THESIS

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EFFECTS OF PERGOLA AND VERTICAL SHOOT POSITIONING TRELLIS SYSTEMS ON VEGETATIVE AND REPRODUCTIVE PERFORMANCE OF VRANAC VARIETY IN MONTENEGRO

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1. Introduction and objectives

Montenegro has a long history of growing grapevines, especially in the picturesque Podgorica sub-region. It is known that the trellis system has an essential effect on the growth, development, and overall output of the grapevine. Autochthonous grapevine variety Vranac, well-known for its role in Montenegrin viticulture, is not an exception. The description above presents the context of the thesis, studying the effects of vertical shoot positioning (hereafter VSP) and pergola trellis system on the lifecycle of the Vranac variety.

The thesis attempts to analyse the advantages and disadvantages of each system and show insights into the possible advantages of pergola, especially when viticultural methods are constantly changing. Objectives of the thesis could be highlighted:

- Comparison of vegetative growth – assess how VSP and pergola influence vegetative growth of the grapevine,
- Evaluation of the yield – consider the impacts of trellis systems on the yield of the grapevine and
- Assessment of grape quality – measure one of the critical aspects of the quality, sugar content, and conclude the effect of trellis systems on sugar content.

The thesis contributes to Montenegro's, and possibly broader, viticultural knowledge base. In a world where climate change poses new challenges to viticulture, the potential benefits of less common varieties and trellis systems like Vranac and pergola may become increasingly relevant. The increasing need for vineyard irrigation caused by climate changes stresses the importance of researching varieties from dry and hot regions, such as Montenegro. Another important aspect is to discover how those varieties would perform in different conditions, for example, on different trellis systems.

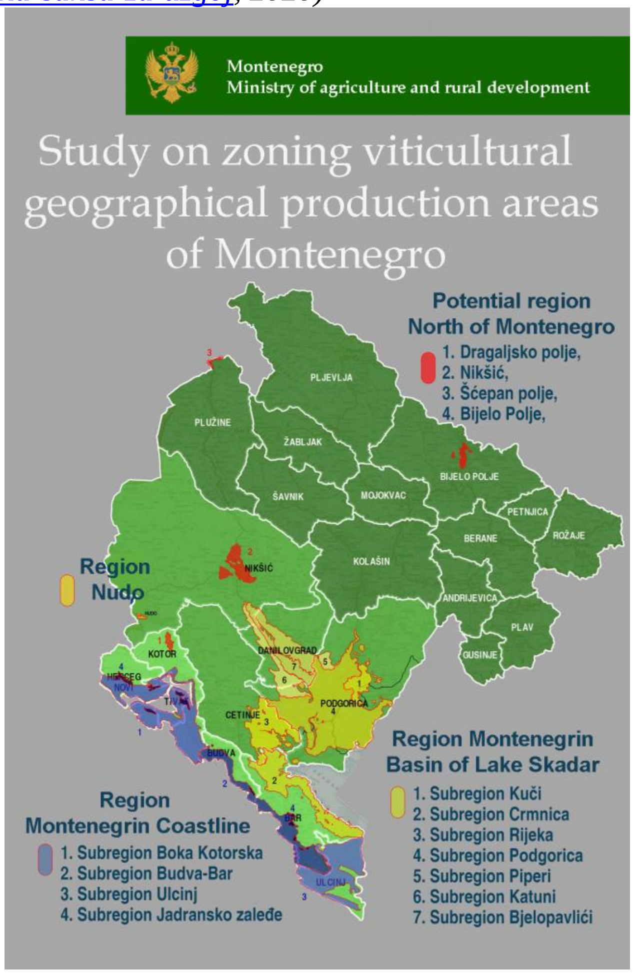
During 11 months (from November 2022 to October 2023), different kinds of measurements and analyses were performed. Weather conditions were carefully monitored and assessed. Similarly, the beginning and ends of phenological phases were noted and evaluated. Measurements were performed during the winter, spring and summer, determining different aspects necessary for the grapevine lifecycle. Collected data was analysed, and the comparison was statistically performed. Results from the analysis were discussed, and different conclusions were drawn. With its results and outputs, the thesis is a starting point for additional studies contributing further to the viticultural knowledge base.

2. Literature review

2.1.Introduction of the region

Ministry of Agriculture and Rural Development of Montenegro in cooperation with Centre for research, testing and training in agriculture from Bari, Italy, started a project "Technical support to renewal of viticulture zoning of Montenegro" in 2015. As a result of the project, four regions were identified (Figure 1): Montenegrin Coastline ("Crnogorsko primorje"), Adriatic Hinterland ("Jadransko zaleđe"), Montenegrin Basin of Skadar Lake ("Crnogorski basen Skadarskog jezera") and Nudo ("Nudo"). The region of Montenegrin Basin of Skadar Lake is further subdivided into seven sub-regions. Although one of the sub-regions is named Piperi, just as the geographical region where Božović vineyard is located, the vineyard is assigned to the viticultural sub-region Podgorica (Figure 2). (Ministry of Agriculture 2017)

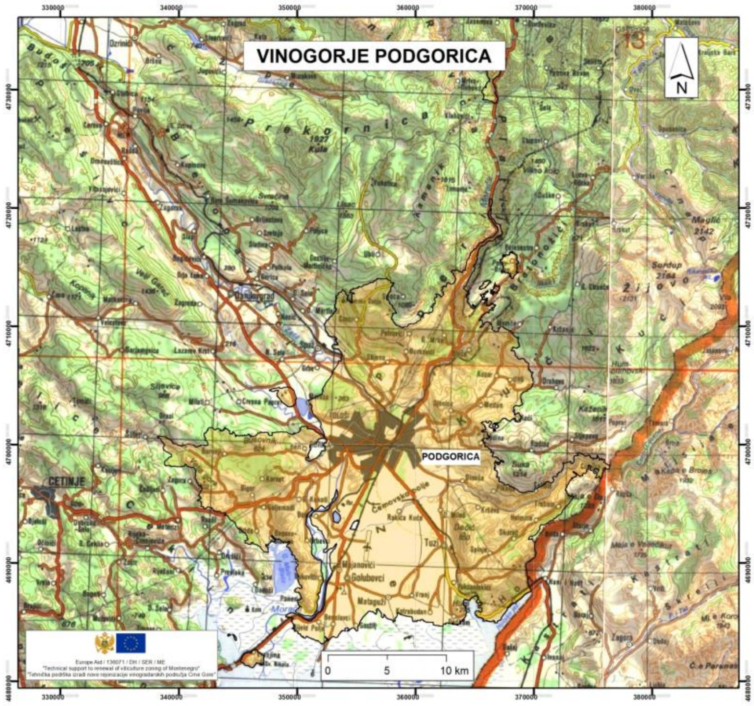
Figure 1: Zoning viticultural geographical production areas of Montenegro
(*Source: https://fosmedia.me/arhiva/infos/drustvo/rejonizacija-od-velike-pomoci-crngorskim-vinarima-sjever-izuzetna-sansa-za-uzgoj, 2020)*



2.1.1. Geographic location

The Montenegrin Basin of Skadar Lake is located in the central and southern parts of Montenegro. On the east it is bordering Albania. On the south it reaches north side of Rumija Mountain, close to Adriatic Sea. On the west it expands on area of Rijeka Crnojevica and in the Bjelopavlici Valley, following the Zeta River. On the north it expands to Piperi region and the canyon Platije of Moraca River. The Podgorica sub region is located in the central part of Montenegro, mostly in Zeta Valley.

Figure 2: Sub-region Podgorica
(Source: Ministry of Agriculture, 2017)



2.1.2. Climate

Due to its proximity to Adriatic Sea in Zeta Valley where Podgorica is situated, climate is classified as Mediterranean (Pejović & Mijović, 2004). The region experiences warm to hot temperatures, with a significant temperature range throughout the year. Summers are long and arid, with average temperatures of 30-35°C. Winters are mild, with average temperatures around 7-10°C. The annual average rainfall is around 1,600 l/m², with the majority of it occurring in the winter and early spring. The dry summers minimize humidity, allowing for healthier grapes. (Montenegro statistical office, 2022)

2.1.3. History and winemaking tradition

Viticulture has a long-lasting tradition in Montenegro, ageing from ancient times of Greek and Roman culture. At several archaeological sites, different kinds of objects and ornaments closely related to viticulture were found, dating from Illyrian and medieval periods. King Nikola Petrović (1860–1918) established necessary regulations and developments in viticulture in Montenegro. In the Podgorica sub region, the inevitable moment was formation of vineyard on Ćemovsko Field. It accounts for more than 70% of total grapevine production in Montenegro. (Maraš, 2019)

2.1.4. Grape Varieties

In the project "Technical support to renewal of viticulture zoning of Montenegro", the list of recommended and permitted wine varieties for producing wines with designation of geographical origin and designation of origin for Podgorica sub-region was created. The list of varieties used for red wines consists of Aglianico, Alicant Buschet, Čubrica, Gamay, Grenache, Cabernet Franc, Cabernet Sauvignon, Kratošija, Lisičina, Marselan, Merlot, Muscat Hambourg, Negro Amaro, Primitivo, Petit Verdot, Sangiovese, Syrah, Viognier and Vranac. (Ministry of Agriculture 2017) In the document, it was stated that the maximum yield for wines with designation of geographical origin was 4 kg per grapevine (for 3,000-4,000 plants per 1 ha) and 3.5 kg (for more than 4,000 plants per 1 ha). Recommended training forms intended for the production of wines with designation of geographical origin and designation of origin in sub region Podgorica are: Guyot – simple, Guyot – double, Royat, asymmetric cord, forms of (Cazen's), Casarsa, Sylvos, Moser, traditional breeding forms, pergola growing forms, training forms similar to those mentioned and other training forms. (Ministry of Agriculture, 2017)

2.2. Trellis systems

Most of plants belonging to *Vitaceae* family needs a trellis system to grow properly. In modern day's viticulture, most of grapevines are grown with trellis system (Pejović & Mijović, 2004).

Keller (2020) defines trellis system as permanent structure that supports grapevine framework and is composed out of stakes, posts and, at least, one wire.

2.2.1. Vertical shoot positioning (VSP) system

Vertical shoot positioning trellis system could be defined as any trellis system where annual canes are trained vertically while fixed to the wires (Skeleton, 2020).

The VSP system should be established in optimal time. If established too late or too early it can damage plants or make other operations more labour intensive. VSP system is composed of wires and posts. Posts could be made of wood, concrete, metal or plastic (Blesić et al., 2013). Establishing a VSP trellis system could account for 60-35% of total costs for vineyard establishment (Pejović & Mijović, 2004).

There are two types of posts: end and in-row posts. Different factors affect the number of posts needed: row length, strength of the posts, training system, soil type, wind, and others. After determining the number of posts, end posts should be placed. Usually, one-third of the post is buried in the soil. Posts could be placed at 90° or tilted outwards from the row at an angle of 25°. End posts should be further fixed with anchor or supporting poles. Posts within rows usually have one-quarter buried in the soil. After placing posts, wire could be stretched and fixed to the posts. Nowadays, galvanized wire is mainly used. It is advised first to place the highest wire, then the lowest wire and then the rest of wires. The height and the distribution of the wires are determined according to training system used. (Blesić et al., 2013)

One of the disadvantages is that the maximum area of green mass and the sun energy absorption could not be achieved in VSP, which further marks the inability to reach maximum potential yield in (Kharibegashvili et al., 2021).

Training – One of the training systems that could be used on VSP is Guyot training. It could be simple (one cane and one spur), double (two canes) or improved (two spurs) (Bálo et al., 2018). Guyot training is suitable for low to moderately tall trunk height. In case of simple Guyot, in the first year, all shoots are removed, and only two overwintering buds are left. In the following year, a single cane is cut up to height of desirable trunk, which is usually the height of the first trellising wire. Two overwintering buds should be left. In the third year, two strong canes should be developed. The uppermost cane is left as moderately long cane and lower cane is cut to form a spur, with two overwintering buds (Milosavljević, 1986). After third year, long cane is removed and two canes developed from spur are left. The upper cane is arched and fixed to the trellis system while lower cane is cut to form a spur. In case only one bud has burst on the spur, long cane is formed from first cane on the cane from last year (Blesić et al., 2013).

2.2.2. Pergola trellis system

Skeleton (2020) defined pergola as any overhead trellising system.

Pejović and Mijović (2004) explain that all pergolas could be differentiated as horizontal or tilted pergolas. One type of horizontal pergola is “Tendona”. It is primarily used in Italy, while in North Macedonia, it is known as “Odrina”. In North Macedonia, it is used in plantations for table grapes. On the other side, in Montenegro it is mainly used around the house, primarily for creating shade. (Pejović & Mijović, 2004)

Row spacing in case of horizontal closed pergola is 3 – 4 m, while distance between grapevines is 2 – 3 m. Pejović and Mijović (2004) explain that supporting poles (metal or concrete) should be placed next to each grapevine. The wires are placed to connect all the poles, and next to these the main wires, 2 to 3 rows of thinner wires will also be placed crosswise, and this is how a network of wire reinforcement is obtained. It is stressed that optimal agro-technical measures should be carefully applied. Yield could be high in this type of trellis system (20 – 40 t/ha). (Pejović & Mijović, 2004)

In pergola trellis system grapevine receives the maximum sun exposure with almost complete green mass exposure horizontally. Likewise, leaves protect fruits from sunburn. Furthermore, this trellis system can increase yield by 2-3 times while providing best quality grapes (Kharibegashvili et al., 2021).

The Pergola trellis system has high cost of installation and maintenance. Very labour intensive maintenance operations need constant labour force which could cause problems with finding skilled workforce (Winkler et al., 1962). Consequently, pergola is not often used in large-scale vineyards or intensive commercial production. Mechanization is limited also, due to specific height and structure of the system (Kharibegashvili et al., 2021). Additionally, vigorous varieties could form dense canopies causing shading and favourable microclimate for diseases (Winkler et al., 1962).

Training - In case of developed grapevines, plants are pruned to short or mixed pruning. In case of mixed pruning, upper cane is arched and fixed to the wire, while lower cane is cut to form a spur. On each grapevine, there are 5 – 7 canes and same number of spurs (Pejović & Mijović, 2004). In case of vigorous varieties, short pruning could be applied, where only spurs are left. In case of less vigorous varieties, mixed pruning should be done. Mixed pruning demands greater vine spacing. (Milosavljević, 1986)

2.3. Effects of trellis systems on grapevine

In a study researching how trellis systems affect vegetative growth and fruit quality, Wang et al. (2023) evaluated two trellis systems, one with horizontal and downwards positioned shoots and one with vertically and upright positioned shoots. In both cases, grapevines were pruned to a single horizontal cordon. The study showed several benefits of trellis system with horizontal and downwards positioned shoots, such as improved fruit quality and flavour, more uniform shoot development, moderate and controlled vine vigour and increased accumulation of monoterpenes and polyphenolic substances. (Wang et al., 2023)

Another study, performed by Volschenk and Hunter (2001), showed the "Effect of trellis conversion on the performance of Chenin blanc/ 99 Richter grapevines". By eliminating alternate vines (extending the cordon in both directions - split cordon) or applying a modified Lyre trellising technique (stretching the cordon lateral), the vertical trellis was adjusted to enable twice the original cordon length of the vines. Two buds were left on spur after pruning. As a result of elongation of cordons of vigorous plants, improved canopy appearance and microclimate led to higher yields without compromising grape quality. Actually, there was an improvement in grape quality overall, and the wine seemed to have a more conventional flavour. The study shows that when balanced growth is established, by the conversion, in rapidly expanding vineyards that provide yields below capacity, grape and wine quality may be at least maintained and income can be enhanced. (Volschenk & Hunter, 2001)

Kliewer et al. (2000) conducted another study researching the effects of trellis and vine spacing on grapevine growth, canopy, yield and fruit composition of cabernet sauvignon. They used six different trellis systems, from which three have horizontal and two have vertical shoot positioning, while one has curtain vertical shoot positioning. Each grapevine was spur pruned (two buds) and cordon trained. Researchers discovered that division of canopy or bigger vine spacing improved micro-climate and lower canopy density. The study has also shown that at the start of the research the best yield was noted at the vines with one meter vine spacing. However, in the third year of research, the best yield was noted at the vines with vine spacing of two meters. Those two meters spaced vines were grown in horizontally divided systems. Additionally, grapes from vines with lower density canopies had lower levels of malic acid, pH and potassium. (Kliewer et al., 2000)

3. Materials and methods of the studies

3.1. Study area

Data is collected in vineyard owned by Božović family (Figure 3) in hamlet "Gola Strana", village "Stijena Piperska", region "Piperi", city of Podgorica, in Montenegro, Europe. The vineyard is family owned and operated by family members. The production is not commercial, but it is nurtured as family tradition practised for a long time. Total land owned by the family where the vineyard is situated is about 0.6 hectares, but the area of the vineyard is about 0.25 hectares.

Figure 3: Google Maps photo of the Božović vineyard
(Source: Google Maps, 2023)

3.2. Time of investigation

The study was conducted in period of November 2022 until October 2023. The measurements and data collection were performed in this period.

3.3.Investigated vineyard

3.3.1. Topographical conditions

The village is located 12 km from the city centre of Podgorica. It is located at the foot of the hill known as Gola Strana. The vineyard is located on the south side, and it gets much sunlight. Also, the hill has a slightly semi-circular shape (Figure 4), which means that the hamlet is protected from strong winds, especially considering that the characteristic winds for the Podgorica area have a north-south direction. The slope of the terrain is not suitable for agriculture, so as a result, the system of terraces has been established. The vineyard is located at an altitude of 200 meters above sea level.

3.3.2. Climate conditions

Apart from topography and geographical location, climate plays a significant role in the production aspect of the vineyard. Since the Montenegro is Mediterranean country, coastal and some central areas are under the influence of Mediterranean climate. It could be observed (Figure 4) that there are no major elevations (such as hills and mountains) between Zeta Valley (where the capital and Skadar Lake are located) and the vineyard and that is the reason why Mediterranean climate has a significant influence on the vineyard. The climate is characterized by all four seasons. Hot and dry summers, followed by rainy, often warm autumns, proceeded with wet and mild winters and warm and rainy springs.

Figure 4: Geographical location of Božović vineyard
(Source: Google Maps, 2023)

3.3.3. Soil conditions

The soil conditions depend on specific locations and terraces. For example, the uppermost terrace has slightly reddish soil with some proportion of clay and a considerable proportion of calcium carbonate rock particles. However, with long cultivation and manuring, the soil has gained some properties of loam soils. Melioration of the soil has a significant role in managing and preserving soil properties. At the top end of each terrace there is a 50 cm deep channel to drain the terrain and conduct excess rainfall in the winter. The lower terrace soil does not have such clay properties as the soil on the upper terrace. In both parcels number 1 and 2, pH is approximately 7.2.

3.3.4. Surrounding environment

At the north and south sides of area where vineyard is located, grasslands are present. On the east and west sides, there are thin layers of forests. Furthermore, on west side there is a small stream which is active only in winter or in case of rainy autumn or spring. It is worth noticing that both grasslands on the south and north sides and forests on east and west sides are not cultivated, so it is important to prevent and control different pests and animals coming from these areas.

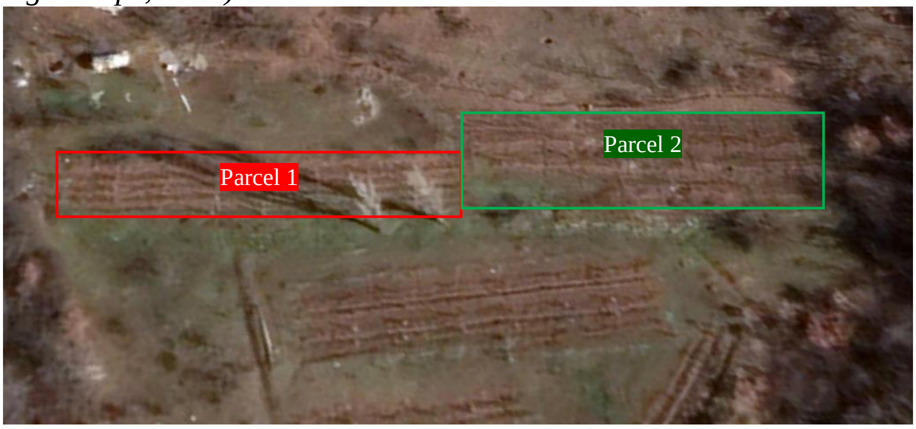
3.3.5. Infrastructure

There is a direct macadam road leading to the vineyard. The road is accessible for small cars, trucks and tractors. The road leads to the uppermost terrace. The lower terraces could be reached only by tractors or agricultural machinery. The road is a dead-end road, so it means that there is no trespassing.

3.3.6. Structure of the vineyard

There are no written records of when the first grapevine was planted in vineyard. The more severe production has started about 40 years ago. Number of grapevines has been almost constantly increasing since then. At the moment there are around 1000 grapevines in the vineyard. Due to topography of the terrain, the system of terraces has been established in certain areas. Consequently, the vineyard could be divided into nine parcels across three terraces. The parcels are divided according to location and trellis system. The subjects of this thesis are parcels number 1 and 2 (Figure 5).

Figure 5: Google Maps photo of parcel 1 and parcel 2
(Source: Google Maps, 2023)

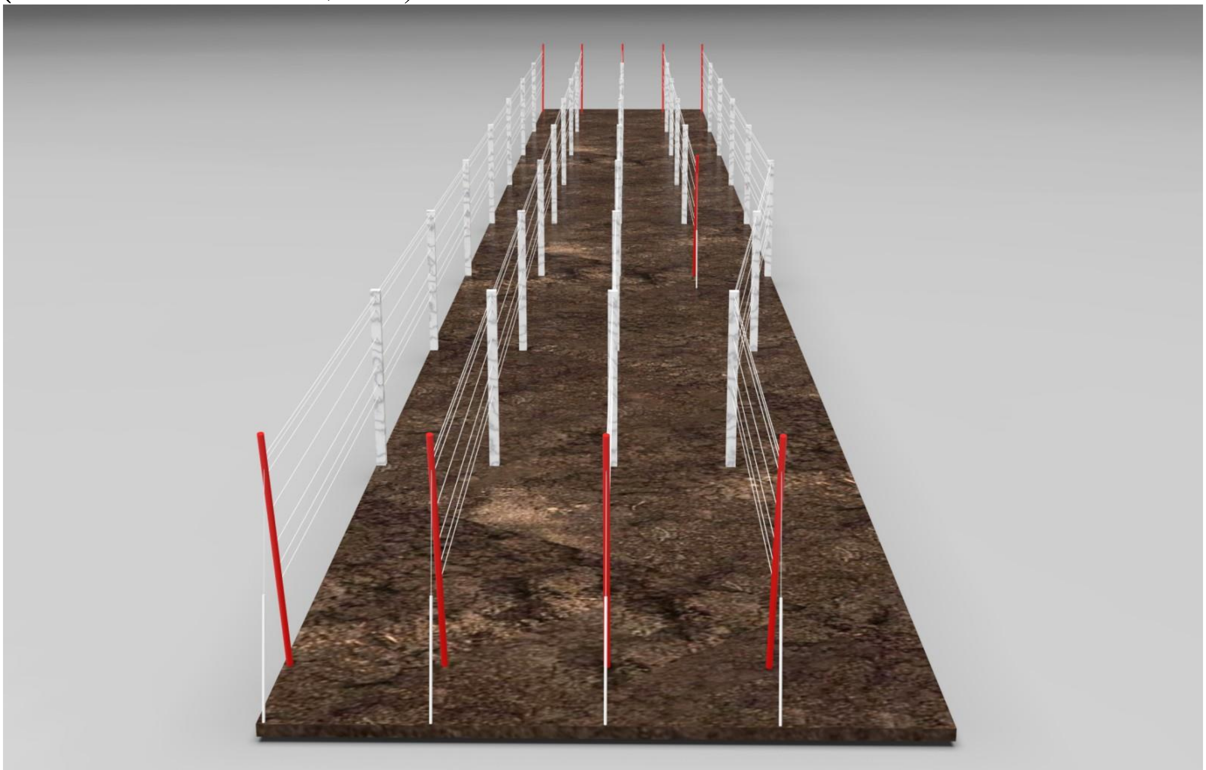


Parcel number 1

Parcel number 1 is 42 m long and 5 m wide. The trellis system in this parcel is vertical shoot positioning (VSP). There are 4.5 rows in this plot, as shown in Figure 6. Since the row at the edge of the terrace follows the curve of the terrace, the width between first and second row at the end is almost double the width between first and second row at the beginning of the row. So, an additional row has been planted between first and second rows. It is 20 m long.

Row orientation is east-west. Trellis system is made out of concrete and metal posts and galvanized wire. Metal posts are used at the end of each row. They are tilted and fixed to an anchor in the soil. Within the row, there are concrete posts. They are two meters high above the ground. The distance between rows is ranging from 1.2 m and 1.6 m. The distance between two posts in the same row is 5 meters. Distance between grapevines in same row is about 70-80 cm. There are seven wires in each row. Wires are fixed at 70, 95, 110, 135, 150, 175 and 190 cm.

Figure 6: Illustration of parcel number 1 and VSP trellis system
(Source: Marko Markišić, 2023)

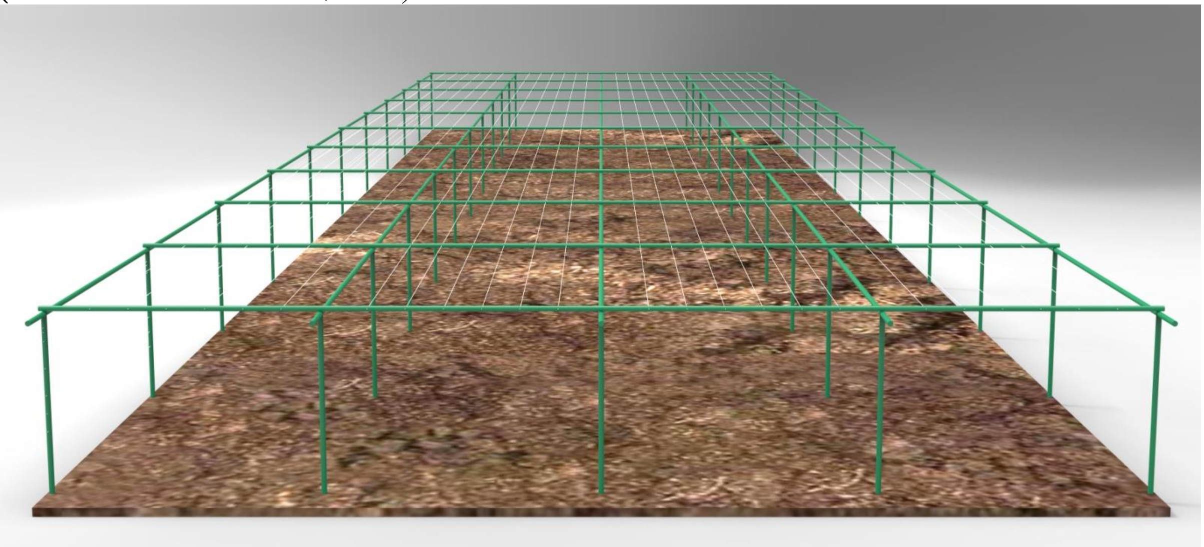


Parcel number 2

Parcel number 2 is 40 m long and 12 m wide. Trellis system used in this parcel is pergola trellis system. The trellis system is entirely made of metal posts. There are five rows of posts. The distance between two posts in the same row is 4 m. The distance between two rows is 3 m. Height of horizontal pole and height of posts is 2.2 m. From each of posts in same row there is horizontal pole connecting it to a parallel post in the next row. Wires are stretched only in one direction, along the length of the pergola as seen in figure 7. On the first horizontal pole, there are metal tensioners, which are fixed for the pole. The spacing between two tensioners is 40 cm. For each tensioner, galvanized wire is fixed and it is stretched for 40 m until it reaches another end of pergola where it is also fixed to tensioner which is fixed for the last horizontal pole.

The distance between grapevines in the same row ranges from 1 to 2 m. It means that there are approximately 2-4 grapevines in every 4 meters.

Figure 7: Illustration of parcel number 2 and pergola trellis system
(Source: Marko Markišić, 2023)



3.3.7. General management

Here is the list of operations performed in period between October 2022 and September 2023, according to each month. All the work is done at the same time in both parcel number 1 and parcel number 2.

November of 2022

Soil cultivation – It is performed only when soil moisture is at optimal level. Soil is cultivated for weed control and incorporation of fertilizers. Cultivation is performed by Goldoni cultivator. Both parcel one and parcel two are fully cultivated at the same time.

Missing vine replacement – Grapevines are replaced by layering or planting pot grafts. In parcel 2, only the latter technique is used. In case of parcel 1, new plant needs less time to reach trellis system and start yielding, than in parcel 2.

Fertilizing – This operation is performed at the same time in both parcels. There are different types of fertilizers and application methods used. Organic such as manure or different kinds of inorganic chemical fertilizers are applied directly in the soil, by broadcasting, through air or by fertigation.

December of 2022

Pruning - Pruning is unquestionably the most significant ampelo-technical practice that helps to create the balance between generative and vegetative growth. Pruning could be defined as all procedures that include removing particular organs from the stem. (Milosavljević, 1986)

Grapevines in both parcels are pruned at the beginning of the winter rather than in spring. It is performed during the sunny days so that the wounds could be dried quickly. Grapevines in parcel 1 are pruned to form simple Guyot training system, where one spur and one long cane (9-10 buds) are left. Grapevines in parcel two are pruned in a specific manner. More (5-7) spurs and long canes are left on the grapevines.

Trunk cleaning – Milosavljević (1986) states that even though it is beneficial for grapevines, the removal of dead organs is not a part of pruning but instead grapevine care. Removing dead grapevine organs, shoots, part of trunks or entire trunks are considered in cleaning (Milosavljević, 1986). It is essential to remove and destroy dead and infested parts in order to suppress further infections.

Spraying - Spraying grapevines with chemical compounds, for protection and fertilization, is performed regularly during the year in the vineyard. These treatments serve as a critical line of defence against a multitude of threats that can compromise grapevine health and grape quality. Spraying is performed in both parcels at the same time and with same solution.

January of 2023

Road and vineyard area maintenance – In order to have undisturbed and facilitated access to the vineyard, it is necessary to perform maintenance of roads, water ditches, irrigation system and general cleaning of surrounding areas.

Trellis system maintenance – Every season there are smaller and bigger operational problems that have to be fixed. Tilted posts, broken posts, ripped wires, loose wires and other issues are fixed. It is worth mentioning that most of the operations connected to trellis system maintenance is performed in parcel number 1, with VSP trellis system.

February of 2023

Arching and fixing canes – Pruned canes must be fixed to the trellis system. Most of the canes growing on VPS trellis system are fixed to the first wire. Canes are arched in order to avoid polar dominance. Grapevines grown on pergola trellis system are also arched and fixed at the most suitable place. Grapevines are fixed manually, using polypropylene tying twine or a hand machine for fixing (using polypropylene tape). Additionally, giant reed (*Arundo donax*) is used to support newly planted or layered plants.

March of 2023

Plant protection - Plant protection could be divided into several categories.

- Protecting grapevines from tiny animals and birds. Different kinds of "scarecrow" objects, such as shiny objects, plastic birds, and clapping objects…) are used to protect fruits from birds.
- Regular cleaning of vineyards from plant debris and dead trunks is beneficial because hazardous inoculum could be located in mentioned materials.
- Regular spraying throughout the year with different chemicals.

Grapevines are sprayed in March as a vital early-season practice to safeguard vines as they exit dormancy. This period marks the onset of bud swell and bud break, rendering grapevines susceptible to fungal diseases like powdery mildew and downy mildew.

April of 2023

Fertilization – Fertilizer is dispersed on the soil surface and then introduced to soil by cultivator. Although April of 2023 had lower amount of precipitation compared to April of 2022, 122 l/m² (2023) was sufficient for proper functioning of fertilizers (Table 2).

Soil cultivation – As elaborated above, soil cultivation performed in spring has a goal of inverting fertilizers in the soil and weed control.

Removal of surface roots – Roots developed from the scion part of the trunk could be problematic regarding phylloxera infection. Additionally, surface roots located in shallow topsoil could cause higher susceptibility to drought and frost. Surface roots are removed manually, using scissors simultaneously in both parcels.

May of 2023

Shoot positioning – In the VSP trellis system, canes are arched and fixed horizontally to the wire, so most of the shoots are growing vertically and fixing themselves with tendrils and do not need special positioning. However, sometimes shoots are not fixed and could fall. Additionally, shoots could be tangled. By shoot positioning proper distribution and foliage wall (VSP) of shoots can be ensured. In VSP trellis system there is no need to fix the shoots with polypropylene tying twine because there are seven wires in trellis system and shoots can be appropriately placed. In pergola trellis system there is no need for fixing the shoots with polypropylene tying twine either, because shoots can be put beneath or above the wire.

Weed control – Depending on weather conditions, vineyard area has to be mowed 2, 3 or even 4 times per season. Weed control between the rows is performed by cultivator. Topsoil is cultivated, soil aggregates broken, turned upside down and tiny weed seedlings destroyed. Weed control beneath the plants is done by hand trimmers. Especially susceptible are plants grown in VSP trellis system. Trunk is only 70 cm high, meaning some weed species can reach the grapevine's canopy. It can create several problems, such as creating favourable conditions for pests and infections, by increasing humidity and obstructing airflow.

Spraying – During May, grapevines have been sprayed twice.

June of 2023

Shoot thinning – Shoots that do not have any flowers are not favoured, if not planned as replacement. Additionally, excess shoots could create too dense foliage, and favourable conditions for pests. Unnecessary shoots are removed manually, predominately by hand or using scissors. It is noteworthy that this process is more labour intensive in parcel 2 due to the over-head trellis system.

Shoot positioning – After shoot thinning, shoots that are hanging between rows or shoots that are tangled should be positioned correctly.

Lateral shoot management – Lateral shoots can be easily broken with hands, but the process should be done while laterals are small. This process is significantly more labour intense in pergola trellis system. Since grapevine is growing horizontally, due to polarity, laterals will be vigorous (Pongrácz, 1978).

Trunk brushing – In case young shoots grow from surface of the trunk, trunk brushing is performed. Young shoots are removed from the surface by hand. This operation has greater importance in pergola trellis system, due to longer trunk.

Defoliating – Too dense canopy in fruit zone could disturb proper development of clusters. Three weeks after bloom, leaves are removed in fruit zone.

It is crucial not to defoliate canopy intensely, in order to preserve enough canopy for sufficient photosynthesis. Defoliation in fruit zone should be performed when berries reach pea size. That is the phase when berries can develop thicker cuticle (protects against sunburn) and the number of berries does not reduce. (Bálo et al., 2018)

Spraying – During the June, spraying was performed three times, each time separately with different chemicals. Foliar fertilization was performed with one of the sprayings.

Shoot topping – Shoot topping is performed in order to increase quality of clusters. Bálo et al. (2018) state that by cutting growing tip of the shoots, vegetative growth is reduced so plant can direct energy produced to the generative growth. All shoots are cut back to the height of the last wire at the trellis system (VSP) or optimal length in pergola system. Since operation is performed manually, it is notably more labour intensive in pergola trellis system. One of the reasons is that in VSP most of the shoots are growing in a similar manner, but in pergola every shoot tip has to be located separately.

July of 2023

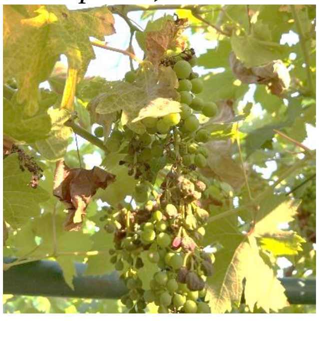
Irrigation – Both in parcel with VSP trellis system and parcel with pergola trellis system, there is a system of drip irrigation. The hose is spread out in every row in both parcels at the height of 70 cm. The vineyard is irrigated from end of June to the end of August, depending on rainfall. In 2023, the amount of precipitation was significantly higher compared to 2022. Nevertheless, July received the least precipitation (Figure 9) in 2023, so the vineyard was irrigated.

Cluster thinning – If the grapevine is bearing too many clusters, some of the clusters are removed in order to preserve quality. The work is done by hand or by using the scissors.

Lateral shoot management and shoot positioning – During the vegetation, these two operations have been constantly practised. It is worth noticing that the most labour intensive processes are the first operations.

Spraying – As a result of high temperatures (Figure 11) and high precipitation, plant protection in 2023 has been challenging for the farmers. Frequent spraying operations have succeeded in protecting the vineyard to some extent, but still, damages were observed (Figure 8). In July, grapevines have been sprayed twice.

Figure 8: Damaged leaves and clusters
(Source: own photo, Gola Strana, 2023)



August of 2023

August of 2023 was the month with the highest precipitation in 2023, after January of 2023 (Figure 12). Such a tremendous amount of rain with average monthly temperature of 27.8 °C (Table 5) puts a great risk in the case of plant protection. As a consequence, numerous damages, such as in figures 9 and 10, could be seen.

Figure 9: Damaged leaf
(Source: own photo, Gola Strana, 2023)

Figure 10: Devastated grapevine
(Source: own photo, Gola Strana, 2023)

Defoliation – In order to ensure better maturation of berries and clusters by providing sufficient sun exposure, fruit zone was defoliated.

September of 2023

Harvesting – Harvest was performed on 08.09.2023. Sugar content and colour of berries were steadily checked until the values were optimal for the harvest. Harvest was performed in the morning, before the temperature was high. All the grapes were harvested manually, by hand using scissors.

3.4. The investigated variety

3.4.1. Origin

Vranac is Montenegrin autochthonous grapevine variety (Maraš et al., 2015). Vranac is the representative variety of Montenegro. In 2020, the study "Population genetic analysis in old Montenegrin vineyards reveals ancient ways currently active to generate diversity in Vitis vinifera", discovered genetic origin of Vranac. Hybridization of Duljenga and Kratošija varieties resulted in Vranac variety. Chlorotype analysis was performed and it was confirmed that Duljenga was female progenitor of Vranac (Maraš et al., 2020).

3.4.2. Distribution

Vranac (*Vitis vinifera l.*) is grown predominantly in Montenegro. It is present on the Balkan Peninsula, primarily former Yugoslavian nations: North Macedonia, Croatia, Bosnia and Herzegovina, and Serbia. (Pajovic et al., 2014; Cindrić et al., 2000)

3.4.3. Botanical description

- Cane top – Colour of young leaves at the top of the cane can differ. Leaves are green with different tinges (red, purple, or bronze) (Burić, 1995). Leaves at the apex of the cane are moderately hairy at the abaxial surface and bare at the face of leaf. (Savić, 2003)
- Mature cane – the shape of the cane is round with smooth surface. Canes are thick and internodes are predominantly short. Colour of bark is brownish with greyish tinge. (Burić, 1995; Avramov & Žunić, 2001)
- Leaf – developed leaf is large to medium size (Avramov & Žunić, 2001). Average length is 17.6 cm (Savić, 2003). The leaf has five sharply toothed parts (Cindrić et al., 2000). The face of the leaf is dark green, not hairy, while abaxial surface is moderately hairy (Avramov & Žunić, 2001).
- Flower – Flower is hermaphroditic and fertilisation is normal and regular (Burić, 1995)
- Berry – Shape of berry is elliptical to round. Colour is uniformly blue to black. Flesh does not have colour. The berry is soft with neutral taste (Savić, 2003). The mass of berry is 1.96 - 2.45 g (Avramov & Žunić, 2001). Mass of 100 berries is 225 g (Savić, 2003).
- Cluster – Savić (2003) explains that the size of Vranac cluster is moderately big. On average it is 17.70 cm long and 10.50 cm wide. On the other side Burić (1995) states that average length is 19.6 cm. Furthermore, Savić (2003) and Avramov and Žunić (2001) state that cluster is compact or moderately compact but Burić (1995) and Cindrić et al. (2000) state that cluster is relatively loose, i.e. more loose than compact. The stalk does not harden greatly, only close to base. It could be broken by hand. Average cluster weight is 200-300 g (Burić, 1995).

3.4.4. Phenophase

Bleeding of grapevine generally occurs on 11.03. and lasts for 21 days. Bud burst on 01.04. and lasts for 56 days. Full bloom occurs on 27.05. and lasts for 10 days. Occurrence of green berries 06.06. and lasts for 40 days. Verasion is occurring on 16.07. and lasts for 54 days. Grapes are harvested on 08.09. Beginning of leaf drop is on 22.09. and the end of leaf drop is on 10.11. (lasts for 50 days). (Savić, 2003)

3.4.5. Agro-biological characteristics

Pruning could be mixed or short. Spurs are cut after 3-5 buds and canes are cut after 6-8 buds (Avramov & Žunić, 2001). Burić (1995) also states that mixed pruning should be used, although it can yield well with long canes. On the other hand, Savić (2003) shows data about bud fruitfulness along spur and cane. In case of longer pruning he noticed that the highest fruitfulness is on the 9th bud. Additionally he states that fruitfulness of first buds on spur is higher than that of first buds on cane (Savić 2003). Savić (2003) explains that out of 32 overwintering buds in study he conducted, 68.8% of them burst in the spring on average. Furthermore, he refers to other studies, with varying data. In case of fertility parameters, in duration of the study (1995-1998), number of inflorescences per bud was 0.88, number of inflorescences per developed shoot was 1.26, number of clusters per plant was 28.38 and mass of cluster was 258.51 g, on average. It is noteworthy that for example number of clusters per plant in 1996 was 15.1 while in 1998 was 41.5. Similarly, mass of cluster in 1995 was 310 g while in 1998 it was 171.3 g. Savić (2003) explains that mass of pruned material is 0.93 kg on average. (Savić, 2003)

Vranac ripens relatively late in general. It fully matures in second half of September (Cindrić et al., 2000). Yield ranges between 12 – 15 t/ha, but in case of irrigated and favourable conditions it could be considerably higher (Burić, 1995). In case of yield per grapevine, Savić states it is on average 6.35 kg (Savić, 2003). Low temperatures are not the most suitable for Vranac since it is moderately sensitive. Overwintering buds are permanently damaged at the temperatures of - 12 to - 14 °C (Avramov & Žunić, 2001).

Grey mold can pose significant problems in production. Since the skin is usually thin, it makes fruits susceptible to the disease, especially in case of increased humidity and precipitation during ripening period. Additionally, strong wind could cause problems due to weak connection between petioles and berries. (Burić, 1995)

3.4.6. Must and wine characteristics

When grapes are fully ripened, must have about 20-24% of sugar and 6.5-8.5% of total acids (Burić, 1995). The berry's skin is rich in colouring compounds, giving a characteristic deep red, almost black, colour to the wine. Must is colourless, sometimes reddish, having pleasant smell and taste. Wine has 11-14% alcohol and 5-6 g/l of total acids. Characteristics of Vranac wine are pleasant and harmonious taste and smell. It is known that Vranac wine was used to improve colour of other wines. Vranac is also used for production of high quality grape brandy (Avramov & Žunić, 2001).

There have been significant advances in selection of Vranac variety. For example between 2004 and 2011, four grapevines with high yield and quality were selected and grapevines passed virus tests, leading to individual clonal selection. These clones were planted and, after crop assessment, were found to produce higher-quality wines than the population (Maraš et al., 2012).

3.5.Treatments of investigation

For study purposes 18 grapevines were selected, and divided into 2 groups, Vertical shoot positioning (VSP) trellis system group and Pergola trellis system group. Groups were made according to the trellis systems used.

- VSP trellis system group – In the VSP group, 9 grapevines were selected. Furthermore, 9 grapevines were subdivided into 3 groups, each group consisting of 3 grapevines. The allocation of the groups was done randomly to minimise potential bias. In one group grapevines are located in same row and one to another.
- Pergola trellis system group - In the pergola group, 9 grapevines were selected. Furthermore, 9 grapevines were subdivided into 3 groups, each group consisting of 3 grapevines. The allocation of the groups was done randomly to minimise potential bias. In one group grapevines are located in same row and one to another.

All grapevines were assigned with a name determining where the location of the grapevine was and which trellis system was used. The name of all grapevines consists of three symbols. The first is a letter, symbolising the trellis system used, “V” in case of VSP trellis system or “P” in case of pergola trellis system. The second symbol is a number, symbolising the number of a group in which grapevine is located (possible numbers: “1”, “2”, and “3”). The third symbol is a number symbolising grapevine in specific group (possible numbers: “1”, “2”, and “3”). For example grapevine named “V21” is located in parcel number 1 because “V” symbolises VSP trellis system. It is the first grapevine in the second group.

3.6. Data collection

3.6.1. Weather data

Hydro-meteorological data (temperature, air humidity, precipitations, rainy days and clear days) is provided by Hydro-meteorological Institute of Montenegro. Collection of these data is done by Institute for Hydrometeorology and Seismology of Montenegro according to the Regulations on establishment of network and work programme as well as observation methods of meteorological stations. (Montenegro statistical office, 2022)

Data is collected at Meteorological station "Podgorica", located 8 km away from the vineyard.

- Relative air humidity is expressed in percentage (%).
- Data about average daily temperature refer to average monthly values calculated from everyday records at 7.14 a.m. and 21.00 p.m. (local time), according to the following formula: (t7+t14+2 t21)/4.
- Maximum daily temperature is the highest temperature measured during 24 hours (usually reached in early afternoon hours of winter days and around 16.00 p.m. of summer days). Minimum daily temperature is the lowest temperature measured during 24 hours (usually in the mornings). Temperature is expressed in Celsius degrees (C°).
- Average annual value has been calculated in the same way.
- The precipitation data relate to monthly and annual precipitation quantities expressed in l/m^2 and measured by corresponding station.

Number of days with rain represents the days where this occurrence was at least 0,1mm. The cloudiness data are result of measuring, which is clear and cloudy days are defined in relation to a parameter N - mean daily cloudiness in tenths of coverage of the sky by clouds. If the parameter N > 8/10 it is a cloudy day. If the parameter N is between 2/10 and 8/10 it is a gloomy day. (Montenegro Statistical Office, 2022)

3.6.2. Phenology phases

Data concerning phenological phases was acquired by visual observation. The dates of vegetation stages were determined by visual observation. Dates were determined when two-thirds of vineyard were in same phenological phase.

3.6.3. Winter measurements

Data concerning vineyard description was collected at the beginning of the study, November 2022. Data was acquired by visual description (number of parcels, number of rows, and structure of vineyard…), by measuring instrument ("Soil analyser PNT 3000 Combi+") or by manual measuring (measuring tape). Mass of pruned material was determined by digital scale.

3.6.4. Spring measurements

Mass of pruned material was determined by digital scale.

3.6.5. Harvest measurements

Data concerning harvest and harvested grapes was collected by visual observation, measuring tape, digital scale and refractometer. Number of grapevine clusters was determined by simple visual observation. Mass of harvested grapes and mass of berries were determined by digital scale. Sugar content of 50 randomly chosen berries was determined by refractometer. Width and length of one representative cluster per grapevine were determined by measuring tape.

Density of the vineyard was determined by dividing 10000 by multiplication of row distance and grapevine distance. Furthermore, yield per hectare is determined by multiplication of vineyard density and average yield per grapevine. Mass of grapes harvested per grapevine was divided by the number of clusters of each grapevine in order to acquire average weight of cluster. One representative cluster was determined by visual observation.

For each grapevine, 50 randomly chosen berries were picked up and their mass was determined by digital scale. Number 50 was divided by the number of clusters per grapevine, and the number got was the number of berries taken from each cluster. Then the mass of 50 berries was divided by 50, to get mass of one berry.

3.7.Data analysis

Data concerning phenological phases was analysed by Microsoft Office Excel 2013. Collected data was entered into Microsoft office Excel 2013 where percentages were calculated.

Data concerning harvest and harvested grapes was entered into Microsoft Office Excel 2013. Same software was used to calculate average values, percentages, standard deviation and ANOVA analysis. Additionally, the software was used to produce tables and graphs.

4. Results and evaluation of results

4.1. Weather

In period of 11 months, from November 2022 to September 2023, in Podgorica sub-region, diverse range of weather conditions was experienced. Table 5, with all data concerning weather conditions can be seen in Appendix.

The autumn of 2022 was characterized by lower air temperature (Table 5) which marks onset of cooler days and shorter daylight hours. Moderate precipitation and sufficient number of clear days in October 2022, ensure that grapevines can mature correctly and accumulate energy for dormancy period. Although temperature is further reduced in November 2023, the frost damages are omitted by high absolute minimum air temperature (3.8 ºC) (Table 5). Amount of precipitation is substantially increased with 465.9 l/m² (Table 5). December receives less, but still significant rainfall, causing high relative air humidity of 87% (Table 5). Temperature continues to drop.

January of 2023, could cause waterlogging problems in the soil, due to high amount of precipitation. However, in February, rainfall is noticeably reduced, mitigating the risk of waterlogging. The lowest temperature of 7.8 ºC ensures dormancy (Table 5). With increasing air temperatures in March, dormancy period is gradually finished. Still, the precipitation amount is 155.3 l/m² (Table 5).

Air temperature continues to gradually increase in April, May, June and July. Precipitation level is higher than 100 l/m² in April and May, which could have caused problems with disease infestation. June and July receive lower amount of rainfall, but total precipitation in August of 2023 is 10.12 times greater than in August of 2022. Great risk is put on the grapevines with 191.5 l/m² of rainfall in August 2023 (Table 5). Temperatures in June, July and August were favourable for grapevines growth and development.

Figure 11: Graph of monthly average, absolute minimum and maximum air temperature
(Source: own work, according to data from Hydro-meteorological Institute of Montenegro, 2023)

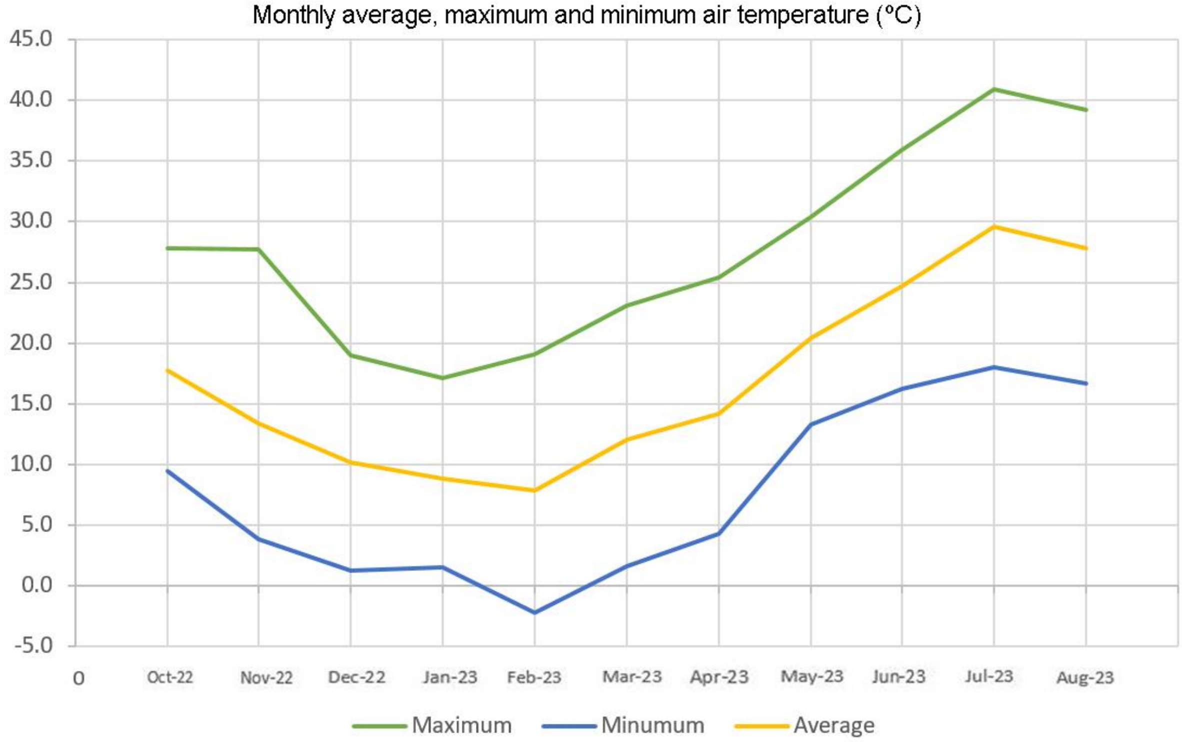
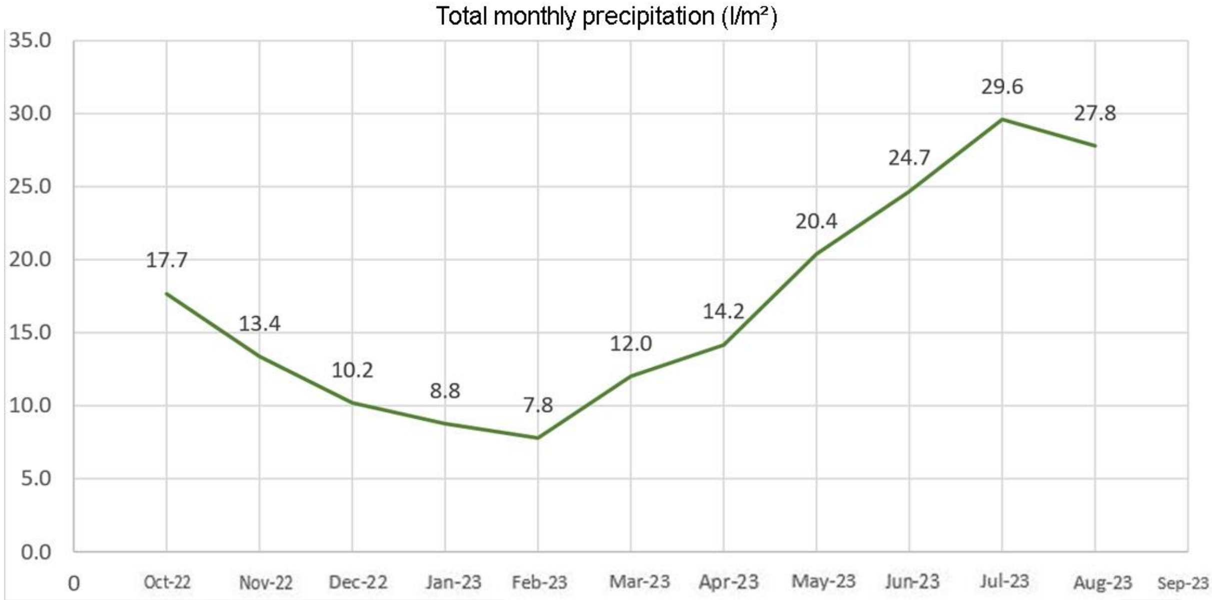


Figure 12: Total monthly precipitation
(Source: own work, according to data from Hydro-meteorological Institute of Montenegro, 2023)



4.2. Overview of 2023 season – 11.2022.-09.2023.

4.2.1. Phenology phases

The Table 1 shows the dates of phenological phases in both parcel number 1 and parcel number 2. There were no significant differences between dates of phenological phases between pergola and VSP trellis system.

Table 1: Dates of occurrence of phenophase
(Source: own work, 2023)

Phenological stage:	Date of occurrence
Bleeding of the grapevine	10.03.2023.
Bud break	05.04.2023.
Growth of the shoots and inflorescence	After bud break
Flowering	25.05.2023.
Growth of the berries	11.06.2023.
Verasion and fruit growth	16.07.2023.
Shoot maturation and leaf drop	After physiological maturation (08.09.2023.)

Bleeding of the grapevine

By visual observation, it was concluded that the grapevines in the vineyard, in both parcel number 1 (VSP trellis system) and parcel number 2 (pergola trellis system) started bleeding on 10.03.2023. (Table 1)

Figure 8: Grapevine bleeding
(Source: own photo, Gola Strana, 2023)

Bud-break

By visual observation, it was concluded that the grapevines in the vineyard, in both parcel number 1 (Figure 15) and parcel number 2 (Figure 14) started bud-break on 05.04.2023. (Table 1)

Figure 9: Bud break in pergola
(Source: own photo, Gola Strana, 2023)

Figure 10: Bud break in VSP
(Source: own photo, Gola Strana, 2023)

Growth of the shoots and inflorescence –

The phase of growth of the shoots and inflorescence is lasting from bud-break until grapevine starts flowering (Table 1). In figure 16 growth of shoots in pergola could be seen while in case of VSP it could be observed in figure 17.

Figure 11: Growth of shoots in pergola
(Source: own photo, Gola Strana, 2023)

Figure 12: Growth of shoots in VSP
(Source: own photo, Gola Strana, 2023)

Flowering

By visual observation, it was concluded that the grapevines in the vineyard, in both parcel number 1 (Figure 19) and parcel number 2 (Figure 18) started flowering on 25.05.2023. (Table 1)

Figure 13: Flowering in pergola
(Source: own photo, Gola Strana, 2023)

Figure 14: Flowering in VSP
(Source: own photo, Gola Strana, 2023)

Growth of the berries

By visual observation, it was concluded that the grapevines in the vineyard, in both parcel number 1 (Figure 20) and parcel number 2 (Figure 21) started growth of the berries on 11.06.2023. (Table 1)

Figure 15: Growth of berries in VSP
(Source: own photo, Gola Strana, 2023)

Figure 16: Growth of berries in Pergola
(Source: own photo, Gola Strana, 2023)

Verasion and Fruit growth

By visual observation, it was concluded that the grapevines in the vineyard, in both parcel number 1 (VSP trellis system) and parcel number 2 (pergola trellis system) started verasion on

16.07.2023. (Table 1). An example of cluster during the verasion is presented in figure 22 while fully grown cluster could be seen in figure 23.

Figure 17: Verasion in pergola
(Source: own photo, Gola Strana, 2023)

Figure 18: Fruit growth in VSP
(Source: own photo, Gola Strana, 2023)

Shoot maturation and leaf drop

Shoot maturation is lasting from the physiological maturation until complete leaf drop (Table 1). Figure 24 presents shoot maturation in pergola system, while figure 25 shows the process of leaf drop in VSP system.

Figure 19: Shoot maturation in pergola
(Source: own photo, Gola Strana, 2023)

Figure 20: Leaf drop in VSP
(Source: own photo, Gola Strana, 2023)

There were not any significant deviations in dates of phenological phases (Table 1) in 2023 year compared to Savić (2003). Additionally it is worth noticing that there have not been any significant difference in dates of phases between two trellis systems, VSP and pergola.

4.3. Winter measurements

Table 6 presents data for each grapevine measured during winter measurements. Complete data regarding descriptive and inferential statistics is shown in tables 9 and 11.

4.3.1. Pruning weight

Pruning was performed in December 2022. Pruning of the grapevines selected for the study was performed on the same day, both in VSP and Pergola trellis system. Canes removed from the grapevine was collected and the mass of pruned canes were determined for each grapevine individually.

As could be seen in table 2, the mean of the mass of pruned canes on VSP is 272.22 g. The standard deviation of approximately 173.33 indicates notable variability in the dataset, with values ranging from 120 g to 650 g (Table 9). In case of pergola, on average, 627.78 g of cane are removed from each grapevine.

One-way analysis of variance (ANOVA) showed that p-value is 0.022. There is significant difference between the mean mass of pruned material of two trellis systems.

4.3.2. Bud load

After pruning, number of overwintering buds was carefully counted. Number of buds was determined for every grapevine in both parcel number 1 and parcel number 2.

The mean number of overwintering buds for the VSP trellis system is approximately 10.889, noticing that almost all grapevines in VSP trellis system had 11 overwintering buds. Average bud count on grapevines in pergola trellis system is 54.778. Taking into consideration range (68), positive skewness of 1.293 and kurtosis of 1.1 the distribution could be characterized as significantly broader than one in VSP trellis system (Table 9).

One-way analysis of variance (ANOVA) showed that p-value is 0.00002 (Table 2). There is significant difference in the mean number of overwintering buds between the VSP and pergola.

Table 2: Winter measurements 1
(Source: own work, 2023)

	Mass of prunned		Budload	
	VSP	Pergola	VSP	Pergola
Mean	272.22	627.78	10.89	54.78
Standard Deviation	173.33	381.22	0.33	22.23
Minimum	120	350	10	33
Maximum	650	1535	11	101
P-value	0.021528		0.000021	

4.4. Spring measurements

Table 7 presents data, for each grapevine, measured during spring measurements. Complete data regarding descriptive and inferential statistics is shown in tables 9 and 11.

4.4.1. Percentage of overwintering buds bursting

By visual observation, the number of buds burst was determined for each grapevine separately. The percentage of overwintering buds burst was determined.

Averagely almost 87% of overwintering buds burst in VSP. Standard error presented in table 9 (2.181) indicates a precise estimation of the sample mean. In case of pergola, almost 84% of overwintering buds burst in spring on average. Furthermore, standard deviation of 9.973 indicates a to some extent bigger variability in pergola than in VSP.

One-way analysis of variance (ANOVA) showed that p-value is 0.45. There is no significant difference in the mean percentage of overwintering buds bursting between the VSP and pergola.

4.4.2. Shoot thinning

Shoot thinning was performed at the beginning of June. Removed shoots were collected and weighted.

The mean mass of removed shoots in VSP is 150.6 g (Table 3). Notably high standard deviation of 115.6 indicates high variability in dataset. Additionally, it is worth noticing that the range is 290. In case of pergola the mean mass of removed shoots is 162.2 g. Similarly to VSP, in pergola there is high standard deviation with notable range of 405. Median and mode, in pergola, are both 110, showing that most observations are concentrated around this value, with few grapevines with noticeably higher values, making distribution right skewed.

One-way analysis of variance (ANOVA) showed that p-value is 0.844. It means that there is no significant difference in the mean of mass of removed shoots from grapevine during shoot thinning between the VSP and pergola trellis systems.

Table 3: Spring measurements 1
(Source: own work, 2023)

	Buds bursting (%)		Mass of shoots	
	VSP	Pergola	VSP	Pergola
Mean	86.77	83.75	150.56	162.22
Standard Deviation	6.54	9.97	115.61	131.77
Minimum	82	64.444	55	50
Maximum	100	96.97	345	455
P-value	0.459		0.844	

4.5. Harvest

As discussed earlier, the harvesting of the grapevine was performed on 08.09.2023. Different parameters were measured during the harvest, such as number of clusters per grapevine, mass of harvested grapes per vine, length of 1 representative cluster per vine, width of 1 representative cluster per vine, mass of 1 representative cluster per vine, mass of 50 randomly chosen berries, and sugar content in 50 randomly chosen berries. Table 8 presents data on each grapevine measured during harvest measurements. Complete data regarding descriptive and inferential statistics is shown in tables 9, 10 and 11.

4.5.1. Number of clusters per grapevine

The number of clusters per grapevine was determined by visual observation for each plant separately.

The mean number in VSP is 7 which is considerably lower than 29, the mean number in pergola. Low standard deviation and narrow range from 5-9 explains relatively consistent number of clusters in VSP system. On the other side, higher standard deviation and range of 62 indicate greater variability in pergola.

One-way analysis of variance (ANOVA) showed that p-value is 0.009 (Table 4). It means that there is a significant difference in the mean number of harvested clusters between the VSP and pergola trellis systems.

4.5.2. Yield

Yield per grapevine

Figure 26 (VSP) and figure 27 (pergola) show the total yield for certain grapevines. All clusters from one plant were separated and arranged accordingly.

Grapevines grown in VSP system produced lower mass of grapes than grapevines in pergola system. The mean mass of harvested grapes in VSP system was 807.78, while in case of pergola system it was 3037.78. On the other side, pergola system had greater standard deviation (2564.83) with notably greater range of 7500.

One-way analysis of variance (ANOVA) showed that p-value is 0.021 (Table 4). It means that there is significant difference in the mean mass of harvested grapes between the VSP and pergola trellis systems.

Yield per hectare

Density of vineyard in parcel number 1 is 9523.8 grapevines/ha, while in parcel number 2 is 2222.2 grapevines/ha. Yield per hectare in case of VSP is 7619.2 kg/ha. In case of pergola it is 7555.5 kg/ha.

Figure 21: Yield of grapevine V13
(Source: own photo, Gola Strana, 2023)

Figure 22: Yield of grapevine P13
(Source: own photo, Gola Strana, 2023)

4.5.3. Weight of clusters

The mean value of VSP system is higher than in case of pergola system, indicating that on average, clusters on VSP weigh 120.5 g while clusters on pergola weigh 92.8 g. Similarly to VSP mean value, SD (standard deviation) and range are higher in case of VSP. Clusters on pergola range from 72-138 g while on VSP 16-235 g.

One-way analysis of variance (ANOVA) showed that p-value is 0.324 (Table 4). It means that there is no significant difference in the mean mass of harvested grapes between the VSP and pergola trellis systems.

4.5.4. Length of one representative cluster per vine

Mean value for VSP system is 19.356 while for pergola system it is 19.3. Standard deviations are low, but in pergola system it is higher (4.567), indicating greater variation than in VSP. Dataset is relatively normally distributed, which is explained by skewness close to zero in both cases.

One-way analysis of variance (ANOVA) showed that p-value is 0.978 (Table 4). It means that there is no significant difference in the mean length of one representative cluster between the VSP and pergola trellis systems.

4.5.5. Width of one representative cluster per grapevine

Similarly to the length of one representative cluster, the mean value width of one representative cluster do not differ to big extent. Pergola system has higher SD (4.346) and range (12.8) indicating greater variance than VSP system. Similarly to the length, data has relatively normal distribution again (skewness close to zero in both cases).

One-way analysis of variance (ANOVA) showed that p-value is 0.99 (Table 4). It means that there is no significant difference in the mean width of one representative cluster between the VSP and pergola trellis systems

4.5.6. Mass of one berry

The SD and sample variance are low in both groups, meaning that there is small variance in both VSP and pergola when it comes to mass of one berry. Mean value for VSP is 1.962 while for pergola it is 2.

One-way analysis of variance (ANOVA) showed that p-value is 0.909 (Table 4). It means there is no significant difference in the mean mass of one berry between the VSP and pergola trellis systems.

4.5.7. Sugar content in 50 randomly chosen berries

Refractometer was used to measure sugar content of juice from 50 randomly chosen berries.

Mean value of parcel 1 is higher than in parcel 2. On average, grapevines have 3% higher sugar content in VSP than in pergola. Higher SD and standard variance indicate higher variance in VSP.

One-way analysis of variance (ANOVA) showed that p-value is 0.091 (Table 4). It means there is no significant difference in the mean values of sugar content between VSP and pergola trellis system.

Table 4: Harvest measurements 1
(Source: own work, 2023)

	Number of clusters per vine		Yield		Weight of clusters		Length of 1 cluster		Width of 1 cluster		Mass of 1 berry		Sugar content	
	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola
Mean	7	29	807.78	3037.78	121.48	100.53	19.36	19.3	12.71	12.69	1.96	2	23.5	20.44
Standard Deviation	1.66	22.16	502.48	2564.83	80.81	21.88	3.61	4.57	3.39	4.35	0.92	0.32	3.96	3
Minimum	5	5	140	155	15.56	72	13.5	12.5	7.2	6.9	0.46	1.4	21	16
Maximum	9	67	1645	7655	235	137.61	24	26.8	16	19.7	3.3	2.4	33	25
P-value	0.0090		0.0210		0.3237		0.9775		0.9905		0.9093		0.0913	

4.6. Discussion

The results presented in this thesis provide valuable insights into the impact of trellis system (VSP and pergola) on various aspects of grapevine cultivation and yield.

Noted dates of phenophases occurrence during the study period comply with the description provided by Savić (2003), without bigger differences. It is important to note that there has not been considerable differences in occurrence of phenophases between VSP and pergola. Similarly, the general operations at the vineyard were performed in the same time in both parcels.

Grapevines in pergola trellis system have higher vegetative growth than grapevines in VSP. Mean value of mass of pruned canes of vines in pergola is more than two times higher than in VSP (Table 1). One of reasons is that the training system differs, where there are 5-7 long canes and spurs left on pergola while it is single cane and a spur on VSP. As a consequence, there are significant differences in bud load. There are more overwintering buds left on vines in pergola than in VSP. Although bud load is significantly higher, there is no significant difference in percentage of buds bursting in the spring. The percentage is higher in VSP but not considerably. Even if mass of pruned canes differs much, there is no significant difference in the mean of mass removed shoots during shoot thinning between VSP and pergola.

Bud load could be associated with number of clusters per grapevine. There are significantly more clusters on vines in pergola than in VSP and consequently higher yield in pergola. Comparison of average cluster weight showed no significant difference between VSP and pergola. Measurements also confirmed that length and width of clusters and mass of one berry do not differ significantly between two parcels, similar to weight of cluster. It is noteworthy that the mass of one berry measured in this study complies with data provided by Avramov and Žunić (2001) and Savić (2003). The length measured in this study complies with Burić (1995) (19.6 cm), while width measured in this study (12.71 cm in VSP and 12.69 in pergola (Table 7)) slightly differs from average width in book by Savić (2003) (10.50 cm). Burić (1995) states that cluster on average has the mass of 200-300 g, while measurements of the study in Božović vineyard showed that in VSP it is 120.5 g and in pergola 92.8 g. This could be attributed to challenging weather conditions and disease infestation, which could reduce the mass of clusters. Sugar content of the berries also does not differ significantly between two trellis systems, although on average it is 3% (Table 7) lower in pergola than in VSP. Yield is especially interesting aspect. In case of yield per vine, pergola results in significantly higher yield. But in case of yield per hectare, there is no significant difference, due to higher plant density in VSP. Although different studies (Kliewer et al., 2000; Volschenk & Hunter, 2001; Wang et al., 2023) showed several benefits of horizontal shoot positioning trellis systems, measurements performed during this thesis could not prove statistically significant differences between pergola and VSP in case of quality of grapes and yield per hectare.

5. Conclusions and recommendations

The thesis presents valuable insight into how different trellis systems affect the growth and development of the autochthonous grapevine variety Vranac. Weather conditions could have imposed risks regarding plant protection since there was substantial rainfall in the spring and summer, followed by high air temperatures.

Operations performed as general management from November 2022 to October 2023 did not differ in time between the VSP and pergola trellis system. However, it was noticed that certain operations in pergola were more labour-intensive than in VSP due to the different height and positions of the system.

It was noticed that defoliation could have different effects in two systems. Although the pergola has greater sun exposure, due to the horizontal positioning of shoots, clusters are less susceptible to sunburn damage than in VSP. The possible reason is that there is still a canopy above clusters in a pergola, so even after defoliation, there is some protection for the clusters. Conversely, in VSP, clusters have greater sun exposure. Sunburn damages were noted in both systems, but to some extent, more often in VSP. Although it could be concluded that VSP is more susceptible to sunburn damages, this harm could be omitted by changing the dates of defoliation.

One of the key findings of this study is that there were no significant differences in the dates of phenological phases between the two trellis systems, VSP and pergola. Due to the structural differences between trellis systems, results showed that the pergola had a significantly higher bud load than VSP. Since there is no significant difference in the percentage of overwintering buds bursting and the mass of removed shoots (shoot thinning) between the two trellis systems, it could be concluded that budburst and the mass of thinned shoots are not influenced by the trellis system.

The harvest presented valuable data regarding yield in different systems. The number of clusters per vine and yield per vine were significantly higher in the pergola system. Conversely, yield per hectare, average cluster weight, length and width of cluster, mass of one berry and sugar content do not show statistically significant differences between VSP and pergola.

Finally, trellis systems (VSP and pergola) in Podgorica sub-region do not significantly impact the timing of phenological phases, budburst, shoot thinning, yield per hectare, mass and dimensions of the cluster or sugar content of grapes. Factors influenced by the choice of trellis system are bud load, pruning weight, the number of clusters, and yield per vine.

Skilled growers looking for a moderate number of high-yielding grapevines could prioritise the pergola trellis system. On the other hand, farmers looking for not labour-intensive and possibly mechanised production of high-density vineyards could find the VSP trellis system beneficial.

Future research in the region should explore the long-term impacts of different trellis systems on vine health, disease susceptibility, and wine quality. Additionally, studies on the economic viability of each trellis system and the relationship between the trellis system and terroir characteristics would be valuable for the local wine industry.

6. Summary

Vranac is autochthonous grapevine variety from Montenegro. The thesis explored effects of two common trellis systems in Montenegro on Vranac variety. Vertical shoot positioning (VSP) and pergola trellis system were studied. The study was conducted in family owned Božović vineyard, in Piperi area, in Podgorica. Time period of the study was from November of 2022 to October 2023. Two separate parcels were main focus of the research. Parcel number 1 is characterized with VSP and parcel number 2 with pergola. In each parcel, three groups consisting of three grapevines were made, resulting with 18 studied grapevines in total. Each phenophase was carefully monitored and every operational process in the vineyard was recorded. Data concerning weather showed possibility for high risk concerning plant protection. As a consequence, serious diseases have infested vineyard.

Measurements have been conducted since winter of 2022, when the mass of pruned material and bud load were monitored. Due to different structure, it was concluded that pergola trellis system could increase the mass of pruned material and bud load significantly. Conversely, percentage of buds bursting in the spring and mass of removed shoots during shoots thinning are not impacted by trellis systems. Another correlation of choice of trellis system and grapevine production could be observed at number of clusters per vine and yield per vine. In both cases, pergola trellis system records higher values. On the contrary, yield per hectare is no significantly different between two trellis systems, due to higher vine density in VSP system. Average cluster weight, length and width are not influenced by trellis system, similarly to mass of one berry. Important aspect of grape quality, the sugar content is also not statistically and significantly impacted by choice of trellis system. The thesis provided some valuable insight in comparison of VSP and pergola trellis system and highlights the importance of further studying of this topic.

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For the balanced growth and development of the grapevine, different factors are needed. For example, good genetics, a suitable environment, nourished soil, adequate climate and weather conditions, proper irrigation, the right trellis system… I want to thank my family for providing good genetics, my Piperi for providing me with a suitable environment, my previous and current professors for delivering me needed nutrients from nourished soil, my friends for giving me always sunny and shiny weather, some special people for irrigating my will and finally, my dreams, the trellis system, for providing me needed support when I needed it the most.

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10. Appendix

Table 5: Weather data
(Source: own work, according to data from Hydro-meteorological Institute of Montenegro, 2023)

	Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Yearly
Average monthly air temperature (ºC)	2022	6.8	8.6	9.9	14.5	22.0	27.6	30.1	28.7	21.6	17.7	13.4	10.2	17.6
	2023	8.8	7.8	12.0	14.2	20.4	24.7	29.6	27.8	/	/	/	/	/
Monthly air temperature, absolute maximum (ºC)	2022	20.1	18.0	22.5	26.1	34.9	37.7	40.4	39.1	32.9	27.8	27.7	19.0	40.4
	2023	17.1	19.1	23.1	25.4	30.4	35.9	40.9	39.2	/	/	/	/	/
Monthly air temperature, absolute minimum (ºC)	2022	-3.1	0.5	-0.5	3.8	9.8	15.6	18.8	19.0	11.4	9.4	3.8	1.2	-3.1
	2023	1.5	-2.2	1.6	4.3	13.3	16.2	18.0	16.7	/	/	/	/	/
Monthly precipitations (l/m²)	2022	58.4	142	36.7	159	33.1	33.9	6.9	18.9	388.5	28.1	465.9	284.5	1656.2
	2023	348	88.5	155	123	149	57.3	34.3	191.5	/	/	/	/	/
Average monthly relative air humidity (%)	2022	55	63	45	60	55	49	35	45	60	64	73	87	58
	2023	73	58	64	57	60	57	46	51	/	/	/	/	/
Monthly average soil temperature at a depth	2022	6.2	7.1	10.1	15.0	23.2	29.3	32.9	32.5	24.6	19.1	14.2	10.1	18.7
	2023	8.1	7.5	12.1	15.2	21.8	26.9	32.6	31.1	/	/	/	/	/
Number of days with the occurrence of rain	2022	8	11	5	12	6	5	2	11	13	5	14	19	/
	2023	12	6	13	10	18	13	4	8	/	/	/	/	/
Number of clear days	2022	15	10	15	6	5	10	21	9	10	14	4	3	122
	2023	7	10	7	2	1	6	24	15	/	/	/	/	/

Table 6: Winter measurements 2
(Source: own wortk)

Grapevine:	Budload:	Mass of prunned shoots (g):
V11	11	330
V12	11	270
V13	11	240
V21	11	120
V22	10	170
V23	11	140
V31	11	410
V32	11	120
V33	11	650
P11	52	380
P12	42	430
P13	38	375
P21	101	725
P22	33	405
P23	76	1535
P31	66	825
P32	45	625
P33	40	350

Table 7: Spring measurements 2
(Source: own work, 2023)

Vine:	Buds bursting (%)	Mass of thinned shoots (g):
V11	82	70
V12	91	325
V13	82	215
V21	82	110
V22	90	110
V23	100	70
V31	91	55
V32	82	55
V33	82	345
P11	88	110
P12	79	50
P13	87	50
P21	82	160
P22	88	100
P23	93	130
P31	97	295
P32	64	455
P33	75	110

Table 8: Harvest measurement 2
(Source: own work, 2023)

Vine:	Number of clusters per vine:	Yield per grapevine (g):	Sugar content (%):	Length of cluster (cm):	Width of 1 cluster (cm):	Mass of 1 berry (g):	Weight of cluster (g):
V11	9	1025	22	24	15	2	114
V12	5	1115	21	24	13	3	223
V13	7	1645	21	22	16	3	235
V21	9	140	/	20	9	0	16
V22	5	280	23	14	7	1	56
V23	8	365	33	17	9	1	46
V31	8	1245	22	21	16	2	156
V32	7	890	22	17	16	2	127
V33	5	565	24	17	13	2	113
P11	43	5155	16	20	14	2	120
P12	15	1415	23	18	12	2	94
P13	28	2545	19	20	14	2	91
P21	5	360	25	13	7	1	72
P22	23	3165	18	21	15	2	138
P23	57	5460	19	27	20	2	96
P31	67	7655	19	24	16	2	114
P32	18	1430	21	16	8	2	79
P33	5	155	24	15	8	2	31

Table 9: Descriptive statistics 1
(Source: own work, 2023)

	Mass of prunned shoots		Budload		Buds bursting (%)		Mass of shoots thinned		Number of clusters per vine		Yield	
	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola
Mean	272.22	627.78	10.89	54.78	86.77	83.75	150.56	162.22	7.00	29.00	807.78	3037.78
Standard Error	57.78	127.07	0.11	7.41	2.18	3.32	38.54	43.92	0.55	7.39	167.49	854.94
Median	240	430	11	45	82	86.8421	110	110	7	23	890	2545
Mode	120	#N/A	11	#N/A	82	#N/A	70	110.00	5	5.00	#N/A	#N/A
Standard Deviation	173.33	381.22	0.33	22.23	6.54	9.97	115.61	131.77	1.66	22.16	502.48	2564.83
Sample Variance	30044.44	145325.69	0.11	494.19	42.79	99.46	13365.28	17363.19	2.75	491.25	252488.19	6578350.69
Kurtosis	2.02	4.27	9.00	1.10	0.45	0.46	-0.63	2.54	-1.67	-0.74	-0.97	-0.59
Skewness	1.43	1.98	-3.00	1.29	1.08	-0.74	1.04	1.69	-0.21	0.70	0.21	0.67
Range	530	1185	1	68	18	32.5253	290	405	4	62	1505	7500
Minimum	120	350	10	33	82	64.4444	55	50	5	5	140	155
Maximum	650	1535	11	101	100	96.9697	345	455	9	67	1645	7655
Sum	2450	5650	98	493	780.909	753.767	1355	1460	63	261	7270	27340
Count	9	9	9	9	9	9	9	9	9	9	9	9

Table 10: Descriptive statistics 2
(Source: own work, 2023)

	Weight of clusters		Length of 1 cluster		Width of 1 cluster		Mass of 1 berry		Sugar content	
	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola	VSP	Pergola
Mean	120.537	92.801	19.36	19.30	12.71	12.69	1.96	2.00	23.50	20.44
Standard Error	25.214	10.306	1.20	1.52	1.13	1.45	0.31	0.11	1.40	1.00
Median	113.889	94.333	19.60	20.40	13.30	13.70	2.20	2.10	22.00	19.00
Mode	#N/A	#N/A	#N/A	20.40	#N/A	#N/A	#N/A	2.10	22.00	19.00
Standard Deviation	75.642	30.917	3.61	4.57	3.39	4.35	0.92	0.32	3.96	3.00
Sample Variance	5721.774	955.848	13.03	20.85	11.47	18.89	0.85	0.11	15.71	9.03
Kurtosis	-0.859	1.171	-1.04	-0.6	-1.36	-1.0	-0.74	0.1	6.54	-1.0
Skewness	0.287	-0.694	-0.14	0.18	-0.65	0.01	-0.39	-0.57	2.50	0.27
Range	219.444	106.609	10.50	14.30	8.80	12.80	2.84	1.00	12.00	9.00
Minimum	15.556	31	13.50	13	7.20	7	0.46	1	21.00	16
Maximum	235	137.609	24	26.80	16	19.70	3	2.40	33	25.00
Sum	1084.837	835.206	174.20	173.70	114.40	114.20	17.66	18.00	188.00	184.00
Count	9	9	9	9	9	9	9	9	8	9

Table 11: Inferential statistics
(Source: own work, 2023)

	Source of Variation	SS	df	MS	F	P-value	F crit
Mass of prunned shoots	Between Groups	568888.889	1	568888.889	6.488	0.022	4.494
	Within Groups	1402961.111	16	87685.069			
	Total	1971850	17				
Budload	Between Groups	8668.056	1	8668.056	35.072	0.00002	4.494
	Within Groups	3954.444	16	247.153			
	Total	12622.5	17				
Percentage of total buds blooming	Between Groups	40.927	1	40.927	0.575	0.459	4.494
	Within Groups	1137.984	16	71.124			
	Total	1178.910278	17				
Mass of shoots thinned	Between Groups	612.500	1	612.500	0.040	0.844	4.494
	Within Groups	245827.778	16	15364.236			
	Total	246440.2778	17				
Number of clusters per vine	Between Groups	2178.000	1	2178.000	8.818	0.009	4.494
	Within Groups	3952.000	16	247.000			
	Total	6130	17				
Yield	Between Groups	22378050.000	1	22378050	6.552	0.021	4.494
	Within Groups	54646711.111	16	3415419.444			
	Total	77024761.11	17				
Weight of clusters	Between Groups	3461.981	1	3461.981	1.037	0.324	4.494
	Within Groups	53420.975	16	3338.811			
	Total	56882.95626	17				
Length of 1 cluster	Between Groups	0.014	1	0.014	0.001	0.978	4.494
	Within Groups	271.042	16	16.940			
	Total	271.0561111	17				
Width of 1 cluster	Between Groups	0.002	1	0.002	0.000	0.990	4.494
	Within Groups	242.838	16	15.177			
	Total	242.84	17				
Mass of 1 berry	Between Groups	0.006	1	0.006	0.013	0.909	4.494
	Within Groups	7.679	16	0.480			
	Total	7.685177778	17				
Sugar content	Between Groups	39.542	1	39.542	3.255	0.091	4.543
	Within Groups	182.222	15	12.148			
	Total	221.7647059	16				

DECLARATION

the public access and authenticity of the thesis/dissertation/portfolio[1]

Student's name:	Balša Božović
Student's Neptun code:	TCAGI0
Title of thesis:	**EFFECTS OF PERGOLA AND VERTICAL SHOOT POSITIONING TRELLIS SYSTEMS ON VEGETATIVE AND REPRODUCTIVE PERFORMANCE OF VRANAC VARIETY IN MONTENEGRO**
Year of publication:	2023
Name of the consultant's institute:	Institute of Viticulture and Oenology
Name of consultant's deparment:	Department of Viticulture

I declare that the final thesis/thesis/dissertation/portfolio submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography.

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[1] The appropriate one should be underlined.
[2] The appropriate one should be underlined.