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Evaluation of Red Wine Grape Varieties for Growth and Yield Parameters in Semi-arid Condition of India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study was carried out at the ICAR-National Research Centre for Grapes, Pune, during the 2022–2023 and 2023–2024 fruiting seasons. Among the red wine grape varieties, Cabernet Sauvignon demonstrated superior growth parameters, including pruned biomass (1.080 kg/vine). The variety Syrah exhibited the highest shoot length (120.44 cm), shoot diameter (9.75 mm), number of leaves per fruiting shoot (25.61), and number of bunches per vine (60.50). Grenache Noir showed the shortest time to bud sprout (8.93 days) and the highest number of berries per bunch (177.47), while Petit Syrah recorded the maximum internodal length (6.94 cm). The Caladoc variety displayed a higher number of leaves (24.42) and the largest leaf area per fruiting shoot (2931.25 cm²), whereas Nielluccio had the highest individual leaf area (141.25 cm²). Cabernet

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Franc clone had the highest chlorophyll content (13.52 mg/ml). Yield-related parameters highlighted Alicante Bouschet for its highest bunch weight (264.80 g) and yield (8.84 kg/vine and 10.70 MT/acre on a pooled mean basis), while Red Muscat had the highest 100-berry weight (221.94 g).

Keywords: Red wine grape varieties; yield parameters; growth parameters; food product.

1. INTRODUCTION

The *Vitis* genus are believed to have originated around 54 million years ago, but humans only began domesticating and cultivating grapes approximately 6,000 years ago (McGovern, 2003). Grapes hold a significant position in the fruit industry both in terms of cultivation area and economic value, and they are extensively grown in subtropical and temperate climates. Although grapes are fundamentally a temperate-origin crop, they are primarily cultivated in subtropical and tropical agro-climatic conditions (Ghule et al., 2021; Somkuwar et al., 2021). In India, roughly 98% of grape cultivation is dedicated to table grapes or raisin production, while only about 2% of the total grape yield is utilized for juice and winemaking (Ausari et al., 2024).

According to the International Organization of Vine and Wine (OIV), wine is a food product produced exclusively by the complete or partial alcoholic fermentation of fresh grapes or their must, either pressed or unpressed. Chemically, wine is a complex beverage consisting of water, ethanol, sugars, amino acids, polyphenolic compounds, anthocyanins, and a range of organic and inorganic substances (Karataș et al., 2015; Bora et al., 2016). During 2023, global wine production, excluding juices and musts, was estimated at 237 mhl (OIV, 2024). Wine is a widely popular beverage made from grapes through fermentation conducted under controlled conditions (Somkuwar et al. 2019). The wine market has experienced rapid growth in recent years due to increasing global demand and consumption, with production rising by over 40% in the past decade (OIV, 2024). Berries with high acidity, low sugar content, and low pH are beneficial for winemaking, as the quality of wine largely depends on its acid content (Jones et al., 2014). Grape composition is influenced not only by climate, which can cause disruptions, but also by vineyard management practices that can enhance the desired levels of acidity, sugar, and pH (Lavras, 2017).

The quality of grape wine is directly influenced by various factors, including the grape variety, environmental and climatic conditions, physical and chemical soil characteristics, the winemaking process, transportation and storage methods, the degree of agro-technical practices employed, and the vineyard's geographical location (Bora et al., 2015a; Condurso et al., 2015). A suitable climate is crucial for maintaining stable productivity, while year-to-year variations in atmospheric conditions can significantly impact grape quality (Jones and Goodrich, 2008) and, in turn, the quality of the wine.

Wineries produce wine using more than 30 different types of white grapes, with approximately 90% of the world's wine grapes originating from the Vitis vinifera species. Key red grape varieties used in winemaking include Cabernet Sauvignon, Syrah, Cabernet Franc, Grenache, Pinot Noir, Merlot, and Petit Verdot, among others. The quality of wine is primarily influenced by the grape variety cultivated, the prevailing climate during growth, vineyard management practices, and the fermentation techniques employed (Karibasappa, 2013). The micro climates of grape growing regions of Maharashtra specifically Nashik and Pune are suitable to grow wine varieties and produce acceptable quality wine.

2. MATERIALS AND METHODS

Experimental Site: In the current study, growth, yield and berry quality parameters of 15 red grape wine varieties (*V. vinifera* L.) grafted on Dogridge rootstock planted at National Research Centre for Grapes, Pune was undertaken during two seasons (2022-23 and 2023-24). The age of the vineyard was seven years old with good health and regular crop. The vines were trained to a mini-Y trellis system with single cordons trained in the horizontal direction while shoots were placed in a vertical position. The soil in the region is heavy black with pH 7.75 and EC 0.46 dS m^{-1}.

Experimental Design: All the varieties were planted at a spacing of 3 m between the rows and 1.5 m between the vines in a completely randomized setup with three replications and five vines per replication.

2.1 Procedure to Record Observations

Fifteen red wine grape varieties (Alicante Bouschet, Cabernet Sauvignon, Cabernet Franc, Cabernet Franc clone, Syrah, Petit Syrah, Tempranillo, Grenache, Grenache Noir, Cinsaut, Caladoc, Nielluccio, Merlot, Petit Verdot and Red Muscat) were used as per the treatments for production and for further use in the study.

2.1.1 Growth parameters

Five vines were selected and marked within each replication and means of five vines was calculated for each parameter.

1. **Weight of Pruned Biomass (kg/vine):** After pruning, pruned material from each vine was collected immediately and weighed using a weighing balance (Param weighing scale). The mean weight of biomass was calculated and expressed in kg/vine.
2. **Days Taken to Bud Sprout:** Days to bud sprout were calculated after each pruning (foundation and fruit pruning). The first sprouted bud with fully expanded leaf was taken as an indicator to count the days to bud sprout (Satisha et al*.,* 2010)
3. **Cane Length (cm):** Five canes were selected randomly and tagged to measure cane length using measuring tape at 90 days after fruit pruning (DAP) and was expressed in cm.
4. **Cane Diameter (mm):** Cane diameter was measured between fifth and sixth node of cane from five different vines and the mean was expressed in millimeters (mm) at 90 days after foundation pruning.
5. **Internodal Length (cm):** Internodal length was measured between fifth and sixth nodes of canes using a measuring scale at 90 DAP during the fruit pruning. The mean was calculated and reported in centimeters (cm).
6. **Number of Leaves per Fruiting Shoots:** Number of leaves per fruiting shoot was recorded by counting the number of leaves from selected canes at 90th day of fruit pruning. The mean number of shoots was worked out.
7. **Leaf Area (cm^2):** Five shoot were selected from each vines and it was measured using BIOVIS, leaf area meter at days after foundation pruning and their mean was expressed in cm^2.
8. **Estimation of Chlorophyll:** The chlorophyll content in the various parts of vine was estimated using the method of Witham et al. (1971).

2.1.2 Yield parameters

After harvesting bunches, five healthy bunches/vine were selected for recording the observations for yield and quality parameters.

1. **No. of Bunches per Vine:** Number of bunches per vine was recorded by counting number of bunches from three different vines and the mean of the three vines was calculated.
2. **No. of Berries per Bunch:** Number of berries was recorded by counting number of berries from five different bunches and mean of the five bunches was calculated.
3. **Average Bunch Weight (g):** Five healthy bunches per replication was selected randomly at the time of harvesting and their mean weight was recorded using weighing balance. The mean average bunch weight was expressed in grams.
4. **100 Berry Weight (g):** A hundred berries from five bunches were selected under each replication and their mean weight was recorded using weighing balance. The mean 100 berry weight was expressed in grams.
5. **Yield per Vine (kg):** At the time of harvest, five vines were selected and tagged. The harvested grapes from these vines under each treatment were weighed using weighing balance. The mean yield of each vine calculated and was expressed in Kg.
6. **Yield per acre (MT)**
   The grape yield per acre was calculated by following formula

$$\text{Yield (t/ha)} = \frac{\text{Yield/vine (kg)} \times \text{Vines/acre}}{1000 \text{ kg}}$$

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

3.1.1 Pruned biomass

Cabernet Sauvignon exhibited the highest pruned biomass weight during both years. This suggests that Cabernet Sauvignon vines are more vigorous. Cabernet Franc clone recorded the lowest pruned biomass weight, indicating less vigorous growth compared to other varieties. In the year 2022-23, Cabernet Sauvignon showed highest weight of pruned biomass. However, lowest weight of pruned biomass was recorded in Cabernet Franc Clone. During fruit

pruning season of 2023-24, higher pruned biomass was recorded in Cabernet Sauvignon variety which was statistically higher than all other varieties while, lower pruned biomass was reported in Merlot variety. Vine vigor is measured by pruning weight, an essential growth characteristic that helps differentiate grape varieties into vigorous and non-vigorous categories based on their growth rates (Benz et al., 2006 and Somkuwar et al., 2024a). Similar significant variation for pruning weight was found by Jayalakshmi et al., (2019); Nidhi et al., (2023) and Somkuwar et al., (2024a).

3.1.2 Days taken to bud sprout

During 1st year of trial, Grenache Noir variety took minimum days to sprout which was followed by Aliquant Bauschet, Cabernet Franc Clone, Petit Syrah, Cabernet Franc, Merlot and Red Muscat. While, maximum days to bud sprout were taken by Grenache Noir. During season 2023-24, minimum days for bud sprout were taken by Aliquant Bauschet, Cabernet Franc, Cabernet Franc Clone, Petit Syrah, Grenache Noir (9.00 days after fruit pruning) while, maximum days to bud sprout were taken by Cinsaut. According to pooled mean data of two years, Grenache Noir showed early sprouting which was followed by Aliquant Bauschet, Cabernet Franc Clone, Petit Syrah, Cabernet Franc and Merlot while Cinsaut was late to sprout. Bud burst is a varietal character as it marks the beginning of seasonal growth and is strongly influenced by temperature. The data on the growth parameter clearly indicated that prevailing temperature after pruning affects the time required for bud break in the same variety and the influence of temperature is more than that of variety (Somkuwar et al., 2024a). Similar studies were reported by Gupta et al., (2015).

3.1.3 Shoot length

Shoot length recorded during both season was maximum in Syrah variety whereas the minimum shoot length in Merlot. Highly vigorous varieties generally produce longer shoots. In contrast, Veena et al., (2015) found that vigorous varieties have produced comparatively shorter shoot than less vigorous varieties. This may be due to number of buds retained on the cane after pruning.

3.1.4 Shoot diameter

Syrah recorded maximum shoot diameter during season 2022-23 and pooled mean of experiment, respectively which was followed by Red Muscat and minimum in Petit Verdot. During season 2023-24, highest shoot diameter was observed in Syrah which was followed by Red Muscat while Nielluccio exhibited lowest shoot diameter. The production of canes and their dimension depends upon vigour of the vine, which in turn depends upon the extent of stored food material in the vine. Vigorous varieties having greater stored food material produce higher number of canes. Several workers recorded similar observations *i.e*., Pina and Bautists (2006), Havinal et al., (2008), Soni et al., (2019) and Nidhi et al., (2023).

3.1.5 Internodal length

Petit Syrah recorded the highest pooled mean internodal length. Syrah, Nielluccio and Red Muscat closely followed to Petit Syrah however, Merlot had the lowest pooled mean internodal length. Syrah showed highest internodal length during 2022-23 season which was closely followed by Petit Syrah, Red Muscat, Nielluccio and Tempranillo and minimum internodal length was noted in Cabernet Sauvignon. During 2023-24 season, Petit Syrah exhibited long internodal which was followed by Syrah, Nielluccio, Caladoc and Red Muscat while short internodal recorded in Merlot, Petit Verdot, Grenache Noir, Aliquant Bauschet and Cabernet Sauvignon. Higher internodal length in Syrah may be due to more shoot length which increases internodal length in between cane. Mostly shorter internodes accumulate higher carbohydrates food reserves which are pre-requisite for flower bud initiation (Jayalakshmi et al., 2019; Somkuwar and Ramteke, 2008).

3.1.6 Number of leaves per fruiting shoot

During both season, Caladoc recorded the maximum number of leaves which was followed by Cinsaut while, Syrah had the fewest leaves per fruiting shoot. Such variation among the colored and white varieties for leaf number may be attributed to difference in number of canes and vigour of the vine and the inherent varietal character (Veena et al., 2015). Similar results were also reported by Anupama et al., (2016).

3.1.7 Leaf area

During both season, Nielluccio continued to show the highest leaf area and followed by Caladoc however, Merlot and Cabernet Sauvignon had the minimum leaf area. Such, high variation among the red wine varieties for leaf area may

be attributed to varietal character (Veena et al., 2015). The increased leaf area results in highest active photosynthesis rate which helps to store more carbohydrate in the sink, bunch (Somkuwar et al. 2013). Somkuwar et al., (2024c, 2024d, 2024e) revealed that leaf area was decreased with increased number of leaves per shoot.

3.1.8 Leaf area per fruiting shoot

During 2022-23 season and pooled mean, Caladoc had the highest leaf area per fruiting shoot which was followed by Cinsaut. On the lower end, Merlot observed the lowest leaf area per fruiting shoot. During 2023-24 season, Caladoc recorded significantly higher leaf area per fruiting shoot among all varieties studied. However, Cabernet Sauvignon reported minimum leaf area per fruiting shoot. The increase in leaf area per shoot and vine with more leaves is due to the direct correlation between the number of leaves and the overall vegetative growth of the vine. Leaf area is strongly correlated with the annual shoots and cane growth; the most vigorous varieties usually have the highest annual growth (Borca et al., 2020). Similar results were reported by Georgeta et al., (2021) in red wine varieties. The optimum leaf number enhanced the overall leaf area, potentially contributing to higher photosynthetic capacity (source) and resource distribution (sink) for grape development (Somkuwar et al., 2024e and Thoke et al., 2024).

3.1.9 Chlorophyll content in the leaves

When considering the pooled mean across both seasons, Cabernet Franc clone maintained the highest chlorophyll content, closely followed by Cabernet Sauvignon. However, Caladoc consistently exhibited the lowest pooled chlorophyll content. The chlorophyll content in leaf gives an indication of the efficiency of leaf to prepare food through photosynthesis (Somkuwar et al., 2024d). More leaves can increase overall photosynthetic capacity. There may be an optimum leaf number beyond which chlorophyll content per leaf might begin to decrease. Maintaining an appropriate number of leaves can produce maximum chlorophyll content and photosynthetic efficiency without any negative effect (Somkuwar et al., 2024d). Petrie et al., (2000) and Somkuwar et al., (2014b) observed that leaf removal led to an increase of chlorophyll content. Somkuwar et al., (2024c) reported that the results illustrated variations in chlorophyll a, chlorophyll b and total chlorophyll concentrations between different treatments. Chlorophyll content in leaf ranged from 29.15 to 25.30 mg/ml and 21.35 mg/ml to 19.14 mg/ml among the treatments.

3.2 Yield Parameters

3.2.1 Number of bunches per vine

Pooled mean values across both seasons was significant with Syrah had the highest number of bunches per vine. On the lower end, Petit Verdot recorded the lowest pooled mean. During 2022-23 season, Syrah exhibited the highest number of bunches per vine which was followed by Grenache Noir, while lowest in Petit Verdot. During 2023-24 season, Syrah recorded a high number of bunches per vine while lowest in Cabernet Franc and its clone, along with Petit Verdot. The increase in number of bunches per vine in Syrah might be due to highest fruitfulness of spur. Similar line of work in grapes was reported by Chalak et al., (2011), Anupama et al., (2016), Leao et al., (2017), Anjanawe et al., (2020), Tecchio et al., (2022), Nidhi et al., (2023) and Somkuwar et al., (2024a).

3.2.2 Number of berries per bunch

During 2022-23, Grenache Noir had the highest average number of berries per bunch and Merlot recorded the fewest berries per bunch. During the 2023-24 season, Grenache Noir again led with higher berries per bunch while Red Muscat had fewest berries per bunch. The pooled mean over both seasons showed that Grenache Noir exhibited the highest average number of berries per bunch (177.47). However, minimum number of berries per bunch observed in Red Muscat (79.67) and Merlot (80.00). Somkuwar et al., (2024a) reported that the maximum number of berries/bunch were recorded in Cabernet Sauvignon (111.00) during the year 2014-15 whereas, in 2016-17 and pooled mean it was maximum in Cinsaut (227.33 and 134.55) and in 2015-16 was recorded maximum in Nielluccio (145.00) variety. While minimum number of berries per bunch was recorded in Merlot (69.00 and 79.00 respectively) during both the year 2015-16 and 2016-17 while, in 2014-15 and pooled data was recorded in Nielluccio and Cabernet Franc (62.33 and 81.55). Jayalakshmi et al. (2019) found maximum number of berries per bunch (278.54) in Manjari Medika, 43.65 numbers of berries per bunch in Zinfandel. Similar line of findings was earlier reported by Havinal et al. (2008); Tecchio et al. (2022).

Table 1. Pruned biomass, days taken to bud sprout and shoot length data of red grape wine varieties during two growing seasons (2022-23 and 2023-24) and pooled mean data

Varieties	Pruned biomass (Kg)			Days taken to bud sprout			Cane length (cm)		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
Alicante Bouschet	0.499	0.492	0.496	8.97	9.00	8.98	53.89	54.50	54.20
Cabernet Sauvignon	1.053	1.107	1.080	11.83	10.33	11.08	62.44	61.20	61.82
Cabernet Franc	0.400	0.397	0.399	9.17	9.00	9.08	77.00	77.10	77.05
Cabernet Franc clone	0.367	0.387	0.377	9.00	9.00	9.00	62.02	62.69	62.35
Syrah	0.583	0.680	0.631	10.73	10.03	10.38	115.44	125.43	120.44
Petit Syrah	0.575	0.616	0.595	9.13	9.00	9.07	91.20	88.67	89.93
Tempranillo	0.674	0.661	0.668	12.17	12.00	12.08	99.33	103.33	101.33
Grenache	0.645	0.627	0.637	11.33	11.67	11.50	80.33	87.03	83.68
Grenache Noir	0.521	0.527	0.524	8.87	9.00	8.93	57.16	56.84	57.00
Cinsaut	0.649	0.612	0.631	13.00	13.00	13.00	87.22	93.90	90.56
Caladoc	0.841	0.836	0.839	12.00	11.33	11.67	91.11	90.33	90.72
Nielluccio	0.720	0.875	0.798	11.00	10.33	10.67	73.67	91.43	82.55
Merlot	0.383	0.376	0.380	9.33	9.67	9.50	49.66	53.00	51.33
Petit Verdot	0.450	0.384	0.418	12.67	12.33	12.50	59.44	61.10	60.27
Red Muscat	0.823	0.839	0.831	10.07	10.00	10.03	71.07	75.00	73.04
S.Em. (±)	**0.011**	**0.009**	**0.007**	**0.510**	**0.456**	**0.325**	**3.563**	**3.393**	**2.170**
C.D. (0.05)	**0.031**	**0.027**	**0.021**	**1.486**	**1.329**	**0.947**	**10.263**	**9.775**	**6.251**

Table 2. Shoot diameter, internodal length and number of leaves per shoot data of red grape wine varieties during two growing seasons (2022-23 and 2023-24) and pooled mean data

Varieties	Cane diameter (mm)			Internodal length (cm)			Number of leaves/shoot		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
Alicante Bouschet	6.02	6.55	6.28	5.04	5.01	5.02	15.67	16.25	15.96
Cabernet Sauvignon	5.22	4.90	5.06	4.01	5.03	4.53	16.44	17.60	17.02
Cabernet Franc	6.67	6.20	6.43	5.18	5.67	5.43	14.67	16.17	15.42
Cabernet Franc clone	6.57	6.93	6.75	5.50	5.97	5.73	15.30	15.65	15.47
Syrah	9.89	9.60	9.75	6.93	6.90	6.92	13.55	14.73	14.14
Petit Syrah	8.52	7.71	8.12	6.84	7.04	6.94	17.93	17.52	17.73
Tempranillo	6.22	5.93	6.08	6.28	6.23	6.26	15.78	16.50	16.14
Grenache	6.89	4.90	5.90	6.23	5.90	6.07	18.34	18.17	18.25
Grenache Noir	8.94	9.09	9.02	4.81	4.79	4.80	14.58	15.31	14.95
Cinsaut	6.11	5.70	5.91	6.01	6.13	6.08	22.89	24.67	23.78
Caladoc	7.86	4.67	6.27	5.98	6.53	6.26	23.67	25.17	24.42
Nielluccio	8.56	4.63	6.60	6.30	6.90	6.60	15.44	16.50	15.97
Merlot	5.22	4.83	5.03	4.59	4.40	4.50	16.50	16.87	16.68
Petit Verdot	5.00	4.80	4.90	4.52	4.60	4.56	17.17	17.17	17.17
Red Muscat	9.27	9.37	9.32	6.33	6.47	6.40	19.26	19.32	19.29
S.Em. (±)	**0.281**	**0.171**	**0.157**	**0.255**	**0.222**	**0.189**	**0.314**	**0.371**	**0.280**
C.D. (0.05)	**0.809**	**0.493**	**0.453**	**0.736**	**0.639**	**0.545**	**0.906**	**1.069**	**0.806**

Table 3. Leaf area per leaf, leaf area per fruiting shoot and cane chlorophyll content of red grape wine varieties during two growing seasons (2022-23 and 2023-24) and pooled mean data

Varieties	Leaf area/leaf			Leaf area/fruiting shoot			Chlorophyll content (mg/ml)		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
Alicante Bouschet	90.03	94.48	92.25	1409.44	1533.08	1471.26	9.78	10.39	10.09
Cabernet Sauvignon	72.52	46.45	59.49	1193.90	816.92	1005.41	12.38	13.68	13.03
Cabernet Franc	73.60	83.56	78.58	1073.68	1353.81	1213.74	10.85	12.48	11.67
Cabernet Franc clone	92.62	84.38	88.50	1416.24	1317.22	1366.73	13.11	13.92	13.52
Syrah	102.96	116.78	109.87	1392.52	1719.76	1556.14	12.29	13.58	12.94
Petit Syrah	103.84	112.88	108.36	1858.19	1968.76	1913.47	11.34	12.78	12.06
Tempranillo	111.37	97.33	104.35	1761.16	1609.35	1685.26	8.10	8.77	8.43
Grenache	99.52	113.48	106.50	1822.23	2059.65	1940.94	12.22	12.98	12.60
Grenache Noir	107.20	103.67	105.43	1562.63	1590.86	1576.74	7.11	8.19	7.65
Cinsaut	104.52	100.46	102.49	2385.10	2467.03	2426.06	9.78	10.59	10.19
Caladoc	107.90	131.20	119.55	2553.85	3308.65	2931.25	5.91	6.79	6.35
Nielluccio	129.77	152.73	141.25	2004.07	2513.12	2258.60	11.73	12.96	12.34
Merlot	55.46	53.48	54.47	912.18	900.07	906.13	8.60	9.32	8.96
Petit Verdot	78.66	76.65	77.66	1349.22	1312.01	1330.61	10.64	12.24	11.44
Red Muscat	112.17	89.96	101.07	2162.22	1738.04	1950.13	9.22	9.79	9.51
S.Em. (±)	**6.396**	**9.496**	**5.636**	**106.827**	**177.142**	**103.640**	**0.284**	**0.303**	**0.184**
C.D. (0.05)	**18.426**	**27.356**	**16.236**	**307.731**	**510.286**	**298.553**	**0.818**	**0.872**	**0.529**

Table 4. Number of bunches per vine, number of berries per bunch and Average bunch weight of red grape wine varieties during two growing seasons (2022-23 and 2023-24) and pooled mean data

Varieties	Number of bunches/vine			Number of berries/bunch			Average bunch weight (g)		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
Alicante Bouschet	32.66	34.04	33.36	140.33	134.50	137.42	261.17	267.83	264.50
Cabernet Sauvignon	37.17	38.37	37.77	96.83	97.33	97.08	105.92	102.57	104.25
Cabernet Franc	29.50	24.33	26.92	93.83	94.50	94.17	116.34	113.27	114.81
Cabernet Franc clone	28.28	24.58	26.43	103.83	104.50	104.17	122.33	118.90	120.62
Syrah	43.17	43.27	43.22	111.44	107.03	109.24	137.89	144.27	141.08
Petit Syrah	35.80	36.03	35.92	131.00	130.67	130.83	165.30	163.70	164.50
Tempranillo	35.00	35.00	35.00	114.00	115.30	114.65	201.00	197.67	199.34
Grenache	35.50	35.67	35.58	142.50	140.33	141.42	157.30	149.27	153.28
Grenache Noir	39.03	39.00	39.02	175.60	179.33	177.47	179.23	185.57	182.40
Cinsaut	30.50	29.00	29.75	116.83	118.63	117.73	151.57	149.80	150.69
Caladoc	36.00	36.67	36.33	89.00	85.33	87.17	147.08	145.50	146.29
Nielluccio	25.67	26.33	26.00	128.00	117.70	122.85	183.45	181.60	182.53
Merlot	27.17	27.00	27.08	81.67	78.33	80.00	92.57	92.60	92.59
Petit Verdot	24.00	25.00	24.50	97.67	101.00	99.33	94.53	93.40	93.97
Red Muscat	30.08	30.29	30.19	85.33	74.00	79.67	179.33	171.50	175.42
S.Em. (±)	**1.827**	**1.635**	**1.316**	**3.540**	**3.724**	**2.447**	**6.423**	**4.548**	**3.292**
C.D. (0.05)	**5.262**	**4.710**	**3.790**	**10.198**	**10.727**	**7.048**	**18.502**	**13.101**	**9.483**

Table 5. 100 berry weight, yield/vine and yield/acre of red grape wine varieties during two growing seasons (2022-23 and 2023-24) and pooled mean data

Varieties	100 berry weight (g)			Yield/vine (Kg)			Yield/acre (MT)		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
Alicante Bouschet	186.52	199.15	192.83	8.57	9.12	8.84	10.37	11.03	10.70
Cabernet Sauvignon	109.70	105.49	107.59	3.92	3.94	3.93	4.75	4.77	4.76
Cabernet Franc	123.87	120.01	121.94	3.44	2.76	3.10	4.16	3.34	3.75
Cabernet Franc clone	117.61	113.94	115.77	3.48	2.91	3.20	4.21	3.52	3.87
Syrah	124.42	134.89	129.65	5.93	6.25	6.09	7.18	7.56	7.37
Petit Syrah	126.36	125.28	125.82	5.92	5.91	5.91	7.16	7.15	7.15
Tempranillo	176.31	171.63	173.97	7.06	6.92	6.99	8.55	8.38	8.46
Grenache	110.64	106.45	108.54	5.60	5.33	5.46	6.77	6.44	6.61
Grenache Noir	102.24	103.89	103.07	7.00	7.24	7.12	8.47	8.76	8.61
Cinsaut	130.89	126.53	128.71	4.63	4.34	4.48	5.60	5.25	5.43
Caladoc	165.53	170.51	168.02	5.30	5.34	5.32	6.40	6.46	6.43
Nielluccio	143.37	154.89	149.13	4.75	4.78	4.76	5.75	5.78	5.77
Merlot	113.71	119.56	116.63	2.51	2.50	2.51	3.04	3.03	3.03
Petit Verdot	96.96	92.55	94.75	2.27	2.34	2.30	2.74	2.83	2.79
Red Muscat	212.15	231.72	221.94	5.39	5.20	5.30	6.52	6.29	6.41
S.Em. (±)	**7.438**	**5.147**	**4.057**	**0.389**	**0.270**	**0.217**	**0.470**	**0.327**	**0.263**
C.D. (0.05)	**21.428**	**14.826**	**11.687**	**1.119**	**0.777**	**0.626**	**1.354**	**0.941**	**0.758**

3.2.3 Average bunch weight

When analyzing the pooled mean along with both seasons, it was found that Alicante Bouschet consistently emerged as the variety with the highest bunch weight. In contrast, Merlot and Petit Verdot had the lowest pooled mean bunch weight. The variation in the bunch weight among different varieties may be attributed to inherent genetic character of the variety, number of berries per bunch, difference in number of canes and berry size and also the size of vine canopy where varieties with larger canopy sizes were noted to have higher bunch weights (Somkuwar et al., 2024a; Nidhi et al., 2023; Anjanawe et al., 2020; Havinal et al., 2008;). Tecchio et al., (2022) found that Cabernet Sauvignon was one of the cultivars that had the lowest bunch mass (85.5 g). Moreover, this value was 76% lower than those detected by Rizzon and Miele (2002) under temperate conditions. Similar line of work was done earlier by Leao et al., (2017); Ingole et al., (2018).

3.2.4 100 berries weight

The analysis of 100 berry weight for various red wine grape varieties over two seasons (2022-23 and 2023-24) demonstrated noticeable differences among the varieties. Red Muscat variety had the maximum 100 berry weight followed by Alicante Bouschet . The Petit Verdot variety showed the minimum 100 berry weight, making it the variety with the lightest berries overall. The variation in berry weight may arise from differences in both the diameter of the berries and the number of berries/bunch (Thakur et al*.,* 2008). The present studies are in confirmation with the results of Ratnacharyulu (2010); Ghosh et al. (2012); Anupama et al., (2016); Pal et al., (2018); Soni et al., (2019); Nidhi et al., (2023); Somkuwar et al., (2024a, 2024b).

3.2.5 Yield

Alicante Bouschet recorded the highest yield and lowest yield was observed in Petit Verdot and Merlot varieties. Disparities in yield per vine among various grape cultivars may be attributed to variations in bunch weight, number of bunches, and berry weight besides their successful adoption to the varying agro-climatic conditions under which they are cultivated (Havinal et al*.,* 2008). The positive correlation of yield per vine with average bunch weight and berry weight was recorded. Crop yield was found to increase in proportion to the number of clusters/vine, a trend similarly observed in the findings of Myers et al*.* (2008) in Sangiovese grape wines. Orlando et al. (2008) assessed the productive performance of Syrah and Cabernet Sauvignon under similar climatic conditions and they observed that Syrah was also more productive than Cabernet Sauvignon regardless of the rootstock. Similar line of work is reported by Somkuwar et al. (2024a, 2024b), Tecchio et al., (2022); Anjanawe et al., (2020); Ingole et al. (2018); Vijaya et al., (2018); Leao et al., (2017); Veena et al. (2015); Chalak et al., (2011).

4. CONCLUSION

The evaluation of growth and yield parameters of different red wine grape varieties over the 2022-23 and 2023-24 seasons revealed significant varietal differences. The variety Cabernet Sauvignon showing superior growth parameters like pruned biomass while higher shoot length, shoot diameter, number of leaves and yield parameter like number of bunches was recorded in Syrah. Minimum days taken to bud sprout and number of berries was recorded in Grenache Noir. Maximum internodal length was recorded in Petit Syrah. Higher number of leaves in Caladoc, leaf area was recorded in Caladoc and Nielluccio varieties. Higher chlorophyll content was recorded in Cabernet Franc clone. Yield-related metrics like bunch weight and yield was recorded higher in Alicante Bouschet, 100 berry weight (221.94 g) in Red Muscat for pooled mean basis.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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