

# Effect of planting density on growth, yield and wine quality of Cabernet Sauvignon

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## Abstract

The present study was conducted at ICAR- National Research Centre for Grapes, Pune, for three years (2018-19 to 2020-21). The experiment was laid out using a Randomized Block Design, with three treatments replicated seven times. Three planting spacing were evaluated as 8 x 2 feet, 8 x 3 feet and 8 x 4 feet. The findings of the study revealed that yield and quality are affected by planting distance/density. Higher pruning weight (0.760 kg/plant), early sprouting (11.33 days after pruning), number of bunches/vine (42.47), number of berries/bunch (106.19), higher yield (3.60 kg/vine), berry quality parameters, *i.e.*, TSS (23.49 °Brix), potassium content (948.83 ppm), carbohydrate (29.17%) and wine quality parameters like- better sweetness and higher acidity were observed in 8 x 4 feet planting distance. Shoot length (78.84 cm), average bunch weight (92.36 g), 100-berry weight (101.10 g), phenol content (0.90 mg/L), and wine quality parameters like- aromatic intensity and tannin content were higher in 8 x 3 feet planting distance. The spacing 8 x 2 feet was better for shoot diameter (5.77 mm), yield (19.06 t/ha), berry quality parameters like- acidity (6.32 g/L), juice pH (3.68), volatile acids (0.13 g/L), total acid content in wine (5.14 g/L) and wine organoleptic taste like- colour, body, alcohol, length and overall acceptability.

**Key words:** Grapevine, planting distance, production, spectrography, 110R rootstock.

## Introduction

Grape (*Vitis vinifera* L.) is known as an important fruit crop in temperate regions. However, in India, it is mainly grown in sub-tropical and tropical agro-climatic conditions (Ghule *et al.*, 2021; Somkuwar *et al.*, 2021). According to an estimate in India, grapevines are spread over an area of 1.71 lakh ha and production was 37.81 lakh MT in the country during the year 2023-24 (Anonymous 2024). India ranks first in the world for grape productivity and 7<sup>th</sup> for grape production during 2023-24 (APEDA, 2024).

In India, about 98% of the total area of grapes is covered for table or raisin purposes. Out of total production, only about 2% of the total production of grapes is being used for juice and wine making (Ausari *et al.*, 2024). Wine is one of the most popular beverages prepared from grapes through fermentation under controlled conditions (Somkuwar *et al.*, 2019). Due to rising worldwide demand and consumption, the wine market has the quickest rate of growth, and the output increased by more than 40% in the last ten years (OIV, 2024). Berries with a high acidity and low sugar content and pH are advantageous for wines, as their quality is mostly determined by their acid level (Jones *et al.*, 2014). Climate not only affects and disrupts grape composition but vineyard management practices can also help optimize acidity, sugar and pH levels (Lavras, 2017).

Planting density or the number of vines per unit area arranged within and between rows, is the only factor that determines production. It influences other yield components, such as the number of buds and shoots per vine, the number of clusters per

vine and may affect the number of berries per cluster and berry weight (Keller *et al.*, 2004; 2015), Reynolds and Heuvel 2009). The planting density is important in terms of wine grapes for its long-term effects on wine quality.

Higher planting densities are believed to enhance competition among vines for resources, which reduces shoot growth and yield per vine while raising the yield of crops per unit of land area and reducing wine quality (Mullins *et al.*, 1992). However, there is little evidence to support this competition concept; mostly based on pruning weight per vine and/or leaf area measurements (Reynolds and Wardle, 1994). According to certain research, the impact of planting distance on pruning weight varies or found that pruning weight per vine decreased as vine spacing decreased but increased when expressed per unit canopy length (Reynolds *et al.*, 1996; 2004a; 2004b).

In temperate wine-growing regions, planting density has been extensively studied and optimized to achieve desired outcomes in grape yield, vine vigor, and ultimately wine quality. However, the applicability of these findings to tropical climates remains uncertain due to significant differences in environmental conditions, grapevine physiology, and disease pressures. Understanding the interaction between planting density and wine quality under tropical conditions is crucial for maximizing the potential of vineyards in these regions. Therefore, this work proposes to compare three vine planting distances and their effects on vine performance and wine quality, to recommend the most appropriate management for Cabernet Sauvignon variety to produce quality wines, in western Maharashtra.

## Materials and methods

A field experiment was carried out for three consecutive years (2018-2019 to 2020-2021) at the experimental farm of ICAR-National Research Centre for Grapes, Pune (18.32°N and 73.51°E). Six-year-old vines of Cabernet Sauvignon grafted onto 110-R rootstock were selected for the study. The soil of this region is black having pH 7.75 and EC 0.46 dS/m. However, water used for irrigation had EC 1.8 and pH 8.3 (Somkuwar *et al.*, 2019). The vineyard planting orientation was North-South. The vines were pruned twice in a year, once after harvest of the crop (during April) and another for fruits (during October). The vines under experiments were drip irrigated as well and the recommended fertilizer dose was given through drips. All the recommended cultural practices were followed during the period of study. The experiment was conducted in a Randomized Block Design, with three treatments replicated seven times. Five vines were selected under each replication. Three planting densities were evaluated as 8 x 2 feet, 8 x 3 feet and 8 x 4 feet thus accommodating 2722, 1815 and 1361 vines per acre, respectively.

**Growth parameters:** The observations on pruning weight, days to bud sprouts, average shoot length, shoot diameter, days to veraison and days to harvest were recorded during each season. Pruning weight was recorded after fruit pruning by weighing the vegetal material on a digital electronic scale and expressed in kg. The first sprouted bud with a fully expanded leaf was taken as an indicator to calculate the days taken for sprouting and was recorded on a day-to-day basis by visual observations. The shoot length and shoot diameter were measured using measuring tape and digital Vernier caliper (0-300 mm RSK™, China), respectively. Days to veraison were measured by calculating days from the pruning date to change in berry colour. Days to harvest are measured by calculating days from the date of pruning to the date of harvesting.

**Photosynthetic efficiency:** Transpiration rate, assimilation rate, and stomatal conductance were recorded using Infra-Red Gas Analyzer made in USA (IRGA model Li 6400, LI-COR Biosciences, NE, USA). Matured leaves *i.e.*, fifth to sixth from tip were used for measuring these parameters. Observations were recorded during bright sunlight during 11:00 to 12:30.

**Yield and yield components:** The total number of bunches per vine was recorded by manual counting. Average bunch weight (g) was calculated from the average weight of 10 bunches while yield per vine (kg) was recorded at the time of harvest. Randomly selected berries from bunches at harvest were used for 100 berry weight. To measure average berry length and berry diameter, 10 berries were selected randomly from different bunches from a given replication and were measured using Digital Vernier Caliper (0-300 mm RSK™) and were expressed in millimeters.

**Physico-chemical analysis:** After harvest, fresh berry samples were collected and hand-pressed for extraction of juice and filtered through muslin cloth. Samples were kept at -20°C until analysis was performed. Ten milliliters of extracted juice were centrifuged at 5000 rpm for 5 minutes to estimate total soluble solids (TSS), acidity (g/L), pH and volatile acids (g/L) using OenoFoss an FTIR-based wine analyzer (FOSS). The total phenolic content in berries was estimated using 1 g fresh berry sample homogenized in 80% ethanol repetitively and the final volume was made up to 10.0 ml. The mixtures were sonicated

for 15 min for complete extraction and centrifuged at 9,000 rpm for 10 min. The supernatants were utilized for analysis of total phenolic contents. The total phenolic contents were determined by the Folin-Ciocalteu method using gallic acid as the standard (Singleton and Rossi, 1965). The total phenolic concentration was calculated from a calibration curve using gallic acid as a standard (0-10 mg L<sup>-1</sup>). Data were expressed in mg·g<sup>-1</sup> gallic acid equivalent (GAE). Estimation of carbohydrates was done using the anthrone reagent method (Hedge and Hofreiter, 1962).

**Wine preparation:** At harvest, 20 kg of grapes from each replication were manually crushed and placed in stainless steel containers for winemaking. 0.6 g SO<sub>2</sub> was then added to the must, and SO<sub>2</sub> content reached about 60 mg/L. Pre-fermentation maceration was then conducted at 18-20°C for 24 h and 3.6 g commercial Lalvin strain D254 yeast (Laffort, France) was activated and inoculated into the must. The fermentation was carried out at 20-22 °C. When the sugar level reached about 1 g/L, the fermentation process was stopped and the skins and seeds were then removed, and 0.02 g of *Lactobacillus* (Lalvin31, Lallemand Inc., French) was added to start the malolactic fermentation. When the malolactic fermentation ended, 1.2 g SO<sub>2</sub> was added to the wines and the total SO<sub>2</sub> content reached about 80 mg/L. After that, the wines were bottled in 750 mL bottles and refrigerated in a cold chamber (12-16°C, without light) until analysis.

**Wine quality parameters:** Wine quality parameters (volatile acid, mallic acid, total acids, pH and ethanol) were estimated using OenoFoss. Sensory evaluation of wine was done by a panel comprising 10 individuals using a 5-point hedonic scale (Cuarto and Magsino, 2017).

**Statistical analysis:** Analysis of variance was performed for each variable using SAS statistical package Version 9.3 (SAS Institute, Cary, NC, USA). The significance of the results was tested by Analysis of Variance (ANOVA) and comparisons were analyzed using the Tukey test for pairwise comparison with mean separation by  $P < 0.05$ .

## Results and discussion

**Effect of planting density on growth parameters:** Significant variations were observed in pruning weight, days to bud sprout and shoot length among the different spacings while shoot diameter, days to veraison and days to harvest were not affected.

Vines subjected to 8 x 4 feet spacing exhibited maximum pruning weight/vine (0.760 kg), followed by spacings of 8 x 3 feet (0.633 kg) and 8 x 2 feet (0.503 kg). The pruning weight of wider spacing was significantly higher than closer spaced vines which was due to accommodation of higher shoot growth in a given area (Table 1). However closer-spaced vines produced higher pruned biomass per hectare area due to the higher number of vines per hectare in comparison to wider spacing (Leeuwen *et al.*, 2019). Similar results were also reported by Kamel *et al.* (1972), Archer and Strauss (1991) and Hunter (1998).

The variations in spacing showed a significant effect on days to bud sprout. However, vines spaced at 8 x 4 feet distance sprouted slightly earlier (11.33 days) in comparison to other spacings. This might be due to less competition of roots for water and nutrients in wider-spaced vines.

Shoot length and shoot diameter were significantly influenced by the spacing. Vines grown in the 8 x 3 feet spacing exhibited the longest shoot length (78.84 cm), although no significant difference was observed between the 8 x 2 feet and 8 x 3 feet spacing. Shoot diameter did not significantly differ among the spacing treatments. An increase in spacing produced longer and wider vines with higher yield capacity which is probably a normal vine response to a promotion in available soil space per vine (Archer and Strauss, 1991). The days to veraison and days to harvest did not show significant differences among the spacing.

Table 1. Effect of planting density on growth parameters of Cabernet Sauvignon

Spacing (feet)	Pruning Weight (kg)	Day to sprout	Shoot length (cm)	Shoot diameter (mm)	Days to veraison	Days to harvest
8 x 2	0.503	12.22	74.98	5.77	103.62	146.05
8 x 3	0.633	12.02	78.84	5.70	104.10	147.05
8 x 4	0.760	11.33	78.68	5.72	103.19	146.67
S.Em±	0.005	0.047	0.391	0.0267	0.4826	0.6941
CD at 5%	0.016	0.146	1.205	NS	NS	NS

**Effect of planting density on yield parameters:** A significant difference in average bunch weight was observed among the different spacing. Vines under 8 x 3 feet spacing exhibited the highest average bunch weight (92.36 g), followed closely by those under 8 x 2 feet (91.92 g), while vines in the 8 x 4 feet spacing had a slightly lower average bunch weight (88.51 g).

Vines spaced at 8 x 4 feet distance produced the highest number of bunches per vine (42.47), followed by 8 x 3 feet (33.47) and the lowest number in 8 x 2 feet spacing (28.59). In general, the cluster number increased as the spacing increased (Almeida *et al.*, 2020). Because of leaf overlap, treatments with narrow in-row spacing had shaded canopies, whereas those with large in-row spacing had more light input because of canopy gaps. Inflorescence induction and differentiation were impacted by the shade and canopy gaps, which decreased bud fruitfulness in narrower in-row spacing and increased in larger in-row spacing, as corroborated by Sanchez and Dokoozlian (2005) and Li-Mallet *et al.* (2016).

The number of berries per bunch significantly varied among the spacing treatments. Vines in the 8 x 4 feet spacing had the highest number of berries per bunch (106.19), followed by 8 x 3 feet (100.28), while the lowest number of berries per bunch was observed under 8 x 2 feet spacing (95.48). Significant differences in 100 berry weight were observed among the spacing configurations. Vines in the 8 x 3 feet spacing had the maximum 100 berry weight (101.10 g) followed by 8 x 2 feet spacing (94.76 g), while minimum 100 berry weight was found under 8 x 4 feet spacing (93.38 g). The dense canopy hampers the sunlight distribution in closed-spaced vines thereby decreasing the fruit bud differentiation. In addition, during the berry setting the leaf becomes yellow which hampers the sunlight required for photosynthesis. According to Vasconcelos *et al.* (2009), low leaf area and shade during flowering can hinder berry setting as less photoassimilates are available to disperse among the sink organs. This reduces the number of berries, which results in low cluster weight even when there are no changes in berry weight.

Yield per vine was significantly influenced by the spacing. Vines spaced at 8 x 4 feet distance, recorded the highest yield per vine (3.600 kg), followed by 8 x 3 feet (3.133 kg) and the lowest yield

Table 2. Effect of planting density on yield parameters of Cabernet Sauvignon

Spacing (feet)	Average bunch weight (g)	Number of bunches/ vine	Number of berries/ bunch	100 berry weight (g)	Yield/ vine (kg)
8 x 2	91.92	28.59	95.48	94.76	2.837
8 x 3	92.36	33.47	100.28	101.10	3.133
8 x 4	88.51	42.47	106.19	93.38	3.600
S.Em±	0.392	0.291	0.568	0.424	0.021
CD at 5%	1.210	0.897	1.751	1.307	0.067

was observed under 8 x 2 feet spacing (2.837 kg). The reason behind this could be because cluster number had a higher impact on yield than other components as noted by Clingeffer *et al.* (2001), Dias *et al.* (2017), and Almeida *et al.* (2020). While this trend is reversed for yield in terms of t/ha *i.e.*, 8 x 2 feet spacing (19.06 tonnes), 8 x 3 feet spacing (14.05 tonnes) and 8 x 4 feet spacing (12.10 tonnes). This is due to the higher number of vines per hectare area. A similar finding was also reported by Martinez-Salinas (2017) and Keller and Mills (2021).

#### Effect of planting density on photosynthetic efficiency:

Transpiration rate varied among the spacing configurations, with mean values of 2.37 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 2, 2.86 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 3 feet, and 2.90 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 4 feet. The critical differences indicated that there was a non-significant difference in transpiration rate between the different spacing. There was no significant difference in the assimilation rate among the spacing configurations. Mean assimilation rates were 11.00 μmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 2, 10.78 μmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 3 and 10.94 μmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 4 feet. The difference in stomatal conductance varied significantly among the spacing configurations. Mean stomatal conductance values were 101.20 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 2 feet, 119.03 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 3 feet and 117.91 mmol m<sup>-2</sup> s<sup>-1</sup> for 8 x 4.

Table 3. Effect of planting density on photosynthetic efficiency of Cabernet Sauvignon

Spacing (feet)	Transpiration rate (E <sub>t</sub> ) mmol m <sup>-2</sup> s <sup>-1</sup>	Assimilation rate (A) μmol m <sup>-2</sup> s <sup>-1</sup>	Stomatal conductance (G <sub>H<sub>2</sub>O</sub> ) mmol m <sup>-2</sup> s <sup>-1</sup>
8 x 2	2.37	11.00	101.20
8 x 3	2.86	10.78	119.03
8 x 4	2.90	10.94	117.91
Significance	NS	NS	NS

#### Effect of planting density on berry biochemical parameters:

Significant differences were observed for TSS among the spacing configurations. Higher TSS (23.49 °B) was recorded in 8 x 4 feet spacing vines and lowest under 8 x 2 feet spacing indicating a positive effect of wider spacing on sugar accumulation in grapes. It may be due to a higher accumulation of sugar in wider-spacing vines. However, Archer and Strauss (1991) and Hunter (1998) reported higher sugar concentrations for closer spacing.

Acidity also varied significantly among the spacing treatments. The mean total acidity ranged from 6.32 g/L for 8 x 2 feet to 6.06 g/L for 8 x 4 feet spacing, and VA values ranged from 0.13 g/L for 8 x 2 feet to 0.07 g/L for 8 x 4 feet, indicating that lower spacing may lead to slightly higher volatile acidity levels in grape juice. The results of the present findings are in agreement with the results of Archer and Strauss (1991).

There were significant differences in juice pH among the spacing configurations. Higher pH values (3.68) were observed in 8 x 2 feet spacing; while lower pH values (3.46) were observed in 8 x 4 feet spacing. The results indicated that wider spacing resulted in slightly lower pH levels. Archer and Strauss (1991) found that wider spaced vines with their denser canopy had a higher pH value than the grapes from the closer-spaced vines.

Table 4. Effect of planting density on photosynthetic efficiency and biochemical parameters

Spacing (feet)	TSS (°B)	Acidity (g/L)	Juice pH	VA (g/L)	Phenol (mg/L)
8 x 2	22.36	6.32	3.68	0.13	0.75
8 x 3	23.12	6.25	3.54	0.09	0.90
8 x 4	23.49	6.06	3.46	0.07	0.70
S.Em±	0.1174	0.0269	0.0150	0.0001	0.81
CD at 5%	0.3619	0.0828	0.0463	0.0004	0.01

Phenol concentration differed significantly among the spacing treatments. Higher phenol values (0.90 mg/L) were observed for 8 x 3 feet spacing which was followed by 8 x 2 feet spacing vines (0.75 mg/L) and 8 x 4 feet (0.70 mg/L) spacing. There was no clear trend in phenol concentration with respect to spacing. Bernizzoni *et al.* (2009), Heuvel *et al.* (2013), Reynolds *et al.* (2004) and Almeida *et al.* (2020) concluded that in-row spacing has minimal or no effect on berry composition.

**Effect of planting density on wine quality parameters:** There were minor variations observed among the different spacing for total acid content in wine. The higher acid content was observed in 8 x 2 feet spacing (5.14 g/L) which was statistically similar to 8 x 3 feet spacing (5.13 g/L) and lower acid content was found in 8 x 4 feet spacing (4.97 g/L). The acidity of wine and grapes showed a positive linear connection, meaning that acidity raised linearly with shade. Reynolds *et al.* (1994b) and Reynolds *et al.* (2007) reported similar results, connecting deeper canopies with increased overall acidity for the cultivars Riesling and Chardonnay Musque. This indicated that some degree of shade is beneficial for the production of sparkling wine, as suggested by Jones *et al.* (2014).

The wine's pH remained stable at 3.45-3.46, indicating consistent acidity due to the medium's buffering capacity. Ethanol levels were steady across conditions, ranging from 12.28% to 12.30%. Malic acid concentrations varied slightly (2.23-2.24 g/L) but were not statistically significant, suggesting minimal impact from experimental conditions. The decline in malic acid was primarily attributed to increased light exposure and higher temperatures during cellular respiration (Jackson, 2008; Sweetman *et al.*, 2014). Volatile acid content, an indicator of microbial activity and fermentation quality, exhibited slight differences among the conditions, with values ranging from 0.27 g/L to 0.30 g/L. However, similar to other parameters, the observed differences were not statistically significant (NS). The outcomes of the wine composition also concur with Bernizzoni *et al.* (2009), Heuvel *et al.* (2013), Reynolds *et al.* (2004) and Almeida *et al.* (2020) who concluded that the composition of wine was not significantly affected by in-row spacing.

**Effect of planting density on organoleptic taste:** Data presented in Fig. 1 show that the training system affects wine quality and sensory parameters. More vibrant or deeper color, better wine body, higher alcohol content, better wine length and overall

Table 5. Effect of planting density on wine quality parameters of Cabernet Sauvignon

Spacing (feet)	Total Acid (g/L)	pH	Ethanol (%)	Mallic acid (g/L)	Volatile acid (g/L)
8 x 2	5.14	3.46	12.30	2.23	0.30
8 x 3	5.13	3.46	12.28	2.24	0.28
8 x 4	4.97	3.45	12.30	2.23	0.27
CD at 5%	0.12	NS	NS	NS	NS

acceptability was determined under 8 x 2 feet spacing. The higher tannin content of wine was recorded in 8 x 3 feet spacing while, higher aromatic intensity, higher sweetness and higher acidity were determined in 8 x 4 feet spacing. Archer and Strauss (1991) found that closer-spaced vines produced a wine with better colour than the wider-spaced vines. Insufficient colour production in grapes is mainly due to the adverse effects of shade produced by excessively dense canopies (Rojas-Lara and Morrison, 1989). The wider spacing vines created canopy shade due to high canopy densities which prevents colour development in the grapes (Archer and Strauss, 1991). On the other hand, the better-exposed grapes of the closer-spaced treatment plots developed a higher sugar concentration as well as better colour which eventually resulted in better overall wine quality. Hunter (1998) also found similar findings.

The study concludes that planting distance significantly influences yield and quality. An 8 x 4 feet spacing resulted in higher pruning weight, early sprouting, more bunches per vine, better yield, and superior berry quality (TSS, potassium, and carbohydrate content). An 8 x 3 feet spacing enhanced shoot length, average bunch weight, 100 berry weight, phenol content, and wine quality (aromatic intensity and tannin content). Vines at 8 x 2 feet spacing excelled in shoot diameter, berry acidity, juice pH, volatile acids, and wine attributes such as color, body, alcohol, length, and overall acceptability. However, planting distance had no significant effect on shoot diameter, days to veraison or harvest, photosynthetic efficiency, or wine parameters like pH, ethanol percentage, malic acid, and volatile acids.

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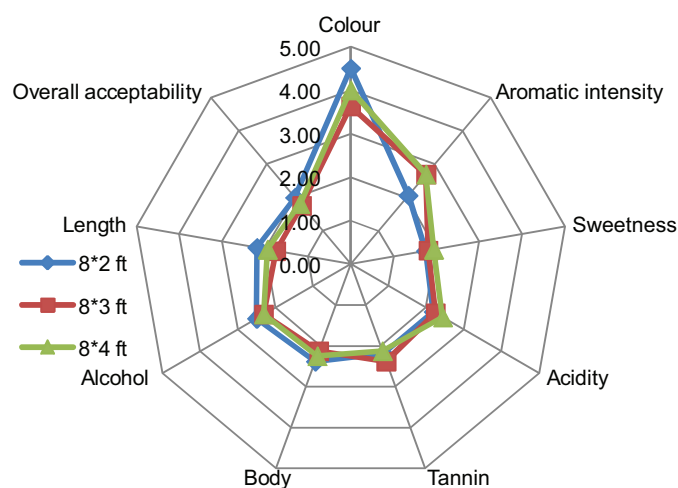


Fig. 1. Effect of planting density on organoleptic taste of Cabernet Sauvignon wine grafted on 110 R

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