regarding the percentage of external bunches, San Isidro presented the lowest value significantly (p<0.05) in relation to the other geographical zones. According to Smart (1987), the ideal porosity is between 20 and 40% of hollows or between 10 and 20% as described by Palliotti and Silvestron (2004) to guarantee adequate sunlight capture. These results differ from the optimal values proposed by Smart (1987) but they are consistent with those of Palliotti and Silvestron (2004), as the values observed at La Joya, San Isidro and El Pedregal were similar to those reported in their study. Mato Monge (2016), found a mean value of 22% of gaps, with a range of variation from 0 (very leafy vines) to 87% (vines with a high percentage of gaps) in a trellis training system.

According to Smart (1987), the optimum percentage of external bunches ranges from 50 to 100%, or 0% in very warm locations. The results of this study do not coincide with those values. In contrast, the findings of Mato Monge (2016) are consistent with the present results, as an average of 22% of exposed bunches was observed in El Pedregal, Corire, and La Joya, differing only in San Isidro, where a higher leaf density was recorded. In this study, significant differences were observed among localities (p < 0.05).

El Pedregal and Corire showed the highest canopy cover, in contrast to San Isidro and La Joya. Conversely, Corire and La Joya exhibited the highest canopy porosity values ($p < 0.05$), opposite to the patterns observed in El Pedregal and San Isidro.The results of this study do not align with Smart's (1987), who reported optimum values for outer leaves (80–100 %), but they agree with his estimates for leaf layers in La Joya and El Pedregal (1.25–2.25).

The Viti Canopy method proposed by De Bei *et al.*, (2016) was used to evaluate canopy cover and porosity (Table III). For this reason, the structure of the canopy-determined by the training system and the spatial distribution of leaves-is critical for light interception and productivity. Carbon dioxide fixation depends on total leaf area, leaf surface distribution, canopy architecture, and the photosynthetic capacity of individual leaves (Keller, 2010). The distribution of leaf surface area in space can cause the physiological functioning of the plant to vary; the degree of exposure of the leaf surface to radiation (Yuste, 1995), which could be influencing the phenology of the vine, either by decreasing or extending it, being the case for the Pedregal locality.

Table III

Canopy development for each phenological stage of 'Moscatel' in La Joya, San Isidro, El Pedregal and Corire, Arequipa.

Zone	Canopy Coverage	Canopy Porosity	External Bunch Percentage	External Leaf Percentage	Gape Percentage	Leaf Layers
Corire	89.56 ± 2.51 a	22.11 ± 1.55 a	23.49 ± 1.93 a	28.15 ± 2.77 b	4 ± 1.15 b	3.11 ± 0.3 a
La Joya	70.29 ± 2.19 b	23.08 ± 1.31 a	18.11 ± 8.96 a	41.25 ± 3.11 a	16 ± 5.03 a	1.89 ± 0.21 b
El Pedregal	100 ± 0 a	7.31 ± 1.51 b	23.17 ± 5.04 a	27.84 ± 2.52 b	9.33 ± 2.91 b	2.59 ± 0.28 ab
San Isidro	77.97 ± 6.97 b	16.71 ± 4.33 b	8.11 ± 4.16 b	25.87 ± 0.44 b	8.67 ± 0.67 b	3.38 ± 0.14 a

Values are average of 5 independent biological replicates± standard error.

Yield

Significant differences in the yield of 'Moscatel' grapes were observed among the localities of the Arequipa region (Table IV), represented by the parameters: bunch weight (kg), berry width and length (mm), berry weight (g), number of bunches, number of berries/bunch and yield/plant (number of bunches x weight of bunches).

Table IV

Yield for each phenological stage in *Vitis vinifera*, 'Moscatel' in La Joya, San Isidro, Pedregal and Corire, Arequipa.

Zone	Corire	La Joya	El Pedregal	San Isidro
Berries per bunch	222 ± 11.53 a	196.33 ± 4.7 a	220 ± 8.02 a	208.33 ± 4.33 a
Berry Length	13.26 ± 0.49 a	13.55 ± 0.29 a	14.86 ± 0.42 a	14.29 ± 0.16 a
Berry Weight	2.32 ± 0.2 a	2.22 ± 0.1 a	2.66 ± 0.17 a	2.52 ± 0.16 a
Berry Width	13.35 ± 0.51 a	13.47 ± 0.19 ab	15.01 ± 0.43 ab	14.56 ± 0.25 b
BRIX	22.57 ± 0.47 a	21.17 ± 0.17 a	21.87 ± 0.33 a	22.07 ± 0.52 a
CE	2.59 ± 0.04 ab	2.37 ± 0.08 a	2.21 ± 0.03 b	2.33 ± 0.08 ab
Bunch Count	10 ± 1.53 a	7.87 ± 1.38 a	36 ± 3.61 b	12.33 ± 1.71 a
Bunch Weight	0.42 ± 0.06 a	0.43 ± 0.07 a	0.42 ± 0.02 a	0.46 ± 0.04 a
Yield per Plant	4.88 ± 2.01 a	3.41 ± 0.91 a	17.59 ± 2.87 b	6.31 ± 0.97 a

Values are average of 5 independent biological replicates± standard error.

These indicators are commonly used to determine the yield of a particular grape variety (Yuste and Martín, 2004). It is noteworthy that the highest yield was obtained in Pedregal and the lowest one was obtained in La Joya ($p<0.05$).

Layme and Alonzo (2018), reported that grape yield per hectare is primarily determined by the number of bunches per vine. In terms of organoleptic quality, the 'Moscatel' variety achieved the highest sensory scores when vines bore 20–24 bunches per plant.

According to Jackson and Lombard (1993), excessive yields tend to reduce grape quality, due to a decrease in probable alcohol, higher titratable acidity, lower color intensity, lower concentration of polyphenols and delayed grape ripening. The yields observed in Corire are consistent with results presented by other authors. In contrast, El Pedregal exhibited higher yields, which is often associated with a reduction in grape quality and consequently to the wine quality.

Harvest time

The optimum harvest time was determined considering the parameters of soluble solids content. As shown in Table IV, significant differences in pH were observed ($p<0.05$). El Pedregal and La Joya differed from San Isidro and Corire, the latter two showing similar pH values. Regarding soluble solids content, no significant differences were observed among the studied locations. The variability in the present data may be explained, as suggested by Kodur (2011), by differences in canopy density. Denser canopies promote greater internal shading, which in turn can increase potassium concentration and the pH of the must. Accordingly, Corire and San Isidro, which exhibited higher canopy density, also showed higher pH compared to the other locations (Tables III and IV). In addition, the soil analysis at Corire revealed high potassium content compared to the other localities. According to Cabaut (2013), berry sugar levels are related to the mean values of maximum, and minimum temperatures, and UV. In this study, the locality of Corire recorded the highest temperature during ripening (23.2°C; Table 1) and exhibited the highest soluble solids content.

Thermal requirement expressed in Degree Days of Development

Table V shows the accumulation of growing degree days (GDD), from pruning to budbreak across the four sites. In La Joya, 274.75 ºC.day were accumulated over 30 days, with a daily mean temperature of 8.89°C. In San Isidro 273.79 ºC.day were accumulated over 30 days, with a daily mean temperature of 9.11°C. In El Pedregal, 342.10 ºC.day were accumulated over 44 days, with a daily mean temperature of 11.04°C. Finally, in Corire, 390.44 ºC.day were accumulated over 40 days, with a daily mean temperature of 10.89°C. Ramos (2017), reported that from pruning to budbreak, Chardonnay accumulated 93±45 ºC.day, a value that differs from our findings. Chacón-Vozmediano *et al.*, (2021) reported that from pruning to budbreak, Tempranillo accumulated 180±40 ºC.day, while Chardonnay accumulated 276±52 ºC.day. In contrast, Ramos *et al.* (2018), observed that Tempranillo accumulated 250±45 ºC.day, and Cabernet-Sauvignon accumulated 205±43 ºC.day. These discrepancies may be attributed to differences in the base temperature (Tb) used by each study. In this study, a Tb of 10ºC was employed to calculate GDD. From budbreak to flowering, the thermal requirements were as follows: in La Joya, 492.01 GDD were accumulated over 52 days, with a daily mean temperature of 9.73 °C; in San Isidro, 408.73 GDD over 44 days, with a daily mean temperature of 10.14 °C; in El Pedregal, 525.19 ºC.day over 45 days, with a daily mean of 11.83 °C; and in Corire 558.53 ºC.day over 43 days, with a daily mean of 12.53 °C.

These values are consistent with those reported by Ramos *et al.* (2018), who found that 250±45 ºC.day for 'Tempranillo' and 205±43 ºC.day for 'Cabernet Sauvignon' are required from budbreak to flowering. Similarly, for the same stage, Ramos (2017), reported 247±72 ºC.day for 'Chardonnay', 299±52 ºC.day for 'Macabeo', and 294±33 ºC.day for 'Parellada'. Pedro Júnior *et al.* (2020) found 342 and 400 ºC.day for this stage. The most influential factor determining these differences seems to be the air temperature, particularly in the localities of Corire and El Pedregal.

Table V

Degree days of development, accumulated days for each phenological stage of 'Moscatel' in La Joya, San Isidro, El Pedregal and Corire, Arequipa.

Stage	La Joya		San Isidro		El Pedregal		Corire	
	GDD (ºC.day)	Days	GDD (ºC.day)	Days	GDD (ºC.day)	Days	GDD (ºC.day)	Days
Pruning - budbreak	274.75	30	273.79	30	342.10	44	390.44	40
budbreak - flowering	492.01	82	408.73	74	525.19	89	558.24	83
Flowering - veraison	739.15	153	779.60	147	780.10	153	848.60	143
Veraison - maturation	589.75	204	533.05	196	811.45	222	717.55	186

From flowering to veraison, the thermal requirements were as follows: in La Joya, 739.15 ºC.day were accumulated over 71 days, with a daily mean temperature of 10.14 °C; In San Isidro, 779.6 ºC.day over 73 days, with a daily mean of 10.68 °C; In El Pedregal, 780.1 ºC.day over 64 days, with a daily mean of 11.83 °C; and in Corire 848.6 ºC.day over 60 days, with a daily mean of 14.14 °C. Ramos (2017) reported thermal requirements of 663±92 ºC.day for 'Chardonnay', 891±96 ºC.day for 'Macabeo', and 840±83 ºC.day for 'Parellada' to reach this stage. Similarly, Pedro Júnior *et al.* (2020) indicate that 791 and 870 ºC.day are required for flowering to the beginning of ripening. However, these values differ from those observed in the present study. The discrepancies with Ramos *et al.* (2018), may be ascribed to differences in the accumulated daily mean temperature, which in could exceed 14.14 °C in the present study. Differences with Chacón-Vozmediano *et al.* (2021) are likely due to the use of much lower base temperatures, such as 3.2 and 1.1°C.

From veraison to ripening, the thermal requirements were as follows: in La Joya, 589.75 ºC.day were accumulated over 51 days, with a daily mean temperature of 11.34 °C; in San Isidro, 533.05 ºC.day over 49 days, with a daily mean of 10.88 °C; in El Pedregal, 811.45 ºC.day over 69 days, with a daily mean of 11.76 °C; and in Corire, 715.55 ºC.day over 43 days, with a daily mean of 16.69 °C. A relationship was observed with the 'Chardonnay' variety, as reported by Ramos (2017), who found a thermal requirement of 541±81 ºC.day, very close to the values observed in the localities of La Joya and San Isidro. However, the findings of the present study diverge from those reported by Ramos *et al.*, (2018), likely because their analysis was based on an optimum temperature of 26 °C and a base temperature of 4 °C. Differences with Chacón-Vozmediano *et al.* (2021) may be assigned to the use of base temperatures greater than 10 °C during this stage, while discrepancies with Pedro Júnior *et al.* (2020) are likely due to contrasting climatic conditions.

The thermal requirements from budbreak to ripening in the studied locations ranged from 1721.38 to 2122.39 ºC.day. These results are consistent with the findings of Ramos (2017), in vineyards of northeastern Spain, as well as Ramos *et al.* (2018) in the Ribera del Duero Denomination of Origin, Spain, and Pedro Júnior *et al.* (2020) in vineyards in the northwestern region of São Paulo, Brazil. In contrast, the values differ from those reported by Chacón-Vozmediano *et al.* (2021) in vineyards of the La Mancha Denomination of Origin, Spain, probably due to differences in base temperatures at each stage, which directly influence GDD accumulation.

Principal Component Analysis (PCA)

A principal component analysis (PCA) was conducted to simplify the trends and potential clusters among the variables related to canopy development and yield of 'Moscatel' across the four localities of Arequipa. The analysis aimed to identify the most important variables contributing to each cluster, summarizing all evaluated variables in just two Principal Components (dimensions). In Figure 1, the first principal component accounts for 36.9% of the variation, while the second principal component accounts for 26.5%. Figures 1A and 1B depict the contribution of each variable under study, represented by the heat map and the grouping of variables for each studied area.

The contribution of each variable is indicated by the length and orientation of its vector. In general, in dimensions 1 and 2, the variables related to yield — such as cluster length, cluster weight, berry length, number and weight of clusters, and total yield (number of clusters x berry weight)—were grouped specifically for El Pedregal. In San Isidro, variables related to the canopy, including canopy cover, leaf layers, ºBrix, were grouped together. For La Joya, percentage of gaps and external leaves formed a distinct cluster, while in Corire, canopy porosity and electrical conductivity were clustered together.

A greater contribution to yield was clearly observed for El Pedregal, while the contribution of variables related to canopy development was highest for San Isidro, followed by La Joya and then Corire.

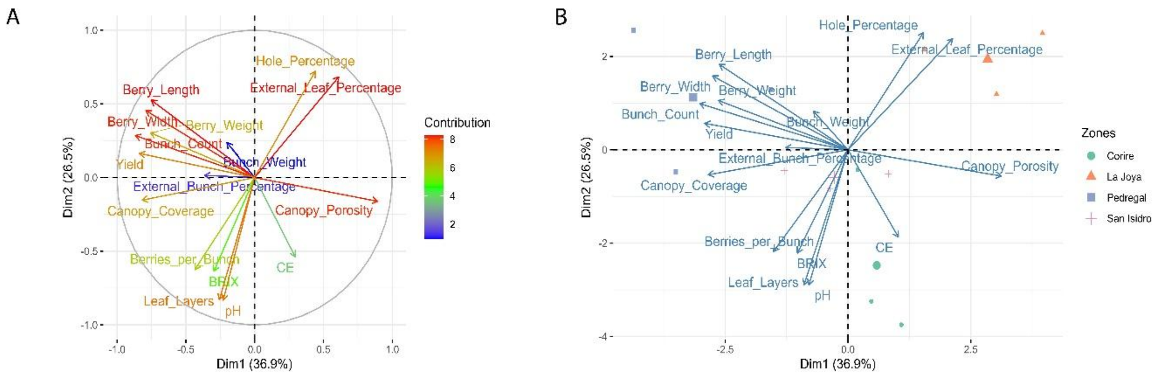

Figure 1. PCA of variables corresponding to canopy development and yield in 'Moscatel' variety for 4 locations in the Arequipa Region. A) Contribution (represented by the heat diagram in colors and on the scale of 2-8) of the different variables under study. The contribution of each variable is a function of the length of the vector and its inclination, related for each study area. B) Clustering of the different variables under study, where the length of the vector and its inclination determine their contribution for each study area.

CONCLUSIONS

It was observed that the geographic locations under study, each with distinct edaphoclimatic conditions, exerted a significant influence on several parameters related to phenology, canopy development and yield in 'Moscatel'. In particular, the complete phenological cycle was longest in El Pedregal (222 days) and shortest in Corire (186 days), attributable to differences in accumulated temperature at these locations. In terms of canopy development, Moscatel' grown in El Pedregal exhibited the greatest canopy cover, which was associated with lower porosity and higher yield per vine (calculated as number of bunches x bunch weight) compared to vines in La Joya. These differences may arise because the ecotypes under study vary in their interception of solar radiation, photosynthetic capacity, and transpiration rates. In turn, these differences influence the translocation of solutes that determine the wine quality. Understanding these responses—specifically, the duration of each phenological stage, GDD, and yield under the distinct edaphoclimatic conditions of La Joya, Corire, San Isidro, and El Pedregal—can enhance vineyard management. This knowledge enables more accurate estimation of production and harvest timing, optimization of labor and resources, and appropriate use of chemical inputs, ultimately contributing to improved productivity and wine quality in 'Moscatel'.

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