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# Effect of Covering Crops between Rows on the Vineyard Microclimate, Berry Composition and Wine Sensory Attributes of 'Cabernet Sauvignon' (*Vitis vinifera* L. cv.) Grapes in a Semi-Arid Climate of Northwest China

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**Abstract:** Covering crops was a commonly used viticultural technique to adjust the vineyard microclimate, thus affecting the grape and wine quality. In this two-year study, the purslane (*Portulaca oleracea* L.) was used to cover the lands between rows in the vineyards located in the semi-arid Northwest China, Xinjiang. Results showed that the photosynthetically active radiation around the fruit zone and the temperature with the purslane covering treatment decreased. Compared with the clean tillage, covering purslane had lower TSS and higher TA in the grape berries, while lower alcohol content and higher TA was also found in their corresponding wines. Covering purslane treatment significantly increased the contents of anthocyanin and flavonol in the grapes and wines in the year 2018, but no significant effect on flavanols was observed in the wines. Norisoprenoids, esters, and $C_6$ alcohols in the grapes and wines were increased in the purslane covering treatment, respectively. Additionally, compared to the clean tillage, the purslane covering treatment significantly improved the sensory value of the wines, especially the floral aroma and the complexity of the wines. This study helped us to better understand the feasibility of applying covering purslane in viticulture in the semi-arid climate of Northwest China.

**Keywords:** cover crop; purslane; microclimate; wine; aroma compounds; phenolics



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## 1. Introduction

Wine quality is influenced by plenty of parameters, including the grape variety, the viticultural management techniques, and the environmental factors, like the soils and the climates [1]. The influence of the environmental factors on the wine quality and characteristics, even including the viticultural practices, was referred to as the "terroir" effect [2]. It was a common observation by winemakers that even the quality of the aging bouquet varies with the precise origin of the wines (including the vineyard soil and microclimate) and the vintages (reflecting the climatic conditions of the year of production) [3]. Therefore, the French term "terroir" includes all the regional parameters with an impact on the wine composition such as the characteristics as the soil type, the climate (sunlight, temperature, and rainfall), and the topography [4,5]. Van Leeuwen et al. [6] concluded that climate had the most significant effects on the grape properties from a multi-season study in Bordeaux vineyards. Climate had an important effect on the grape and wine composition and quality.

The effects of the canopy microclimate on the grape and wine composition were also important [7–9]. The canopy microclimate of the vineyard had become one of the key focuses of current researches. The common cultivation measures to change the microclimate of the vineyard included leaf removal, canopy shading, crop covering, spur-pruning, etc. The vineyard canopy microclimate and its management has become one of the key focuses of current researches [10,11].

In various attempts, covering crops might have the potential to improve the wine quality by changing the microclimate of the grape growing, especially in arid environments [12]. Furthermore, in the sustainable or the organic vineyard systems, the introduction of covering crops could represent a powerful tool for viticultural practices to positively influence the agro-ecosystem by promoting the whole soil-plant system equilibrium. Furthermore, covering crops practice might be capable of controlling the soil erosion, reducing the ground pressure, improving the soil structure, and easing the viticultural mechanization [13,14].

There were more than 30 species of plants that were used as inter-row covering crops in the vineyards, mainly including grasses and legumes [15]. Furthermore, after the agronomic strategy of covering crops was introduced into China, according to the current situation of the drought and cold weather in winter and spring, in Northwest China, alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.), and purslane (*Portulaca oleracea* L.) were often selected to carry on as the covering crops in their vineyards [16]. Covering purslane usually led to the decrease of the total soluble solids, the increase of the titratable acid, the phenolic contents of the treated grape berries, especially those of the tannins and anthocyanins, and was also beneficial to the accumulation of the aroma components of grapes [17–19]. This was because in the semi-arid North China, wine grapes often ripened quickly in the latest years, as a result of global warming, where the heatwaves frequently occurred in the grape development stage. Thus, the grape berries often matured with extremely high sugar contents (TSS $\geq$ 27°Brix) and low titratable acid ($\leq$3 g/L) without special viticultural treatments. Besides, due to the wine grapes maturing too quickly, they often could not accumulate enough flavor compounds, especially the flavonoids and the aroma compounds, which limited their potential for finest winemaking. Covering crops could influence the reflected light intensity in the fruit zone modifying the grape microclimate to accumulate more flavors improving the vegetative–productive balance [19–23].

In the present study, the covering purslane in the vineyard of 'Cabernet Sauvignon' (*Vitis vinifera* L. cv.) grapevines was carried out in northwest China for the two consecutive years of 2018 and 2019. Their influences on the quality of grape berries and wines were analyzed, especially on the compositions of the flavonoids and the aroma compounds. By comparing with the clean tillage, covering crops with purslane could enhance the taste and aroma expression of their corresponding wines, which had great potential to produce high-quality wines in that region.

## 2. Materials and Methods

### *2.1. Experimental Site and Design*

The vineyard was located in Manas County of Xinjiang Uygur Autonomous Region, one of the famous wine regions at the north foot of the Tianshan Mountains (44°14′0″ N-86°14′39″ E, elevation 498 m), in Northwest China. The soil type was "silt loam", with 1.2% organic matter content and the pH value was about 8.3. The cultivar used in the experiment was own-rooted 'Cabernet Sauvignon' (*V. vinifera* L. cv.) grapevines planted in the year 2002. Row and vine spacing were 2.8 × 1.0 m, respectively, with the direction of the plant being 66° north by east. All the experimental vines were trained to the modified vertical shoot-positioned spur-pruned cordon system (M-VSP) [21], with a canopy of 1.2 m in height and 0.8 m in width. The cordon was 0.6 m above the ground. The experiment was carried out in the two successive years of 2018 and 2019, which were the normal vintages in Xinjiang. And the irrigation method for grapes was furrow irrigation.

In order to monitor the grape development process, the samples were collected at five developing stages: pea size, veraison 5%, veraison 100%, 10 days after veraison 100%,

and the commercial harvest stage. Three adjacent experimental rows were treated as replicates in each block. There were three statistical replications for this experiment. And for obtaining the representative grape berries, there were 20 vines with similar growth vigor for each replicate. Five hundred berries of each replicate were randomly collected from different positions of the clusters at harvest. After sampling, 100 berries were randomly selected to measure the physicochemical parameters, and the remaining berries were frozen immediately in liquid nitrogen and stored at −80 °C for the subsequent analysis of the flavonoids and aroma compounds.

The treatments were:

Control: clean tillage between rows;

Treatment: purslane (*P. oleracea* L.) was grown between rows in the vineyards.

The covering crop used in this study was purslane (*P. oleracea* L.), which belonged to the dicotyledonous plants. In the management of the vineyard ground, purslanes were planted manually in the spring and pruned regularly to keep their height at about 15 cm above the ground, and maintained this state until the grapes were harvested. For the control, it adopted the management of the clean tillage, and the weeds between rows were removed regularly, according to that of the purslane covering. There was no irrigation between rows regardless of the treatment and the control during the whole grape berry development.

### *2.2. Climate and Microclimate Data Observation*

The meteorological data, including the average daily temperature and the rainfall in the whole growing season (from 1 April to 30 September) in the years 2018 and 2019 at the experimental site, was obtained from China Meteorological Data Service Centre (http://cdc.cma.gov.cn/, accessed on 27 April 2022). The fruit-zone microclimate was monitored in one of three replicates for each treatment or the control. The temperature sensor (S-THB-MOO2, Onset, Bourne, MA, USA) and the PAR sensor (S-LIA-M003, Onset, Bourne, MA, USA) were installed parallel with the cordon at the fruit zone. In addition, the soil moisture was monitored using thermocouples (S-TMB-M002, Onset, Bourne, MA, USA) which were buried 40 cm beneath the ground surface. The meteorological data were recorded at five-minute intervals via a HOBO micro station logger (H21-002, Onset, Bourne, MA, USA).

### *2.3. Measurement of Vine Growth and Yield Parameters*

In the year 2019, one week before the harvest, the area of primary and lateral leaves of ten shoots per replicate was measured by using a portable leaf area meter (Yaxin-1242, Beijing, China). The length and the diameter (the third internode from the base) of ten shoots per replicate were measured. At harvest, ten randomly sampled bunches per replicate were weighed to calculate the average bunch weight, and the number of the bunches was counted on ten vines for each replicate. The yield at harvest was monitored by weighing vine bunch weight. During winter pruning, canes from five vines per replicate were pruned and weighed.

### *2.4. Analysis of Berry and Wine Physiochemical Composition*

One hundred berries were weighed and manually pressed. The must was determined for the total soluble solids (TSS), the titratable acidity (TA) and the pH value. TSS was measured by using a PAL-1 digital hand-held refractometer (Atago, Tokyo, Japan). TA was analyzed by titration with NaOH (0.05 M) to the endpoint of pH 8.2 and expressed as tartaric acid equivalents in accordance with the National Standard of the People's Republic of China (GB/T15038-2006, 2006) [24]. The pH value was measured by using a Mettler LE438 pH meter (Mettler, Toledo, Switzerland).

Wine pH was determined by using a pH meter (Sartorius PB-10, Gottingen, Germany). Wine total acidity (TA) was analyzed in the same way as titratable acid in the grape juice. Before analysis, carbon dioxide was extracted by using a degasser. The residual sugar, the volatile acidity, and the ethanol content of the wines were determined according to OIV

(2014) [25]. CIELAB formulae were used to determine the wine color parameters: lightness (*L*), red-green color contribution (*a*), yellow-blue color contribution (*b*), chroma (*C*), and angular hue (*H*), as described in Ayala et al. [26].

### *2.5. Extraction of Flavonoid Compounds in Berry Skins and Seeds*

The berry skins were manually peeled off and the seeds were manually selected, which were grounded to powder separately in the frozen status under the protection of liquid nitrogen, then were dried at −40 °C under vacuum. The dried skin powder was used to extract anthocyanins, flavonols, and flavan-3-ols. Dried seed powder was used to extract flavan-3-ols.

Flavonols and anthocyanins were extracted following the procedure reported by Downey et al. [27] and He et al. [28]. Dried skin powder (0.100 g) was macerated and sonicated in 50% (*v*/*v*) methanol in water (1.0 mL) for 20 min. The extraction was then conducted with centrifugation for 10 min at 12,000 rpm. The supernatant was collected and the residue was extracted twice. Flavan-3-ol was extracted according to Liang et al. [29]. To determine the content of various flavan-3-ol units, grape sample powder (0.10 g) was mixed with 1 mL of phloroglucinol buffer (0.5% ascorbate, 300 mmol/L HCl and 50 g/L phloroglucinol in methanol), incubated at 50 °C for 20 min, neutralized with 1 mL sodium acetate (200 mmol/L, pH 7.5) and finally centrifuged at 8000 rpm for 15 min. This procedure was repeated three times and the supernatants were combined. For the preparation of free flavan-3-ol monomers, 0.1 g of the dried sample powder was extracted into 1 mL of 70% acetone with 0.5% ascorbate, mixed, and centrifuged and repeated twice. Then 400 µL of the pooled supernatants were dried rapidly with a dry nitrogen stream at 30 °C. The dried samples were dissolved in 200 µL acidified methanol with 1% (*v*/*v*) HCl and then neutralized with 200 µL aqueous sodium acetate (200 mM) [30].

### *2.6. HPLC-MS Analysis of Phenolic Compounds in Berries and Wines*

An Agilent 1200 series high-performance liquid chromatography (HPLC) coupled with a Poroshell 120 EC-C18 column (150 × 2.1 mm, 2.7 µm), and an Agilent 6410 triple-quadrupole tandem mass spectrometry (QqQ-MS/MS) equipped with an electrospray ionization (ESI) source (Agilent, Santa Clara, CA, USA) was used for flavan-3-ols analysis, which was in accordance with the procedure described by Li et al. [31]. Mobile phase A was aqueous 0.1% (*v*/*v*) formic acid, and mobile phase B was acetonitrile/methanol (1:1, *v*/*v*) with the addition of 0.1% (*v*/*v*) formic acid. The elution gradient was from 10% to 46% B for 11 min and from 46% to 10% B for 1 min with a flow rate at 0.4 mL/min. The injection volume was 1 µL, and the column temperature was 55 °C. The ESI source temperature was 150 °C, spray voltage was set at 4 kV in negative mode, dry nitrogen gas temperature was 350 °C, gas flow was 12 L/h, and nebulizer pressure was 35 psi. (+)-Catechin, (−)-epicatechin, (−)-epigallocatechin and (−)-epicatechin-3-*O*-galate were used as external standards for quantification of flavan-3-ols. Concentrations of flavan-3-ols in grape skins and seeds were expressed in mg/kg berry fresh weight and µg/berry, and concentrations of flavan-3-ols in wines were expressed in µg/L. An Agilent 1200 series of HPLC-MSD trap VL linked to a Zorbax Eclipse XDB-C18 column (250 × 4.6 mm, 5 µm) and a variable wavelength detector (Agilent, Santa Clara, CA, USA) was used for flavonols analysis, which was performed as described by Sun et al. [32]. Mobile phase A was acetonitrile/formic acid/water (5:10:85, *v*/*v*/*v*), mobile phase B was acetonitrile/methanol/formic acid/water (25:20:10:45, *v*/*v*/*v*/*v*). The elution gradient of solvent B was from 0% to 14.2% for 24.2 min, from 14.2% to 15.7% for 1.5 min, from 15.7% to 18.8% for 6.4 min, from 18.8% to 23.5% for 5.4 min, from 23.5% to 26% for 6 min, from 26% to 27.4% for 2 min, from 27.4% to 32% for 4.6 min, from 32% to 40% for 10.2 min, from 40% to 100% for 6 min, and from 100% to 0% for 10.6 min with a flow rate at 0.63 mL/min. The injection volume was 50 µL, the column temperature was 40 °C, and detector wavelength was 360 nm. MS conditions were as follows: ESI source, negative mode, dry nitrogen gas temperature at 325 °C, gas flow at 12 mL/min, nebulizer pressure at 30 psi, and scan range at 100–1000 *m*/*z*. The flavonols

concentrations were expressed as equivalent quercetin-3-*O*-glucoside in grapes (mg/kg fresh berry weight and μg/berry) and wines (μg/L). An Agilent 1100 series HPLC-MSD trap VL coupled with a Zorbax SB-C18 column (250 × 4.6 mm, 5 μm) and a diode array detector (Agilent, Santa Clara, CA, USA) was used for an-thocyanins analysis following the method descried by He et al. [28]. Mobile phase A was formic acid/acetonitrile/water (2:6:92, *v*/*v*/*v*), and mobile phase B was formic acid/acetonitrile/water (2:54:44, *v*/*v*/*v*). The elution gradient of solvent B was from 6% to 10% for 4 min, from 10% to 25% for 8 min, equilibration at 25% for 1 min, from 25% to 40% for 7 min, from 40% to 60% for 15 min, from 60% to 100% for 5 min, and from 100% to 6% for 5 min with a flow rate at 1 mL/min. The injection volume was 30 μL, the column temperature was 50 °C, and detector wavelength was 525 nm. MS conditions were as follows: ESI source, positive mode, dry nitrogen gas temperature at 350 °C, gas flow rate at 10 mL/min, nebulizer pressure at 35 psi, and scan range at 100–1000 *m*/*z*. Anthocyanins concentrations were expressed as the equivalent malvidin-3-*O*-glucoside in grapes (mg/kg fresh berry weight and μg/berry) and wines (μg/L). Chromatograms of identified flavonoids were shown in in Table S1.

### *2.7. Extraction of Berry Aroma Compounds*

Free and bound aroma compounds were extracted according to the method of Lan et al. [33]. For each replicate, 80 g de-seeded berries were grounded with 1 g polyvinylpolypyrrolidone and 0.5 g *D*-gluconic acid lactone in liquid nitrogen, then were macerated at 4 °C for 4 h and centrifuged to get clear must. A total of 5 mL grape must was added in a 20 mL vial with 1 g NaCl and 10 μL 4-methyl-2-pentanol (internal standard). Bound aroma compounds were isolated using Cleanert PEP-SPE resins and enzymatic hydrolysis of glycosidic precursors was conducted at 40 °C for 16 h by adding 100 μL AR 2000 (Rapidase, 100 g/L). Samples were placed in a CTC-Combi PAL autosampler (CTC Analytics, Zwingen, Switzerland) equipped with a 2 cm DVB/CAR/PDMS 50/30 μm SPME fiber (Supelco, Bellefonete, PA, USA) and agitated at 500 rpm for 30 min at 40 °C. The SPME fiber was then inserted into the headspace to absorb aroma compounds at 40 °C for 30 min and was instantly desorbed into the GC injector to desorb the aroma compounds.

### *2.8. GC-MS Analysis of Aroma Compounds in Grapes and Wines*

Aroma compounds from grape and wine samples were extracted by headspace solid-phase microextraction (HS-SPME) and analyzed by gas chromatography-mass spectrometry (GC-MS) as described by Wen et al. [34]. Qualitative and quantitative methods were used as described by Wang et al. [35]. Aroma compounds were analyzed using Agilent 6890 GC equipped with Agilent 5973C MS and fitted with an HP-INNOW AX capillary column (60 m × 0.25 mm, 0.25 μm, J & W Scientific, Folsom, CA, USA). Oven temperature began with 50 °C for 1 min, then increased to 220 °C at a rate of 3 °C/min and held at 220 °C for 5 min. The temperature of the ion source and quadrupole was set at 250 °C and 150 °C, respectively. Helium was the carrier gas at 1 mL/min and the GC inlet was set in the splitless mode. The full scan mode was employed to collect electron ionization mass data from *m*/*z* 30–350. The ionization voltage was set at 70 eV. Aroma compounds were identified based on mass spectra matching in the standard NIST08 library and retention indices in the literature. The quantification procedure was based on a previous report [36]. The concentrations of volatile compounds were expressed as μg/L in wines and μg/kg of fresh berry weight in grapes.

### *2.9. Small-Scale Fermentation*

Bunches were manually harvested from 30 vines for each replicate and then were transported to the laboratory immediately. For each replicate, 10 kg of bunches were selected randomly and manually crushed, and then transferred to 10 L stainless steel containers, and 10 mL 4% $H_2SO_3$ was added to the must at the same time. Then 0.2 g of pectinase (Optivin®, Sydney, Australia) and commercial yeast (Lalvin D254) were added to the must. Alcohol fermentation was conducted in a temperature-controlled room at

about 22 °C, and the skins were punched down twice a day. When the reduced sugar reached below 4 g/L and never changed, the wines were separated from the must, and then lactobacillus was added to start the malolactic fermentation at about 20 °C. When the malolactic fermentation ended, 6 mL 6% ppm $H_2SO_3$ was added to the wine, and the wine samples were filtered, bottled and stored for one month at 10–15 °C before analysis [20].

### *2.10. Sensory Evaluation*

The sensory evaluation experiment was carried out by a panel of 10 expert judges. The order of samples was shuffled each time so as to eliminate the different sensory evaluations of the same wine. The wines were coded randomly and presented arbitrarily to the panel. The valuation consisted in describing the aspect of visual, aroma, taste, and harmony found in the wine samples, which accounted for 10, 30, 50, and 10 scores, respectively [37].

### *2.11. Statistical Analysis*

The SPSS version 22.0 was used for all significance analysis at $p < 0.05$ (Duncan's multiple range test or *t*-test). The figures were drawn using the Origin 2021b software, Simca 14.1, and GraphPad Prism 8.0.2.

## 3. Results

### *3.1. Meteorological and Microclimate Data*

As shown in Figure 1, the 2018 and 2019 vintages had relatively high temperatures and few rainfalls in the summer, which was typical of the semi-arid continental climate in Xinjiang. The monthly air temperatures and the rainfalls were almost within the range of those between the years 2009 and 2019. There were 20 and 25 high-temperature days ($T_{max}$ > 35 °C) from the anthesis to the harvest in the years 2018 and 2019, respectively. The average monthly temperature peak began at the end of June to the beginning of July, and began to show a downward trend in August. In terms of rainfalls, the total rainfalls in the two years had little difference, but the distribution was different. The rainfalls in the year 2019 during the berry setting period and the berry expansion period were higher than that in the year 2018, but the rainfalls in 2019 during the veraison period (3.6 mm) were significantly lower than in 2018 (21.9 mm). In addition, there was also a significant difference in the sunlight duration between the two years. During the grape growing season, compared to the year 2019, there were a higher sunshine duration and rainfall during the veraison period in the year 2018, but the temperature did not have a significant difference. And at the harvest (in September), there were higher sunlight duration and lower temperature in the year of 2018.

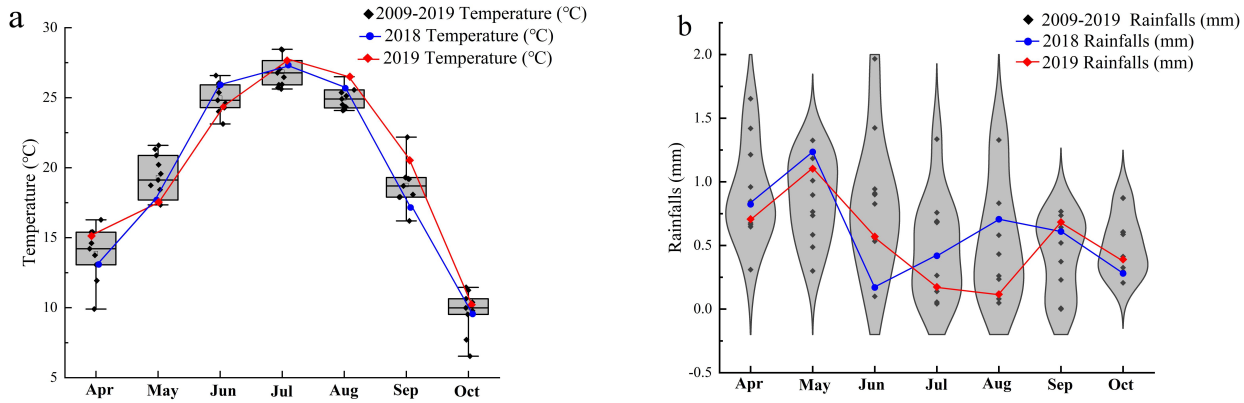


**Figure 1.** Summary of the monthly average meteorological data, (**a**) temperature, and (**b**) rainfalls from April to October in the experimental vineyards compared to the vintages from 2009–2019.

The climate indices chosen for the analysis were described in Table 1. Growing season temperature (GST) is the mean air temperature of all days (from 1 April to 30 September).

Because temperature is generally recorded as minimum and maximum temperatures each day, GST is an estimate of the average temperature [38]. The results showed the experimental area was 'Hot region' (19.6–20.4 °C). In general terms, GSTs between 13 and 21 °C are considered suitable for quality wine grape production with different varieties being more suitable to different temperature regimes [39]. The growing degree-days (GDD) index is a measure of heat summation. The accumulation of heat units over time is a common method of describing the suitability of growing crops in different climates. It is calculated by subtracting a base temperature (10 °C for winegrapes) from the average temperature recorded each day (from 1 April to 30 September) and then summating all values above zero. This experimental area was 'region IV', which was the 'warm region'. The Huglin Index (HI) [40] is a variation on the GDD, differing in three ways. Instead of using average temperature over a 24-h period, the HI effectively uses an estimate of the daytime temperature by taking the mean of the average and maximum temperatures in its calculation. And in this study, the results showed that the experimental area was 'very warm' [41]. The rainfalls in the experimental area were 109.6 mm and 102.0 mm in the year 2018 and the year 2019. The bioclimatic indices confirmed that the experimental area was a hot and dry climate.

**Table 1.** Meteorological data from the vintages of 2018 and 2019.

| Bioclimatic Indices | 2018 | 2019 |
|---|---|---|
| Growing season temperature (GST, °C) | 19.57 | 20.39 |
| Heliothermal index (HI, °C) | 2741.0 | 2966.4 |
| Growing degree-days (GDD, °C) | 2011.3 | 2126.7 |
| Cumulative rainfall (mm, (from 1 April to 30 September)) | 109.6 | 102.0 |
| Daily average sunshine duration (h, (from 1 April to 30 September)) | 9.92 | 9.21 |
| Daily average mean temperature of July (°C) | 27.33 | 27.65 |
| Daily average maximum temperature of July (°C) | 33.69 | 33.67 |

After covering purslane, the solar radiation around the bunch zone and the temperature were decreased, as shown in Figure 2. Figure 2a clearly showed that the bunch-zone temperatures after covering purslane were lower (approximately 2.5 °C) than those of the control in the year 2018, and there was the same trend in the year 2019. It was worth noticing that the temperatures of the fruit zone in the year 2018 were higher than those in the year 2019, which meant the treatment of covering purslane in the year 2018 magnified its effect in the extremely hot weather to balance the temperatures.

Photosynthetically active radiation (PAR) was also decreased after the treatment of covering purslane as expected: in the year 2018, covering purslane reduced the PAR by 16.9–54.4% compared with the control from the anthesis to the harvest (Figure 2b). In the year 2019, covering purslane increased the PAR in the bunch zone by 5.6% in the pea-size period. During the veraison period, covering purslane reduced the PAR in the bunch zone by about 42.3%. The reason was the insufficient irrigation of the vineyards by the local government's water control in May and June. The growth of the purslane in the early period was weak. In July, the rainfall and the irrigation increased during the veraison period, which made the purslane vigor better. So the covering purslane reduced the PAR in the fruit zone significantly at 40–62 days after anthesis.

In terms of the relative humidity, the covering purslane increased the relative humidity (Figure 2c,f). It was speculated that the respiration of the grapevines increased the water content in the air of the fruit zone, which further led to an increase in the relative humidity there. On the other hand, the covering purslane decreased the water content in soil 40 cm below the ground surface, and it was speculated that purslanes could compete with the grapevines for the water absorption and utilization, resulting in a decrease in the soil water content (Table S2).

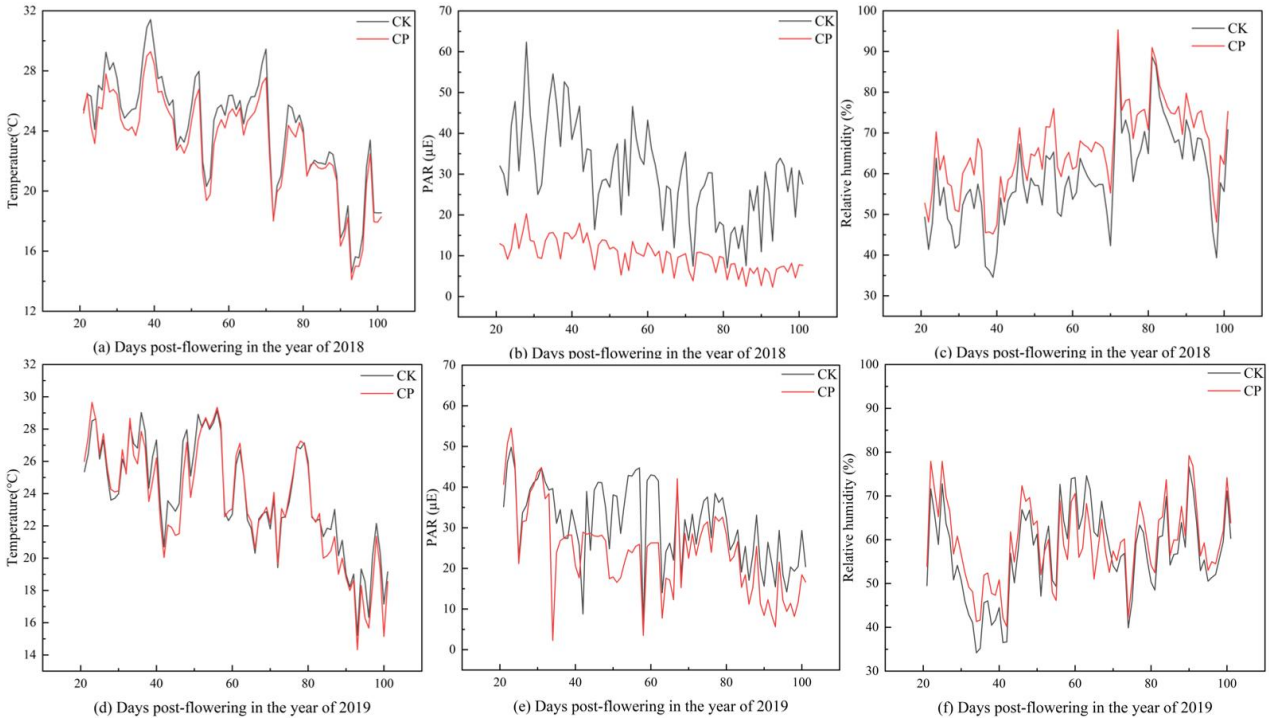


**Figure 2.** Effect of covering purslane on the microclimate around the bunches. (**a**) changes in the average daily temperature after clean tillage and covering purslane of 'Cabernet-Sauvignon' grapevines in the year 2018; (**b**) changes in the average daily PAR in the year 2018; (**c**) changes in the relative humidity in the year 2018; (**d**) changes in the average daily temperature after clean tillage and covering purslane of 'Cabernet-Sauvignon' grapevines in the year of 2019; (**e**) changes in the average daily PAR in the year of 2019; (**f**) changes in the relative humidity in the year of 2019. CK: clean tillage; CP: covering purslane.

### *3.2. Effect of Covering Purslane on the Grape Vegetative Parameters*

As shown in Supplementary Table S3, the date of the onset of veraison, the end of veraison, and the harvest was delayed by 7, 8, and 9 days, respectively, by covering purslane in the year 2018. Moreover, covering purslane increased the veraison period duration by 3 days. Thus, covering purslane could delay the berry ripening. Similar results were also obtained in the year 2019, while the effect was not as remarkable as that in the year 2018.

A decrease in the pruning weight and the berry size was observed by the covering purslane in the year 2019 (Table 2). Compared to the control, covering purslane resulted in a 22.3% reduction in the pruning weight and a 4.7% reduction in the berry size. Furthermore, the main shoot leaf area and the lateral shoot leaf area also decreased by 27.1% and 22.8% in covering purslane compared to the control. The yields were not affected by covering purslane. Therefore, the leaf area/yield was significantly decreased by covering purslane, which might be caused by the competition between the vines and purslane in the rows for nutrients. This indicated that the biomass reduction was associated with a decrease in the photosynthesis capacity caused by covering purslane. Besides, covering purslane did not influence average shoot length, the third internode diameter, the seed number, the seed weight, or the skin weight.

**Table 2.** Vine parameters of clean tillage control (CK) and covering purslane (CP) of 'Cabernet-Sauvignon' in the year 2019.

| Parameters | Treatments | | Sig. |
|---|---|---|---|
| | CK | CP | |
| Total shoot leaf area/meter ($m^2$/m) | 12.64 ± 0.79 | 9.53 ± 1.01 | * |
| Main shoot leaf area/meter ($m^2$/m) | 5.27 ± 0.17 | 3.84 ± 0.75 | * |
| Lateral shoot leaf area/meter ($m^2$/m) | 7.37 ± 0.80 | 5.69 ± 0.67 | * |
| Yield/meter (kg/m) | 3.44 ± 0.18 | 3.42 ± 0.29 | ns |
| Leaf area/yield ($m^2$/kg) | 3.67 ± 0.45 | 2.75 ± 0.42 | * |
| Average shoot length (cm) | 126.00 ± 9.70 | 117.80 ± 7.94 | ns |
| Third internode diameter (mm) | 0.82 ± 0.11 | 0.84 ± 0.03 | ns |
| Pruning weight/meter (kg/m) | 1.97 ± 0.13 | 1.53 ± 0.18 | * |
| Yield/pruning weight | 1.84 ± 0.15 | 2.75 ± 0.19 | * |

Values are reported as means ± SD of three biological replicates. * indicates there are significant differences between CK and CP ($p < 0.05$, *t*-test). ns = not significant.

### *3.3. Effect of Covering Purslane on the Grape Physiochemical Indexes*

During the growing period of grapes, the physiochemical indexes of the 'Cabernet Sauvignon' grapes, including the 100-berry weight, soluble solids (TSS), the titratable acidity (TA), and the pH values, were monitored, and the results were shown in Figure 3. In the year 2018, a noticeable difference in grape physiochemical indexes was observed in the ripening process between the control and covering purslane. In the year 2018, Covering purslane significantly decreased the berry TSS from the second sampling time of veraison 5%. The maximum difference in the TSS between the control and covering purslane was 2°Brix, when the control berries had almost reached the ending of veraison, while covering purslane berries were at mid-veraison stage (at approximately 60% of their color). The grapes of control were harvested when the berry TSS had reached 25.1°Brix, while at this time the berries covering purslane treatment only reached about 24°Brix. There was no significant difference between the two treatments in the berry weight and TA at their respective harvest times. The grapes covering purslane had lower berry TSS and pH than the control. The maximum difference between covering purslane and the control in terms of the weight of 100 berries at the third sampling stage was 20.4 g. Although there was a significant difference between the two treatments in pH in the last sampling stage, it was mitigated compared with those in other sampling stages.

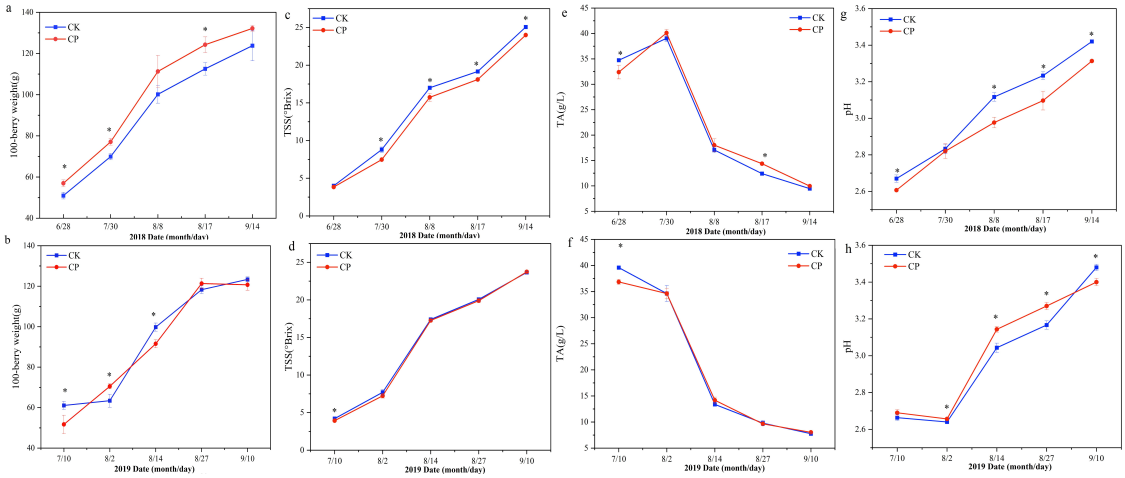


**Figure 3.** Berry physicochemical parameters of clean tillage (CK) and covering purslane (CP) of 'Cabernet Sauvignon' grapes. (**a**) 100-berry weight in 2018; (**b**) 100-berry weight in 2019; (**c**) total soluble solids in 2018; (**d**) total soluble solids in 2019; (**e**) titratable acidity in 2018; (**f**) titratable acidity in 2019; (**g**) pH value in 2018; (**h**) pH value in 2019. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test).

In the year 2019, compared to covering purslane, the berries of clean tillage had higher pH, and the 100-berry weight, TSS and TA had the same trend as those in the year 2018, but were not affected significantly. Combined with the meteorological data, compared to CP, CK had higher temperature and PAR. The moderate-high temperature was conducive to the accumulation of sugar content [42,43].

### *3.4. Effect of Covering Purslane on the Quality of the Grape Berries*

There were minor differences in the total concentrations of anthocyanins, flavonols, and flavanols between the treatment and the control, as shown in Table 3. Covering purslane decreased the concentration of the total flavonoids by 4.5% and 1.7% in the year 2018 and the year of 2019. This phenomenon was mainly due to the covering purslane reducing the concentration of flavanols, but the effect was not significant between the treatment and the control.

**Table 3.** Effect of covering purslane on the flavonoid compounds of 'Cabernet Sauvignon' grapes.

| Years | Treatments | Concentration (mg/Kg FW) | | |
|---|---|---|---|---|
| | | **Anthocyanins** | **Flavonols** | **Flavanols** |
| 2018 | CK | 665.79 ± 4.68 | 30.45 ± 0.74 | 7149.12 ± 116.33 |
| | CP | 681.78 ± 22.47 | 34.12 ± 0.20 | 6595.01 ± 259.35 |
| | Sig. | ns | * | ns |
| 2019 | CK | 1033.00 ± 18.66 | 63.08 ± 8.87 | 6599.76 ± 60.33 |
| | CP | 1061.54 ± 76.22 | 75.24 ± 1.16 | 6452.28 ± 102.71 |
| | Sig. | ns | * | ns |

Values are reported as means ± SD of three biological replicates. Sig., significance. * indicates there are significant differences between treatments ($p < 0.05$, Duncan's multiple range test) of 'Cabernet Sauvignon' ($p < 0.05$, *t*-test), ns, not significant. CK: clean tillage; CP: covering purslane.

In the year 2018, grape berries covering purslane treatment had higher flavonol and anthocyanin concentrations than the berries of clean tillage, while the difference in anthocyanins was not significant. In the year 2019, the concentrations of anthocyanin and flavonol in grape berries had the same trend as in the year 2018. Compared to the year 2018, the total concentration of flavonoids composition increased by 3.2% after covering purslane in the year 2019. Flavonols were positively related to sunlight and protected berries from UV damage [44], and the authors speculated that covering purslane inhabited the vigor and decreased the leaf area, which led to an increase in the reflected light in the fruit zone and further increased the concentration of flavonols. Another reason could be that clean tillage had a higher temperature and PAR, which led to excessive induction: for flavonols [45]. The concentration of flavonols in the grape berries decreased with the increase of light, which could well explain the higher levels of flavonols in the year 2019 than in the year 2018. The concentration of anthocyanin was negatively related to temperature, and to a certain extent, low temperature is conducive to the accumulation of anthocyanins [46].

The concentration of different flavonoids, including anthocyanins, flavonols, and flavanols were shown in Figure 4. Covering purslane did not affect the anthocyanin composition, including the non-acylated (Glu), acetylated (Ace) and coumarinylated (Cou) anthocyanins in 'Cabernet Sauvignon' grape berry skins significantly in both of the two years. In the year 2018, there were fewer glucoside from flavonols (Glu), glucuronide form flavonols (Gluc), 3′-hydroxylated flavonols (F3′H) and 3-hydroxylated flavonols (F3H) in berries by clean tillage than those by covering purslane. Compared to clean tillage, there was no significant difference in galactosidic flavonols (Gal) and 3′5′-hydroxylated flavonols (F3′5′H) by covering purslane, as shown in Figure 4b. Compared to clean tillage, the berries by covering purslane had a lower concentration of seed flavanols and the free monomers. In the year 2019, compared to clean tillage, grape berries covering purslane had no significant difference in anthocyanin types, flavonol types, and flavanol types except for reducing the concentration of 3-hydroxylated flavonols (F3H), as shown in Figure 4d–f.

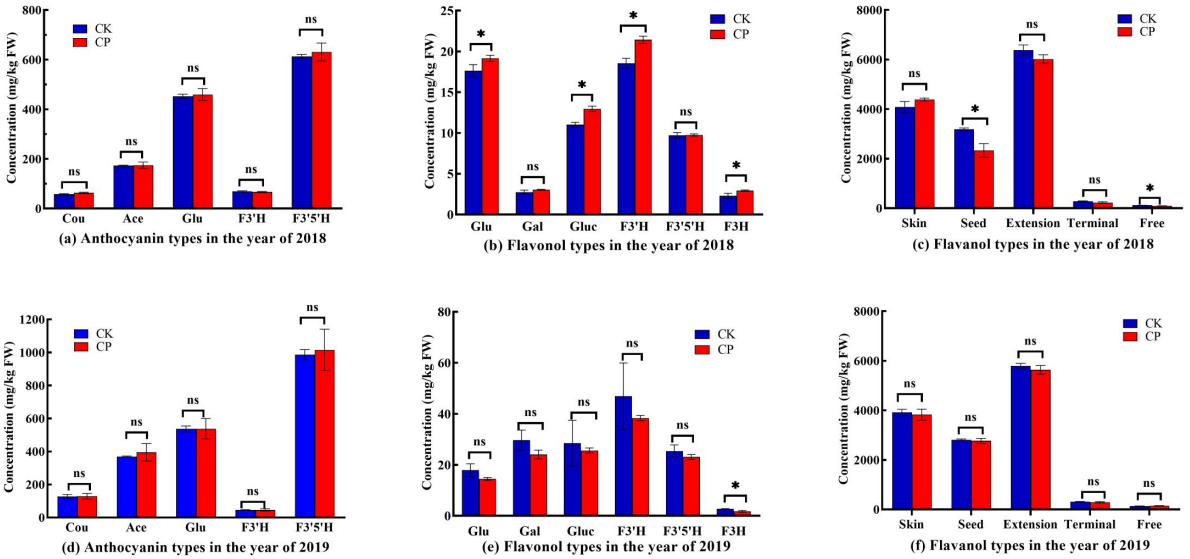


**Figure 4.** Effect of covering purslane on different flavonoid concentrations of grape berries. Glu, glucoside from anthocyanins or flavonols; Ace, acetylated anthocyanins; Cou, coumarylated anthocyanins; Gal, galactosidic flavonols; Gluc, glicironide form flavonols; F3′H, 3′-hydroxylated anthocyanins or flavonols; F3′5′H, 3′5′-hydroxylated anthocyanins or flavonols; F3H, 3-hydroxylated flavonols; Free, free monomers. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test), ns, not significant.

In grape berries, the significantly influenced compounds of flavonoids in different treatments were shown in Figure 5. In terms of flavonols, the significantly influenced compounds of flavonols had the same trend. Grape berries of clean tillage had lower concentrations of kaempferol-3-*O*-glucoside, quercetin-3-*O*-glucoside and quercetin-3-*O*-glucuronide. Compared to the flavanols in grape skins, flavanols in grape seeds were most influenced by different treatments. Grape berries of clean tillage had higher concentrations of free monomers, extension subunits, and terminal subunits in grape seed than those of covering purslane, leading to increasing total flavonols concentration. The covering purslane had lower concentrations of ECG, EGC, C, EC, EGCG, ECG-P, EGC-P, C-P, and EC-P in the seed than clean tillage, leading to the decreased total flavonols concentration in seed.

According to structures, volatile compounds identified by GC-MS were sorted into eight categories in the grape berries, as shown in Table 4. There were four categories of aroma compounds that were significantly affected by covering purslane in the year 2018, while there were no significant differences in each aroma compound in grape berries in the year 2019. In the year 2018, grapes of covering purslane were more abundant in berries C6/C9 compounds, norisoprenoids, aldehydes/ketones, and esters than those of clean tillage. Compared to clean tillage, covering purslane decreased the concentration of fatty acids in grape berries, especially in the commercial matured samples.

In the year 2018, only one category of volatile compounds was significantly affected by CP. CP increased the concentrations of C6/C9 compound. C6/C9 compounds are called green leaf volatiles (GLVs) because of their fresh grass and crushed leaf aroma, leaving the sensory impression that the red wine is immature. CP significantly increased concentrations of (*E*)-2-hexenal, (*E*)-2-hexen-1-ol, (*Z*)-3-hexen-1-ol, 1-hexanol and cyclohexanol, as shown in Figure 6a. In the year 2019, CP didn't significantly affect the concentration of volatile compounds of grape berries at commercial harvest, as shown in Figure 6b.

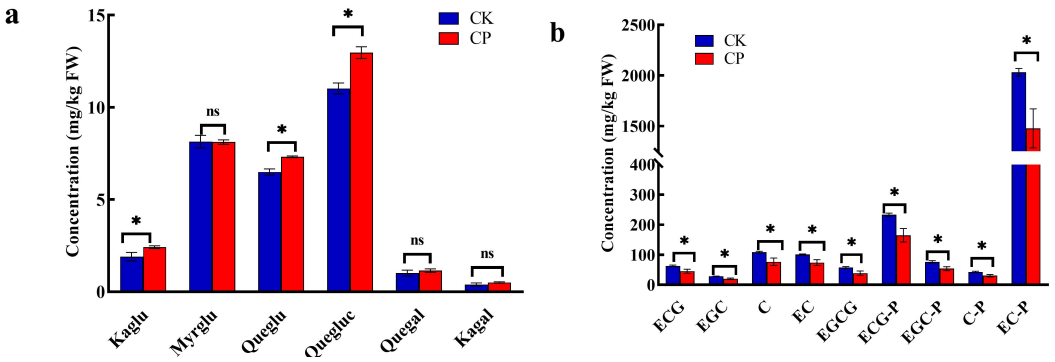


**Figure 5.** Significantly influenced flavonoid compounds by covering purslane in the harvest grapes in the year 2018. (**a**) flavonols of grape berry skins; (**b**) flavanols of grapes berry seeds. Flavonols: Kaglu, kaempferol-3-*O*-glucoside; Myrglu, myricetin-3-*O*-glucoside; Queglu, quercetin-3-*O*-glucoside; Qugluc, quercetin-3-*O*-glucuronide; Qugal, quercetin-3-*O*-galactoside; Kagal, kaempferol-3-*O*-galactoside. Flavanols: ECG, (−)-epicatechin-3-*O*-gallate; EGC, (−)-epigallocatechin; C, (+)-catechin; EC, (−)-epicatechin; EGCG: (−)-epigallocatechin-3-*O*-gallate; -P, extension subunits; without -P, Free monomers. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test), ns, not significant.

**Table 4.** Effects of covering purslane on different volatile compounds concentration of grape berries at commercial harvest (μg/kg FW).

| Compounds | 2018 | | | 2019 | | |
|---|---|---|---|---|---|---|
| | CK | CP | Sig. | CK | CP | Sig. |
| C6/C9 | 3514.16 ± 314.81 | 4457.56 ± 176.56 | * | 5525.61 ± 930.72 | 4643.98 ± 198.10 | ns |
| norisoprenoids | 23.69 ± 2.29 | 30.98 ± 2.47 | * | 13.88 ± 0.87 | 14.12 ± 1.72 | ns |
| terpenes | 1.53 ± 0.18 | 1.57 ± 0.32 | ns | 8.13 ± 0.16 | 8.35 ± 0.21 | ns |
| benzenes | 17.62 ± 1.40 | 17.87 ± 0.33 | ns | 17.23 ± 0.73 | 17.44 ± 0.45 | ns |
| aldehydes/ketones | 11.70 ± 0.56 | 12.93 ± 0.50 | * | 9.29 ± 0.87 | 9.04 ± 1.22 | ns |
| alcohols | 33.15 ± 1.59 | 35.99 ± 1.41 | ns | 488.07 ± 45.83 | 494.48 ± 4.97 | ns |
| fatty acids | 217.16 ± 55.12 | 128.32 ± 8.68 | ns | 753.80 ± 122.05 | 685.15 ± 89.96 | ns |
| esters | 11.70 ± 1.21 | 14.69 ± 1.24 | * | 7.69 ± 0.48 | 7.90 ± 0.56 | ns |

Values are reported as means ± SD of three biological replicates, * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test). ns = not significant.

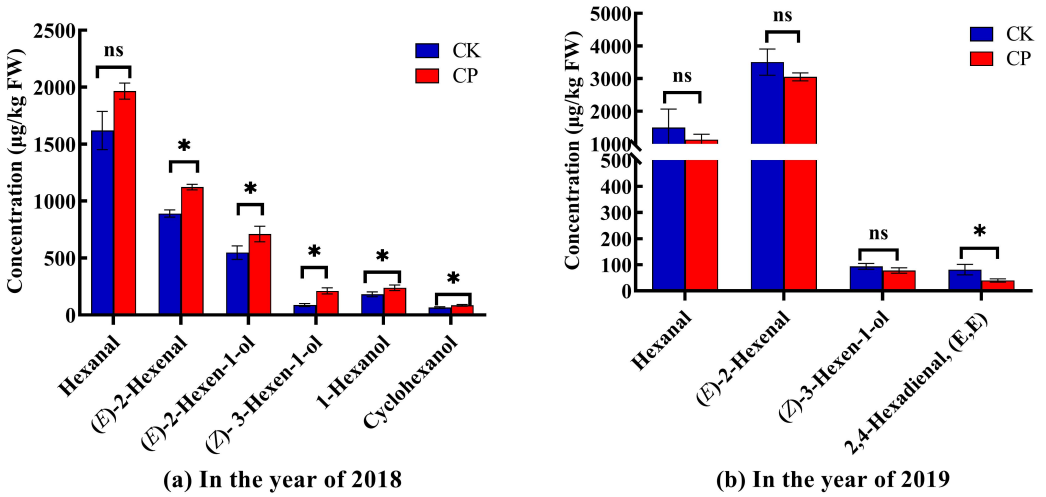


**Figure 6.** Main differential compounds of clean tillage (CK) and covering purslane (CP) berries. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test), ns, not significant.

The PCA analysis was used to identify variations between different treatments based on berries' volatile compounds and flavonoid compounds, as shown in Figure 7. In terms of years, two predictive components explained 82.1% of the total variation. R2X [2], which discriminated clean tillage and the covering purslane, accounted for 5.3% (R2X [1] = 0.053) of the total variance. In the year 2018, the different treatments were clearly different, but the differences were not clear between clean tillage and covering purslane in the year 2019.

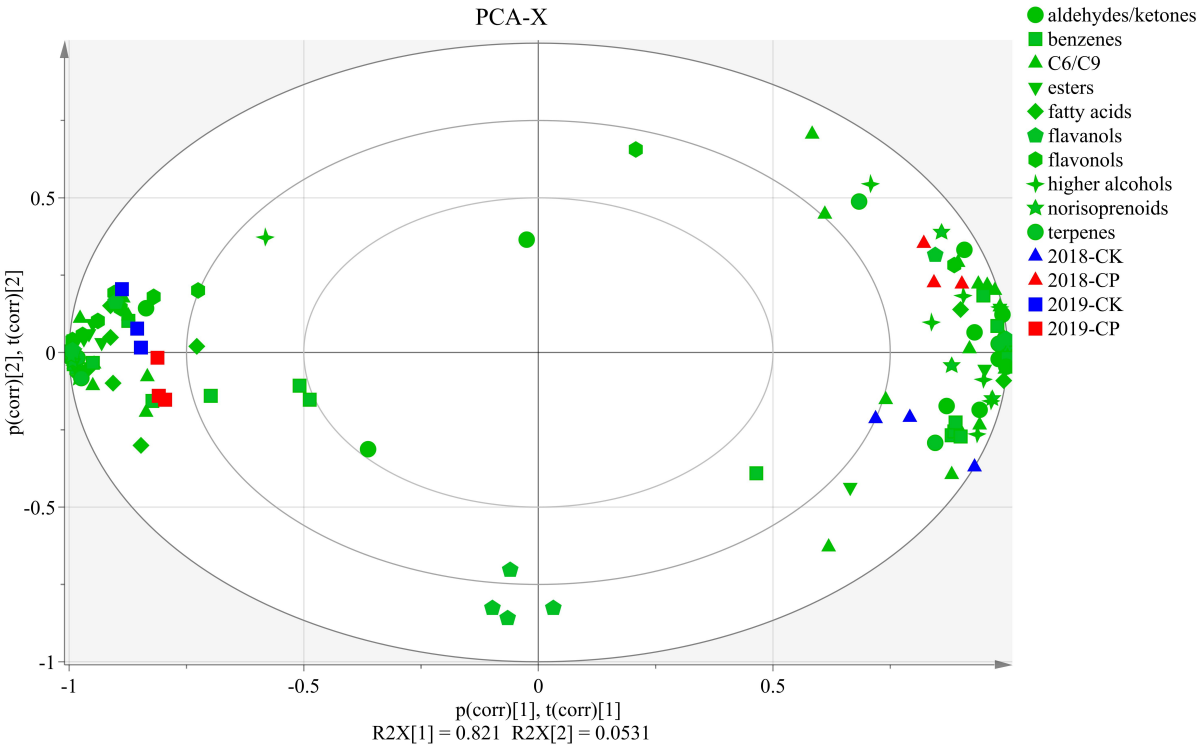


**Figure 7.** PCA analysis based on aroma compounds and flavonoid compounds by CK and CP in 2018–2019.

In this study, compared to the CK, CP had a higher the total concentration of flavonols, lower the concentration of flavanols in the seed, and higher the concentration of main differential compounds in grape berries, and the differences in the year 2018 were more significant than that of in the year of 2019.

### *3.5. Effect of Covering Purslane on the Must and Wine Physicochemical Parameters*

Must physicochemical parameters were shown in Table 5. In terms of total soluble solids (TSS), pH, and titratable acidity (TA), there were no significant differences between the control and covering purslane in the year 2018. The wine alcohol content of covering purslane was lower than that of the control, which might be due to the lower TSS in harvest grapes and their must of covering purslane. Residual sugar in the control and covering purslane wines both reached below 4 g/L, indicating that both the two wines met the standards of dry red wine. And covering purslane increased the content of TA in wines by 7.5% and 8.4% in the years 2018 and 2019, respectively.

### *3.6. Effect of Vintage and Treatments on Wine Flavonoids and Colorimetric Parameters*

The flavonoid compounds in wines were shown in Figure 8. Compared to the clean tillage, the concentration of anthocyanins and flavonols was increased by 12.6% and 16.7% by covering purslane, and the flavan-3-ols did not have significant differences in the year 2018 (Figure 8a). But, the concentration of flavonoid compounds was not affected by covering purslane in the year 2019 (Figure 8b), which was similar to the results in the harvest of grape berries.

**Table 5.** Must and wine physicochemical parameters of the clean tillage (CK) and covering purslane (CP).

| Fermentation Stage | Years | Parameters | Treatments | | Sig. |
|---|---|---|---|---|---|
| | | | CK | CP | |
| Must | 2018 | TSS (°Brix) | 23.47 ± 0.18 | 23.00 ± 0.26 | ns |
| | | TA (g/L) | 8.90 ± 0.13 | 8.70 ± 2.85 | ns |
| | | pH | 3.48 ± 0.01 | 3.29 ± 0.01 | ns |
| | 2019 | TSS (°Brix) | 24.03 ± 0.22 | 23.30 ± 0.12 | * |
| | | TA (g/L) | 7.34 ± 0.23 | 7.40 ± 0.11 | ns |
| | | pH | 3.42 ± 0.01 | 3.45 ± 0.13 | ns |
| Wine | 2018 | Residual sugar (g/L) | 1.98 ± 0.33 | 1.88 ± 0.17 | ns |
| | | pH | 4.09 ± 0.01 | 3.93 ± 0.00 | * |
| | | TA (g/L) | 4.95 ± 0.19 | 5.33 ± 0.17 | * |
| | | Alcohol degree (%, *v*/*v*) | 12.90 ± 0.58 | 12.40 ± 0.10 | * |
| | | Volatile acid (g/L) | 0.51 ± 0.03 | 0.53 ± 0.01 | ns |
| | 2019 | Residual sugar (g/L) | 1.73 ± 0.11 | 1.17 ± 0.06 | * |
| | | pH | 4.07 ± 0.12 | 4.14 ± 0.01 | ns |
| | | TA (g/L) | 4.90 ± 0.01 | 5.53 ± 0.06 | * |
| | | Alcohol degree (%, *v*/*v*) | 12.57 ±0.07 | 12.22 ± 0.12 | ns |
| | | Volatile acid (g/L) | 0.55 ± 0.02 | 0.63 ± 0.08 | ns |

Values are reported as means ± SD of three biological replicates, * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test). ns = not significant.

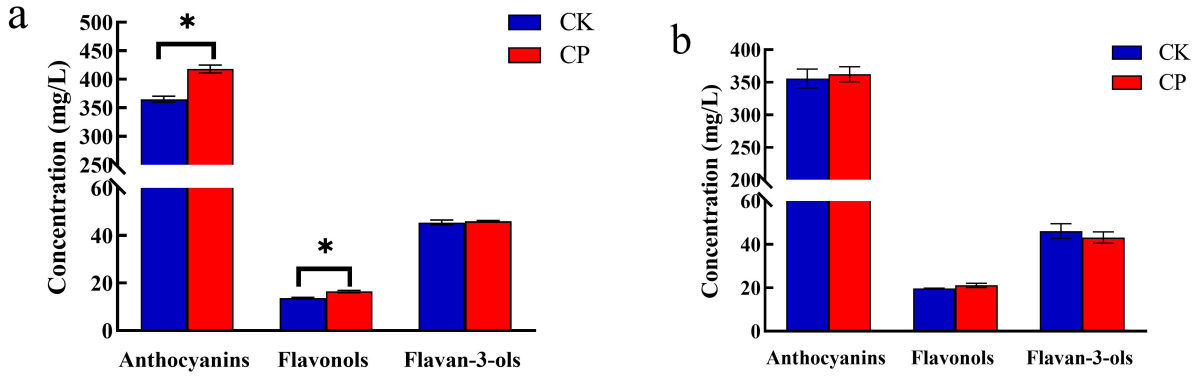


**Figure 8.** Effect of covering purslane on the concentrations of different flavonoid compounds in wines. (**a**) in the year 2018; (**b**) in the year 2019. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test).

Colour parameters (CIELAB) in wines were shown in Supplementary Table S4. The control wines had higher lightness (*L*), lower red-green color contribution (*a*), higher yellow-blue color contribution (*b*), and lower chroma (*C*) than the wines covering purslane in the year 2018. While the results in the year 2019 were similar to that in the year 2018, but not so significant.

The correlation between the vintage and treatments on wine flavonoids and colorimetric parameters was investigated (Table 6). The results showed that the treatments didn't significantly affect the polyanthocyanins, monoanthocyanins, flavonols, and flavanols in wines. The red-green color contribution (*a*) was not affected by the concentration of polyanthocyanins, monoanthocyanins, flavonols, and flavanols in wines, but the lightness (*L*), yellow-blue color contribution (*b*), and chroma (*C*) were significantly affected by the polyanthocyanins, monoanthocyanins, flavonols.

**Table 6.** Pearson's coefficient of vintage and treatments on wine flavonoids and colorimetric parameters.

| Parameter | | Treatment | Years | *L* | *a* | *b* | *C* | *H* |
|---|---|---|---|---|---|---|---|---|
| Polyanthocyanins | Correlation | 0.196 | 0.862 * | 0.632 * | −0.331 | −0.879 * | −0.415 | −0.676 * |
| | *p* value | 0.541 | 0.000 | 0.027 | 0.294 | 0.000 | 0.179 | 0.016 |
| Monoanthocyanins | Correlation | 0.423 | −0.752 * | −0.731 ** | 0.529 | 0.666 * | 0.584 * | 0.354 |
| | *p* value | 0.170 | 0.005 | 0.007 | 0.077 | 0.018 | 0.046 | 0.259 |
| Flavonols | Correlation | 0.350 | 0.917 * | 0.738 ** | −0.556 | −0.833 * | −0.630 * | −0.521 |
| | *p* value | 0.265 | 0.000 | 0.006 | 0.060 | 0.001 | 0.028 | 0.082 |
| Flavanols | Correlation | −0.286 | −0.255 | −0.247 | 0.215 | 0.504 | 0.268 | 0.427 |
| | *p* value | 0.368 | 0.424 | 0.440 | 0.501 | 0.095 | 0.399 | 0.166 |

Lightness (*L*); red-green color contribution (*a*); yellow-blue color contribution (*b*); chroma (*C*); and angular hue (*H*). * Significant correlation < 0.05, ** Significant correlation < 0.01 (bilateral).

### *3.7. Effect of Covering Purslane on the Wine Volatile Compounds*

Fifty-four and sixty-one aroma compounds were detected in the wines from both treatments in the years 2018 and 2019, respectively, as shown in Supplementary Tables S5 and S6. The compounds had all been grouped into eight categories according to the structure. Aroma profiles were presented as a fold change between the control and the treatment, and each category of clean tillage concentration was defined as 1. There were three categories of volatile compounds that were significantly affected by covering purslane in the year 2018 (Figure 9a). Covering purslane significantly increased the concentrations of norisoprenoids, acetate esters, and $C_6$ alcohols. There were no significant differences between the treatments in the year 2019. CP increased the intensities of the herbaceous aroma, which was mainly from $C_6$ alcohols.

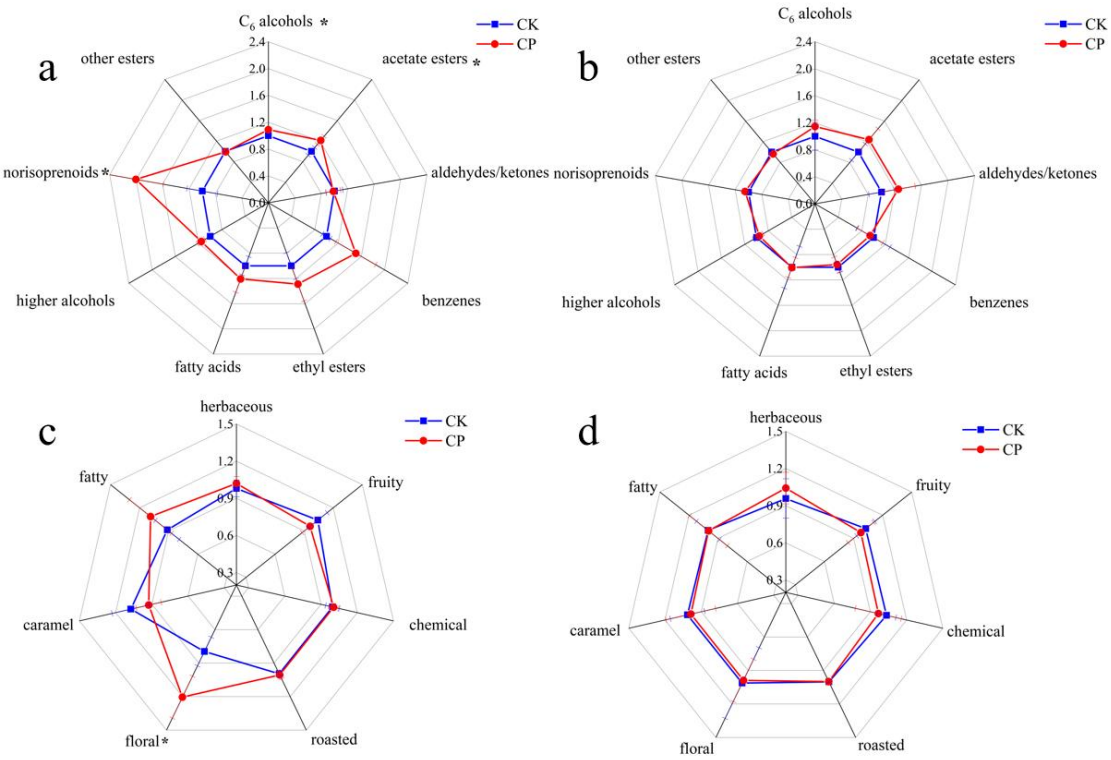


**Figure 9.** Influence of covering purslane on the aroma profiles and odor activity values (OAVs) in their wines. (**a**) aroma profiles in wines of the year 2018, (**b**) aroma profiles in wines of the year 2019; (**c**) OAVs of main aroma compounds (OAV > 0.1) in the year 2018; (**d**) OAVs of main aroma compounds (OAV > 0.1) in the year of 2019. * indicates significant differences between the wines of the control and covering purslane ($p < 0.05$, *t*-test).

The aroma substances detected in the wines with odor activity values (OAVs) > 0.1 were selected and shown in Figure 9c,d. The odor activity value of each volatile compound was also calculated as the ratios of the concentration of an individual compound and its corresponding perception threshold [47]. The active aroma compounds were classed into seven groups according to their odor descriptors. Compared to the wines of clean tillage, covering purslane increased the floral aroma in their wines in the year 2018 (Figure 9c). Combined with wine volatile compounds, wines covering purslane were more abundant with norisoprenoids and esters than those of clean tillage in the year 2018. Norisoprenoids were derived from grapes and greatly contributed to the "varietal aroma" of some aromatic wines. However, they also contribute to the floral and fruity aromas of the wines directly or through synergistic effects [48]. Esters contribute to the floral and fruity aroma of wine, which can balance and harmonize various aroma substances in wine [49,50]. Covering purslane significantly increased the intensities of floral aroma in the wines, which was mainly from norisoprenoids and eaters. This result was the same as the analysis of the aroma profiles in their wine. CP increased the intensities of the herbaceous, which was mainly from $C_6$ alcohols, but the effects were not significant.

### *3.8. Effect of Covering Purslane on the Sensory Evaluation of Wines*

In the year 2018, the scores of various indicators of the wines covering purslane were higher than those of the clean tillage, but there were no significant differences in the year 2019. This result was consistent with the content of the flavonoid and the aroma compounds. Thus, the treatment of covering purslane had a certain positive effect on the sensory quality improvement of the 'Cabernet Sauvignon' wines, as shown in Figure 10.

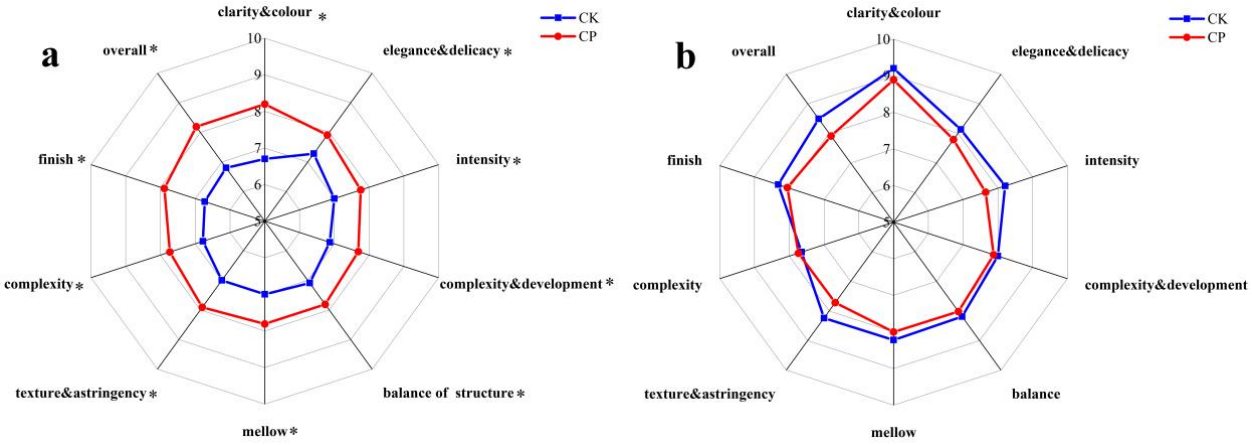


**Figure 10.** Effects of covering crop on sensory evaluation of 'Cabernet Sauvignon' wines. (**a**) wines in the year of 2018; (**b**) wines in the year 2019. * indicates significant differences between the control and covering purslane ($p < 0.05$, *t*-test).

## 4. Discussion

The effects of covering crops on grape growth and related indicators are mostly caused by the competition of water and nutrients in the soil. Linares et al. [51] planted rye (*Secale cereale* L.) and annual bromegrass (*Bromus* L.) between the vine rows (the soil is calcified and dry) in Madrid's 'Syrah' vineyards in Spain. After 8 years of management, the grape growth vigor and other related indicators were measured. The results showed that compared with the treatment of clean tillage, covering crops increased the water competition with the vines, and reduced the yield and the pruning weight. Lopes et al. [52] conducted experiments on covering crops in vineyards in southern Portugal (soil type is silty clay soil) for two consecutive years. The results also showed that covering crops increased the water consumption, and decreased the length of the shoots, the leaf area, the pruning weight, and the berry size compared with the control. Pang [53] conducted an experiment of covering purslane in the vineyards in the Minning area of Ningxia (ordinary

gray calcium soil sandy land). The results showed that covering crops increased the content of total phosphorus in the soil and the activities of various enzymes, and increased the photosynthetic rate of leaves, while having little effect on the yield per plant. In this study, covering crops reduced the leaf area and the pruning weight, which should increase exposure in the fruiting zone and lead to an increase in the PAR. But the results showed that covering purslane decreased the PAR, the authors speculated that vigorous purslane reduced the reflected light from the floor, and the effect of reducing ground reflected light on PAR was greater than those of vine vigor on PAR, which further led to a reduction in the PAR. The inter-row plants competed with grapes for water and nutrients, reducing the vine vigor, which was consistent with the results of Linares et al. [51]. Hubert et al. [54] showed that water stress appropriately can promote the expression of some metabolic genes, and increase the synthesis of the precursors of norisoprenoids in berries.

Covering crops had a certain influence on the physical and chemical indexes of grape berries, such as the soluble solids, the titrated acid, the pH value, and the 100 berries weight. The physical and chemical indexes were important to evaluate the quality of the grapes, and the temperature and the light were important factors to affect these indexes. Gontier et al. [55] conducted a 4-year covering crop experiment in France, and the results showed that covering crop treatments increased the content of the total soluble solids in the grapes. Muscas et al. [56] also showed that covering crop treatment had effects on most of the physical and chemical indexes in grapes, and increased the content of the total soluble solids, but had no significant effect on the titrated acid and pH value. Beslic et al. [57] showed that cover crops increased the soluble solid content of 'Cabernet Sauvignon' fruits, but reduced the content of the titrated acid. They speculated that this result was due to the reduced leaf area, the increased canopy gap, the increased light transmittance, and the improved illumination conditions as the results of the competition of the inter-row plants with grapevines for nutrients. The present study showed that covering purslane treatment decreased the total soluble solids in grapes, and increased the titration acid content. Previously, some researchers speculated that plants on the earth's surface had a certain heat preservation effect after covering crops, reducing the temperature differences between day and night. And in the daytime, the temperature of the fruit zone could be reduced to a certain extent [58]. Other studies also showed that a large temperature difference between day and night would increase the content of the total soluble solids in grape berries [59], and when the temperature was higher than 20 °C, the titrating acid of different grapes will be reduced [60], which showed that the decomposition rate of the organic acids in fruits could be higher than those in the treatment.

The effects on the flavonoid compounds in grape berries and wines between treatments were similar. Covering purslane increased the total concentrations of anthocyanins by 2.3% and 2.7% in the berry skins, and 12.6% and 1.8% in the final wines, respectively in the years 2018 and 2019. Covering purslane also increased the color parameters of wines and improved the color quality of the wine samples. These findings were similar to the results of Lopes et al. [51]. The increase in the anthocyanin concentration in covering purslane berries might be a result of the decreased berry weight because there was no significant difference between the control and the treatment of covering purslane in the anthocyanin contents of each berry. Although the general view was that the increased exposure would result in the enhanced anthocyanin biosynthesis, there was a point at which the temperature load will begin to have a negative impact [61]. The effect of covering purslane on the flavanols in berries and wine was similar [62]. For the two consecutive years, the flavanols of the treatment of covering purslane in grape seeds were reduced, but the effects were not significant. It was speculated that the reflection might be weakened and changed the composition of light by the grass covering between rows [63]. However, there was no significant effect on the wines in their study. The authors presumed that it was mainly due to the small-scale fermentation having a shorter time of maceration. And only a small part of the flavanols in the grape seeds entered the wines through the part of maceration. In the present study, while the decreased solar radiation was an unfavorable factor for the

anthocyanin biosynthesis, a little high-temperature stress in covering purslane bunches was beneficial for the anthocyanin biosynthesis. And more, the combined effects resulted in no significant difference in the anthocyanin content of each berry. However, an increase in flavonols was observed in both berries and wines from the treatment of covering purslane in 2018. It was well known that the primary function of flavonols was to serve as a UV filter, because they absorb light in the 280–330 nm range to protect the plant tissues from UV damage [44,64].

Furthermore, covering purslane increased the contents of the norisoprenoids in grape berries and wines, enhanced the floral, fruity, and caramel flavors in the wines, and also improved the aroma quality of the wines, which had a certain positive effect on improving the aroma quality of the wines. This was the same as the results of Xi et al. [65]. And the results were mainly due to the competition of plants after covering crops, which caused water stress, and then increased the accumulation of the norisoprenoids precursor substances, which increased the content of norisoprenoids [66].

To sum up, the treatment of covering crops, especially the purslane, could regulate the microclimate of the vineyards, which did not affect the yield of grapevines, and it reduced the total soluble solids (TSS) in the grape berries and increased their titratable acidity (TA). Therefore, covering purslane successfully delayed the berry ripening in the semi-arid wine regions of northwest China. Covering purslane there increased the contents of anthocyanins, flavonols, and norisoprenoids substances in grape berries somehow and increased the color value of the resulted wines, as well as the contents of anthocyanins and flavonols in their wines, and enhanced the floral, fruity and caramel tastes.

## 5. Conclusions

Covering crops was a useful horticultural or viticultural technique for postponing the grapevine phenology and protecting grapevines from high-temperature stress. In the present study, it was found that covering purslane successfully delayed the berry ripening. The flavonoid composition of the grapes and their wines were influenced greatly by covering purslane with an increase in the contents of anthocyanins and flavonols. There was a notable improvement in the wine aroma with the treatment of covering purslane, but it was accompanied by an unsatisfactory wine color. Therefore, covering purslane was found to achieve its goal as a strategy for slowing down the grape ripening and improving wine quality, but it also had adverse effects. In future work, we hope to adjust the height of the grass between the rows moderately to overcome these negative effects and make better wines in Northwest China.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae8060518/s1, Table S1: Qualitative and quantitative information of identified flavonoids compounds; Table S2: Water content in soil 40 cm below the surface of clean tillage (CK) and covering purslane (CP); Table S3: Grapevine growth stage of clean tillage (CK) and covering purslane (CP); Table S4: Influence of covering purslane on the colour parameters (CIELAB) of wines; Table S5: Effect of covering crop treatment on wine violate compounds concentration in 2018 (μg/L FW); Table S6: Effect of covering crop treatment on wine violate compounds concentration in 2019 (μg/L FW).

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