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Bud Fruitfulness Indicators of Several Technical and Table Grapevine Cultivars Cultivated in Azerbaijan

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ABSTRACT

Bud fruitfulness is among the principal agrobiological indicators determining productivity potential, pruning strategy, and yield formation in grapevine. In this study, we comparatively evaluated the actual bud fruitfulness along fruiting canes in 63 local and introduced grape varieties, including 25 technical and 38 table grape varieties cultivated under ecological conditions of the Absheron Peninsula during three consecutive seasons (2023–2025). Bud fruitfulness was assessed through phenological observations, and buds were classified by position as basal (1st–3rd), median (4th–6th), and apical (7th and upper) buds. The Wilcoxon–Mann–Whitney test was used to determine statistically significant differences between the locations and fruitfulness of buds. Technical grape varieties were characterized by comparatively higher and more stable bud fruitfulness, with productive zones predominantly concentrated between the 2nd and 7th buds. In contrast, table grape varieties exhibited relatively lower fertility in basal buds, whereas maximum fruitfulness was mainly localized in the median portions of the shoots. This study's findings offer an important scientific and practical basis for identifying productive zones, optimizing dormant pruning, predicting productivity potential, and enhancing future grapevine breeding and cultivation programs.

1. INTRODUCTION

A wide range of plant species are currently cultivated worldwide. However, wheat, chickpea, lentil, grapevine, olive, and several other crops that were among the first plants domesticated by humankind have maintained their nutritional and economic importance to the present day. Among these cultivated plants, grapevine occupies a special position due to its steadily increasing economic value, broad range of utilization, and high production potential. Owing to these characteristics, grapevine is expected to preserve its significance in human life in the future as well [1]. The primary objective of most grape growers, regardless of the cultivation system applied or the intended use of the grape cultivars, is to obtain high yields combined with superior fruit quality. To achieve this goal, various viticultural practices and management strategies are implemented in vineyards. In this context, factors such as fertilization programs and fertilizer applications, irrigation systems and efficient water management, pest control methods, pruning practices and training systems, favorable environmental conditions, and seasonal climatic factors play a crucial role in determining grapevine productivity and fruit quality. Each of these practices is aimed at eliminating or minimizing the effects of different stress factors that limit vineyard productivity and grape quality, thereby ensuring the sustainability of viticulture as an important branch of agricultural production. Among these practices, winter pruning, which must be carried out regularly every year in perennial woody plants, is of particular importance in grapevine cultivation. This practice is considered essential for maintaining balanced vine growth and ensuring stable yields over successive years [2-13].

Numerous researchers have previously reported that grape cluster formation and, consequently, vineyard productivity are directly associated with overwintering buds located on one-year-old canes [14]. Lu et al. [15] reported that, from an anatomical and morphological perspective, overwintering grapevine buds consist of a bud cushion, a main bud, inflorescence primordia, leaf primordia, and accessory or reserve buds. In grapevine, buds are evaluated during the flowering phenological stage and classified as either fruitful or sterile. Buds developing inflorescences are considered fruitful, whereas buds without inflorescence development are regarded as sterile.

According to their position along the cane, buds are generally classified as basal buds (1st–3rd nodes), median buds (4th–6th nodes), and apical buds (7th–10th and distal nodes). In addition to positional differences, these buds also vary considerably in terms of fruitfulness and sterility [16].

Since grape clusters develop from overwintering buds located on one-year-old lignified canes, many researchers have emphasized the importance of investigating the direct relationship between winter buds and grapevine productivity. In this regard, it has been suggested that grapevine productivity, particularly cluster formation, is closely associated with the position of winter buds along the annual cane [14]. Numerous studies have demonstrated that basal buds generally possess lower cluster formation potential compared to distal buds. Researchers have also reported that the distribution of fruitful buds along the cane may vary depending on the cultivar; however, buds located in the median portion of the cane usually exhibit a greater cluster formation potential than both basal and apical buds. Although different methodologies have been applied to evaluate bud fruitfulness, researchers have largely reached a common conclusion that the fruitfulness characteristics of buds vary considerably among grapevine cultivars. In addition, environmental conditions and growth factors have been identified as important determinants influencing bud fruitfulness [17].

In grapevine, it is important to distinguish between potential, embryonic, and actual fruitfulness of buds. Potential fruitfulness refers to the inherent reproductive capacity of each bud formed on a developed vine. Embryonic fruitfulness is determined by the number of inflorescence primordia and the degree of their development within the bud. Actual fruitfulness, on the other hand, is expressed by the number of fruitful shoots that develop and the clusters subsequently formed on them. Studies have shown that the potential (biological) productivity of grapevine buds cannot be fully transformed into actual productivity. This phenomenon occurs under the influence of numerous internal and external factors. Environmental limitations affecting whether buds ultimately develop clusters under vineyard conditions are considered inevitable. At the stage when tendril and inflorescence primordia are still present within the dormant bud, they appear morphologically very similar, resembling unstable protoplasmic structures located in the growing cone of the primary bud. However, under the influence of hormonal activity and various environmental factors, these embryonic structures undergo differentiation and gradually acquire the morphological characteristics of the final organ they will form, namely either an inflorescence or a tendril [18, 19].

This process of variability begins during the previous vegetative cycle with the formation of the young shoot structure that will subsequently develop into the overwintering bud and continues until the formation of either an inflorescence or a tendril on the spring shoot during the following growing season [20]. Studies have demonstrated that the status, timing, and quantity of gibberellin and cytokinin synthesis, particularly the gibberellin–cytokinin balance, significantly influence whether the developing growth cone within the primary bud differentiates into an inflorescence or a tendril. Furthermore, bud fruitfulness may vary depending on the auxin–cytokinin balance. The regulatory role of auxins in bud productivity has also been experimentally confirmed. Studies have demonstrated that bud fruitfulness is determined not only by the genetic characteristics of the cultivar, but is also closely associated with pruning systems and climatic conditions [17, 21-28].

Monteiro et al. [29], in a study conducted in the northwestern region of Portugal, reported that cultivar characteristics significantly affect bud fruitfulness, with the differences being especially pronounced in the first two basal buds. Di Lorenzo and Pisciotta [30], in their study on the ‘Grillo’ grapevine cultivar, observed a higher proportion of blind buds in the basal 1st–3rd nodal positions, whereas bud fruitfulness and cluster number increased in the 4th–9th nodes along the shoot. The fruit-bearing zone was mainly concentrated between the 2nd and 8th buds, and several cultivars exhibited remarkably high fruitfulness levels reaching 80–90% or higher.

Meneguzzi et al. [16], in a study involving 26 Vitis vinifera cultivars cultivated in the Santa Catarina region of Brazil, evaluated bud fruitfulness along the 1st–10th nodal positions of the shoots and reported that bud fruitfulness varied significantly depending on both the cultivar and nodal position. The fruit-bearing zone was predominantly concentrated in the median and apical portions of the shoots, particularly between the 4th and 11th buds. Poudel et al. [31] determined the number of potential inflorescence primordia and evaluated their correlation with the actual cluster number in two grapevine cultivars (‘Himrod’ and ‘Steuben’). The study demonstrated that bud fruitfulness increased progressively from the basal toward the distal portions of the shoots in both cultivars. The first and second basal buds exhibited lower fruitfulness, whereas the third and fourth buds showed higher numbers of inflorescence primordia and observed clusters. A strong positive correlation between potential and actual fruitfulness was also identified ($r = 0.80$–0.92).

In general, grapevine productivity and fruit quality are strongly influenced by the pruning length of one-year-old canes. Under specific environmental conditions, the application of cultivar-adapted optimal pruning strategies makes it possible to obtain targeted yield and quality characteristics. Therefore, determining the appropriate number of annual canes to be retained on the vine, as well as establishing the optimal pruning length and bud load for each cultivar under particular growing conditions, represents an important and actual issue in viticulture research. The Absheron Peninsula is one of the regions of Azerbaijan with an ancient history and potential for table viticulture. In recent years, various table grape varieties have been imported and grown (introduced) to this region from both abroad and other regions of the country. From this perspective, to more accurately determine the yield potential of these varieties in the conditions of the Absheron region, it is important to determine the number of fruiting shoots, the bud load, and the pruning length of fruiting shoots. The present study was conducted over a three-year period and aimed to evaluate the bud fruitfulness of 63 different grapevine cultivars and, based on these findings, determine their optimal pruning levels. The main objectives of the research were: determining the pruning length and number of fruiting shoots in accordance with the biological characteristics of each variety; identifying the fruiting indicators of each bud, including basal, median, and apical ones, along the entire length of the fruiting shoots; determining the "bud rate when pruning" for each variety, depending on the basal bud opening rate and the fruiting characteristics of the buds on each fruiting shoot. The results confirmed that bud position is one of the key factors influencing the formation of grapevine productivity structure and demonstrated the importance of selecting pruning lengths according to cultivar-specific characteristics.

2. MATERIALS AND METHODS

2.1 Study site and environmental conditions

The perimeter of the plot is open and not enclosed by a protective windbreak zone. The area is located at an altitude of 40–49 meters above sea level (coordinates of the location: 40°31'12.5"N 49°52'50.0"E). In the researched vineyard, the planting scheme of the vines is 3 m × 1.5 m. A total of 2,222 vines per hectare are planted and cultivated. The vines are 23–24 years old. The grapes were planted using non-grafted saplings. Since the soils of Azerbaijan's Absheron region, including the research area, are sandy, sandy-loam, and loamy, the dangerous phylloxera pest is not observed here, and this region is considered a phylloxera-free zone. Therefore, grafted saplings are not used in Absheron soils. The climate in the Absheron district is subtropical. Summers are dry and hot, while winters are relatively mild, often cloudy, with frequent rains and occasional snow. The average annual temperature ranges between 13.5 ℃ and 14.4 ℃, the sum of active temperatures is 4,192–4,461 ℃, the annual amount of total solar radiation is 130–135 kcal/cm², and annual precipitation ranges from 200 mm to 460 mm depending on weather conditions. January is the coldest month of the year, while the highest temperatures are recorded in July and August. The number of frost-free days is 308, and the number of sunny days is 220–230. The peninsula is exposed to strong winds. The increase in wind speed enhances transpiration in plants while intensifying evaporation, which leads to soil desiccation. The highest level of evaporation occurs in July–August, and the lowest in February. The soils of the peninsula are mainly gray sandy and clayey types, with saline gray-brown soils being the most widespread. The humus content in the soil is low, ranging from 0.86% to 1.6%. The soil pH in the research area is neutral at 7.6. Nitrogen accounts for 0.28–0.32%, phosphorus 0.14–0.19%, and potassium 2.8–3.2% in these soils. Precipitation during the research years was 235.4 mm (2023), 360.2 mm (2024), and 228.3 mm (2025), respectively. The electrical conductivity of the soil was at the level of EC 0.46 MS/cm, which falls within the normal range (0–4 MS/cm) and does not impede fertilizer absorption. Soil analysis results revealed that depending on the sampling location and depth, the $CaCO_3$ (calcium carbonate) content was 7.3–11.6% (normal range <10%), classifying it as moderately to highly calcareous soil.

2.2 Plant material and vineyard management

The vines are mainly grown on a vertical 3-wire trellis system and trained in a fan shape. In the vineyards, downy mildew (*Plasmopara viticola*) develops primarily when precipitation is high in late spring and early summer; however, because the weather subsequently becomes dry with low humidity, the disease cannot complete its cycle. Vineyards in this area suffer mostly from powdery mildew (*Erysiphe necator*), gray mold (*Botrytis cinerea*), and pests such as the European grapevine moth (*Lobesia botrana*), grape blister mite (*Colomerus vitis*), and mealybug (*Planococcus vitis*). Depending on the weather conditions of the year, spraying with insecticides and fungicides is carried out 5–7 times. Primary fertilization is applied as root feeding in November–December at a rate of 600–700 kg/ha of physical weight using complex fertilizers. During the growing season, foliar spray applications containing key macro- and microelements, amino acids, and other organic acids are carried out 4–6 times.

2.3 Experimental design and bud fruitfulness assessment

The varieties studied are grown using a fan-shaped vine formation, and winter pruning is carried out accordingly. Depending on the variety's specific traits, 3 to 5 perennial fruiting shoots of different lengths are left on the plant. The number of buds per vine ranged from 32.6 to 76.5 among the varieties studied. The number of fruiting shoots left on plants and bud load for each variety are listed in the table in the appendices. The study was conducted over three years (2023-2025), with five plants of each variety selected and studied annually.

The actual bud fruitfulness of the investigated grapevine cultivars was determined under field conditions. The evaluation was performed visually during the phenological stage corresponding to inflorescence development on the shoots. Fruitfulness assessments were carried out at the nodal positions along the canes based on the number of inflorescences formed on the green shoots originating from overwintering buds. For each cultivar, five vines were selected for evaluation. Along each fruiting cane, the number of inflorescences developing on shoots at each node was recorded. Mean values were first calculated for individual vines and subsequently averaged across the five evaluated vines.

The number of inflorescences per shoot (%) was expressed as a percentage. For this purpose, the average total number of inflorescences formed along the shoot was divided by the average total number of nodes and multiplied by 100 according to the following formula:

$$IF = (TNI / TNN) \times 100$$

where,

IF (%) – number of inflorescences per shoot (OIV153) (%),

TNI – total number of inflorescences per shoot,

TNN – total number of nodes.

2.4 Statistical analysis

When conducting statistical analysis, the average results of three years were used, with five vines of each variety annually. The nonparametric U-factor was used in mathematical and statistical analysis. The statistical significance level (p) was set at 0.05 and 0.001.

Hierarchical cluster analysis was performed to categorize the 63 studied grape cultivars based on their yield parameters along the shoot length, recording the number of inflorescences per bud (bud fertility) at 20 consecutive node positions for each cultivar. To eliminate scale-dependent variations, the data were standardized using the Z-score method before analysis. Inter-cultivar dissimilarity was calculated via Euclidean distance, and Ward's method was employed to construct the hierarchical dendrogram. All statistical analyses and dendrogram visualizations were conducted using RStudio.

3. RESULTS AND DISCUSSIONS

The fruitfulness capacity of buds located on one-year-old lignified grapevine canes varies considerably depending on numerous factors, including vineyard management practices during the previous growing season, cultivation techniques, climatic conditions, bud differentiation processes, the number of buds and shoots, vine architecture, pruning length, and the spatial positioning of canes during dormant tying operations. In addition to significantly influencing yield formation, bud fruitfulness also determines the appropriate pruning length to be applied during vineyard management, including short, medium, or long pruning systems. In the present study, the bud fruitfulness of local and introduced table and technical grapevine cultivars cultivated under Absheron conditions was evaluated from the basal toward the distal nodal positions along the fruiting canes and expressed as percentages. The investigated vines were trained in a 3–5 arm fan-shaped system consisting of 3 to 5 one-year-old lignified canes, while the fruiting canes were pruned to 20–24 buds. The study was conducted during the 2023–2025 growing seasons. During the investigation, 5 vines of each cultivar were included in the observations, and the fruitfulness status of buds along each fruiting cane, from the basal to the apical positions, was recorded. Based on these evaluations, average values were determined for each cultivar using observations obtained from five vines (Table 1). As shown in the table, bud fruitfulness varied considerably among the investigated grapevine cultivars. Our observations demonstrated that, in most grapevine cultivars, the first basal bud frequently remained dormant and failed to produce shoots.

Table 1. Fruitfulness coefficients of buds located on the fruiting canes (fruiting spurs) of the investigated grapevine cultivars

No.	Varieties	Number of Inflorescences per Shoot (%) or Bud Fruitfulness (%)				
		Basal Buds 1st to 3rd	Median Buds 4th to 6th	Apical Buds		
				7–10 Buds	11–15 Buds	16–20 Buds
	Wine grape					
1.	Ag Aldara	61.5**	79.4*	65.4**	40.0**	1.54**
2.	Arayatly Gara Uzum	53.5**	55.9	22.5**	7.8**	0.14
3.	Bayanshira	57.5**	78.7**	48.5	19.8	1.96
4.	Khindogny	38.0	64.3	40.4	21.1	3.78**
5.	Madrasa	39.4	43.0*	41.1	34.1**	3.22*
6.	Meleyi	8.6**	42.3*	37.3	18.2	4.62**
7.	Garagat	36.1	36.9**	32.9	11.3*	1.24
8.	Gara Lkeni	14.3**	57.1	42.8	20.0	0
9.	Gara uzum	41.7*	50.1	45.5	5.1**	0
10.	Sultanshira	26.2*	29.5**	22.6**	7.9**	0.88
11.	Kapaz	63.3**	57.5	47.6	27.2*	0
12.	Goy gol	17.0**	69.5	35.5	6.8**	0
13.	Genjevi	46.1*	46.0*	38.2*	21.0	4.64**
14.	Rkasiteli	37.7	49.2*	33.1*	13.1*	1.56
15.	Sykh gara	16.0**	21.2**	45.0	17.8	2.26
16.	Esheni	18.4**	49.2*	48.8	13.8*	0
17.	Kharji	41.8*	50.2*	41.3	35.2**	18.2**
18.	Khojavandi	14.8**	81.5**	62.5*	24.5	5.58**
19.	Zarani gorasy	22.9*	80.8**	56.5	12.8*	0
20.	Aliqote	17.1**	70.4**	43.8	16.6	1.6
21.	Chardonnay	36.7	72.7**	71.3**	20.8	0
22.	Pinot Noir	41.2*	78.3**	92.0**	8.5**	2.8
23.	Merlot	83.0**	99.2***	94.0**	25.8*	0.96
24.	Cabernet Sauvignon	74.8**	87.0**	75.4**	39.8**	8.68**
25.	Syrah	40.3	52.2*	20.3**	2.98**	0
	Mean	38.4	60.2	48.2	19.0	2.55
	Table grape					
26.	Ag huseyni	44.5**	44.5	26.1**	13.8	0
27.	Ag tayfi	48.5**	60.5*	31.2*	18.1	4.52**
28.	Ag Shany	27.0	34.0*	38.0	23.8*	0.54
29.	Sashla white	25.2	45.5	30.5*	10.8*	1.91
30.	Attica Seedless	32.7*	53.4	50.2*	8.0**	0
31.	Arna Grna	3.0**	50.3	20.7**	0.3**	2.38
32.	Bendi	41.2**	53.0	49.4	20.6	0
33.	Black Magic	38.8**	20.1**	25.0**	10.5*	3.66*
34.	Devechi Gyzyl Uzumu	34.2**	62.6*	34.0*	14.8	8.24**
35.	Dekabrskiy	15.2*	37.2*	69.1**	31.8**	0
36.	Doina	39.1**	60.8*	44.8	14.7	7.26**
37.	Mahmudu	0**	52.3	75.9**	49.7**	4.24*
38.	Marandi	42.1**	48.0	41.3	19.0	3.7*
39.	Moldova	24.3	37.4*	32.6*	17.3	4.4**
40.	Michele Palieri	33.3	88.7**	55.8*	27.8*	0.66
41.	Novrast	24.8	81.8**	58.2*	5.2**	2.3
42.	Chahrayi kishmish	23.8	35.1*	30.6*	22.7	2.28
43.	Gara kishmish	35.8*	53.8*	33.6*	13.0**	0
44.	Gara Kechimemesi	45.3**	36.4*	36.4	10.8**	0
45.	Gara khatyny	68.8**	49.9	37.1	14.6**	0
46.	Garabag Gyrmyzy Uzumu	4.8**	63.3*	40.0	8.9**	0

47.	Cardinal	0**	26.7**	54.0*	24.2*	0
48.	Kehraba	17.1*	45.3	42.2	8.6**	0
49.	Kechimemesi	17.8*	55.9*	61.8**	0**	1.88
50.	Crimson Seedless	13.5**	41.1	32.6*	24.7*	0
51.	Ichkimar	4.8**	6.3**	65.3**	47.8**	0
52.	Italia	28.5	28.5**	17.8**	0**	1.0
53.	Huseini	32.9*	43.7	33.5*	18.5	0
54.	Yumru kishmish	0.5**	22.1**	19.8**	0**	0.96
55.	Red Globe	13.7*	30.2*	32.8*	11.8	0
56.	Prima	3.5**	40.7	34.7	0.5**	3.9*
57.	Tabrizi	12.6**	38.6	40.0	18.1	4.5**
58.	Kishmish Sogdiana	38.1*	49.8	42.8	21.4*	1.66
59.	Superior Seedless	54.6**	49.0	47.5	26.3*	3.16**
60.	Sultanina	44.5**	42.6	30.6*	18.8	0
61.	Zeynabi	0.6**	31.1*	71.5**	6.5**	0
62.	Veles	9.5**	67.1**	36.3	2.0**	5.14**
63.	Agadayi	24.8	62.3**	33.9*	16.4	3.9**
	Mean	25.5	46.0	41.0	15.8	1.90

Note: *p < 0.05, **p < 0.001 (by Wilcoxon–Mann–Whitney test).

3.1 Bud fruitfulness of technical grape varieties

In the Ag Aldara cultivar, no cluster formation was observed in the first emerged bud, whereas fruitful buds were generally recorded between the 2nd and 16th nodal positions. The highest percentages among 1th-11th buds were observed in Merlot cultivar buds 5th and 6th reaching 99.2% and 99.6%, respectively. In the 15th–16th buds, cluster occurrence decreased considerably, averaging 7.7–15.4%, which was lower than the remaining nodal positions. No cluster development was observed in the 17th–20th buds. In the Aliqote cultivar, fruitful buds were recorded between the 2nd and 17th nodal positions (Table A1 and A2). In the Arayatly Gara Uzum cultivar, clusters were recorded in both the 1st and 17th buds. The highest fruitfulness was observed in the 3rd–5th buds, ranging between 68.8% and 82.4%. However, bud fruitfulness gradually decreased toward the distal portion of the shoot. No fruitfulness was observed in the 16th bud, whereas the 17th bud exhibited the lowest value (0.7%). In the Bayanshira and Khindogny cultivars, cluster development was observed in all buds along the shoots. In Bayanshira, bud fruitfulness ranged from 0.3% in the 20th bud to 80.9% in the 5th bud. Similarly, in Khindogny, fruitfulness values varied between 2.2% in the 20th bud and 75.6% in the 6th bud. In both cultivars, the highest fruitfulness was concentrated between the 2nd and 7th buds. In the Madrasa cultivar, fruitful buds were recorded between the 1st and 18th nodal positions. The highest fruitfulness values were observed in the 5th bud (53.6%) and the 11th bud (56.8%). In the Meleyi cultivar, bud fruitfulness was predominantly concentrated in the median portion of the shoot. The highest value was recorded in the 7th bud (65.3%). In addition, fruitfulness levels of 50.6% were observed in the 4th and 6th buds. No cluster formation was detected in the 1st bud. Toward the upper portion of the shoot, bud fruitfulness gradually decreased, reaching 11.0–10.6% in the 15th–17th buds, whereas no cluster development was observed in the 18th–20th buds. In the Garagat grapevine cultivar, bud fruitfulness was distributed unevenly along the shoot. Fruitfulness values of 39.7%, 50.0%, and 35.7% were recorded in the 3rd, 6th, and 8th buds, respectively. After the 11th bud, fruitfulness declined sharply, and no clusters were observed in the 17th–20th buds. In the Gara Lkeni cultivar, fruitful buds were mainly concentrated between the 4th and 12th nodal positions. The highest fruitfulness was observed in the 4th bud (71.4%). In addition, fruitfulness values of 57.1% were recorded in both the 5th and 9th buds. Although cluster formation occurred in the first bud, no cluster development was observed in the second bud. In the upper portion of the shoot, fruitfulness decreased to zero after the 13th bud. In the Gara uzum cultivar, the fruit-bearing zone was concentrated between the 2nd and 8th buds. Fruitfulness values of 58.5% and 58.3% were recorded in the 2nd and 6th buds, respectively. Toward the distal portion of the shoot, bud fruitfulness declined progressively, and no clusters were observed in the 16th–20th buds following the 15th nodal position. In the Sultanshira cultivar, bud fruitfulness remained relatively low and stable throughout the shoot, with the maximum value (29.5%) recorded between the 3rd and 6th buds. In addition, fruitfulness levels of 11.8% were observed in the 10th–13th buds. In the upper part of the shoot, cluster formation was almost completely absent after the 14th bud. In the Kapaz cultivar, high bud fruitfulness was observed beginning from the basal buds. Fruitfulness values reached 90.0% in the 2nd bud and 81.8% in the 3rd bud. Moreover, the 5th and 6th buds exhibited fruitfulness levels of 63.6% and 72.7%, respectively. No clusters were observed in the 16th–20th buds located at the distal end of the shoot. In the Goy gol cultivar, the principal fruit-bearing zone was concentrated between the 5th and 7th buds. High fruitfulness values were recorded in the 5th bud (86.6%), 6th bud (86.2%), and 7th bud (66.4%). In the distal portion of the shoot, no cluster development was observed after the 15th bud. In the Genjevi cultivar, bud fruitfulness was distributed relatively uniformly along the shoot. Although the highest value was recorded in the 3rd bud (51.9%), the neighboring 2nd, 4th, 5th, 6th, 7th, and 8th buds exhibited comparable fruitfulness levels ranging between 40.8% and 48.1%. After the 15th bud, fruitfulness gradually declined to 2.8–7.2%, while the 20th bud exhibited the lowest value (0.5%). In the Rkasiteli cultivar, productive buds were mainly concentrated between the 2nd and 7th nodal positions, with the highest fruitfulness (51.8%) recorded in the 3rd and 4th buds. After the 10th bud, fruitfulness gradually decreased, reaching only 0.8–0.3% in the 18th–20th buds. In the Sykh gara cultivar, bud fruitfulness displayed an irregular distribution pattern. The maximum value (90.3%) was recorded in the 7th bud. Fruitfulness values of 25.6% were observed in the 3rd and 4th buds, while the 6th bud exhibited 26.6% fruitfulness. However, no clusters were observed in the 17th–20th buds. In the Esheni cultivar, bud fruitfulness was mainly concentrated between the 3rd and 8th buds, with the highest value (56.5%) observed in the 7th bud. In addition, the 3rd, 4th, and 6th buds exhibited fruitfulness values of 52.1%. Toward the distal portion of the shoot, no cluster development was observed after the 15th bud. In the Kharji cultivar, bud fruitfulness varied considerably along the shoot. High fruitfulness values of 60.7% and 56.2% were recorded in the 5th and 2nd buds, respectively, while the maximum value (65.9%) was observed in the 11th bud. Unlike the majority of the investigated cultivars, cluster development continued in the distal portion of the shoot, with the 16th–20th buds maintaining fruitfulness levels between 16.5% and 21.0%. In the Khojavandi cultivar, the principal fruit-bearing zone was concentrated between the 4th and 8th buds, with the highest fruitfulness value (94.4%) recorded in the 5th bud. Fruitfulness values of 77.8% were additionally observed in the 6th and 7th buds. In the Zarani gorasy cultivar, high bud fruitfulness was observed between the 4th and 7th buds. Fruitfulness values reached 86.0% in the 5th bud, 80.6% in the 4th bud, and 80.2% in the 7th bud. In the distal portion of the shoot, no cluster development was observed after the 15th bud.

In the Chardonnay cultivar, fruitful buds were recorded between the 2nd and 15th nodal positions. The highest fruitfulness was observed in the 6th bud (76.4%), whereas the lowest value (3.4%) was recorded in the 15th bud. In contrast to Chardonnay, the Pinot Noir cultivar exhibited cluster formation between the 1st and 17th nodes. The highest fruitfulness values were observed in the 6th–9th buds, ranging between 95.6% and 98.6%. The lowest values were recorded in the 17th–20th buds (Table A1 and A2). In the Merlot and Cabernet Sauvignon cultivars, inflorescence development was observed in all investigated buds along the shoots (1st–20th buds). In the Merlot cultivar, remarkably high fruitfulness was recorded between the 2nd and 11th nodes, whereas fruitfulness declined substantially in the 12th–20th buds, ranging between 0.3% and 24.2%. Similarly, in the Cabernet Sauvignon cultivar, high fruitfulness values ranging from 72.4% to 98.4% were recorded in the 2nd–12th buds. Beginning from the 13th bud, fruitfulness decreased considerably and fluctuated between 1.6% and 34.6%. In the Syrah cultivar, productive buds were mainly concentrated in the basal and median portions of the shoots and were observed between the 1st and 14th buds. The highest fruitfulness values, ranging from 87.6% to 94.2%, were recorded between the 3rd and 9th buds. In the distal portion of the shoot, no cluster formation was observed after the 15th bud. Meneguzzi et al. [16], while evaluating the fruitfulness of basal, median, and apical buds in several grapevine cultivars originating from France, Italy, and Spain and cultivated in the Santa Catarina region of Brazil, reported that bud fruitfulness in the Chardonnay cultivar reached 49.0% in basal buds, 54.0% in median buds, and 65.0% in apical buds. In Pinot Noir, the corresponding values were 47.0%, 75.0%, and 75.0%, respectively; in Syrah, 45.0%, 70.0%, and 70.0%; in Merlot, 84.0%, 99.0%, and 97.0%; and in Cabernet Sauvignon, 71.0%, 86.0%, and 50.0%, respectively. Dikan [32], while investigating the relationship between the productivity of primary buds in the Syrah cultivar and both shoot characteristics and pruning length under the foothill conditions of Crimea, determined that the fruitfulness coefficient of primary buds with well-differentiated inflorescence primordia averaged 1.41 up to the 15th node. Along the shoot, the fruitfulness coefficient increased to 1.75 at the 8th node, while the highest values were observed at the 14th–15th nodes. When pruning length increased from 3 to 12 buds, the fruitfulness coefficient varied between 0.90 and 1.18. The highest yield was obtained under the pruning treatment with 9 buds, reaching 176.0 c/ha. In contrast, substantially lower productivity (138.7 c/ha) was observed under short pruning (3 buds), whereas a decline in productivity was again recorded under longer pruning treatments (12–18 buds). Gutiérrez-Gamboa et al. [28], in a study conducted in two different regions of the Maule Valley in Chile, investigated the effects of bud number, shoot length, and the shoot leaf-to-cluster ratio on the yield and quality characteristics of Cabernet Sauvignon and Syrah grapevine cultivars. The authors determined that shoot pruning length and bud number exhibited positive correlations with both leaf area and grapevine productivity.

3.2 Bud fruitfulness of table grape varieties

Observations conducted on table grape cultivars demonstrated that bud fruitfulness varied considerably depending on the cultivar. In the Agadayi cultivar, bud fruitfulness was mainly concentrated in the basal and median portions of the shoot, with the highest value (54.8%) recorded in the 3rd bud. In addition, fruitfulness levels of 51.6% and 40.5% were observed in the 4th and 2nd buds, respectively. Toward the distal portion of the shoot, fruitfulness declined after the 15th bud and varied between 0.6% and 3.3%. In the Ag huseyni cultivar, the fruit-bearing zone was concentrated between the 2nd and 6th buds, with the highest fruitfulness value (81.8%) observed in the 3rd bud. Fruitfulness values of 72.7% were additionally recorded in the 5th bud, while the 2nd, 4th, and 6th buds each exhibited 54.5% fruitfulness. No cluster development was observed after the 16th bud. In the Ag tayfi cultivar, bud fruitfulness was distributed relatively uniformly along the shoot. Although the highest value (46.0%) was recorded in the 8th bud, cluster formation of 43.0% and 41.0% was also observed in the 3rd and 7th buds, respectively. In the distal portion of the shoot, fruitfulness in the 18th–20th buds ranged between 3.0% and 5.2%. In the Ag Shany cultivar, productive buds were mainly concentrated between the 4th and 7th nodal positions, with the highest value (50.1%) observed in the 7th bud. Fruitfulness values of 48.0% and 46.8% were additionally recorded in the 6th and 4th buds, respectively. Toward the upper portion of the shoot, cluster formation was almost absent after the 14th bud. In the Attıca Seedless cultivar, the basal buds (1st–3rd buds) were not fruitful. The highest fruitfulness value (69.67%) was observed in the 5th bud. In addition, the 6th and 4th buds exhibited fruitfulness values of 46.67% and 34.6%, respectively. In the upper portion of the shoot, no cluster development was observed after the 13th bud.

İn our study, the principal fruit-bearing zone in the Black Magic cultivar was concentrated between the 3rd and 6th buds, with the highest fruitfulness value (83.6%) recorded in the 5th bud. In addition, fruitfulness values of 65.9% and 46.2% were observed in the 6th and 3rd buds, respectively. After the 15th bud, fruitfulness declined substantially, reaching 2.6% in the 20th bud. According to Ferrara and Mazzeo, the Black Magic cultivar exhibited the highest bud fruitfulness (94%) and the highest actual productivity (2.36 inflorescences per bud). In the Black Magic cultivar, the potential productivity of buds was comparatively high. Bud dissection analyses demonstrated that the number of inflorescence primordia within the buds was substantial, while the highest fruitfulness was mainly concentrated in the median bud positions. In the Mahmudu cultivar, bud fruitfulness remained relatively stable along the shoot. The highest value (52.7%) was recorded in the 3rd bud, while fruitfulness levels in the 4th–8th buds ranged between 42.7% and 51.8%. In the upper portion of the shoot, fruitfulness values in the 16th–20th buds varied between 1.5% and 9.1%. In the Marandi cultivar, bud fruitfulness was mainly concentrated between the 4th and 7th buds. Fruitfulness values in the 5th, 6th, and 7th buds ranged between 36.2% and 38.5%. Toward the distal portion of the shoot, fruitfulness declined sharply after the 15th bud, reaching only 1.5% in the 20th bud. In the Moldova cultivar, the fruit-bearing zone was mainly concentrated between the 4th and 7th buds, with the highest fruitfulness value (92.6%) recorded in the 7th bud. In addition, the 5th and 6th buds exhibited remarkably high fruitfulness values of 92.0% and 91.4%, respectively. Toward the distal portion of the shoot, fruitfulness gradually declined after the 15th bud and reached only 0.1% in the 19th–20th buds.

In the Michele Palieri cultivar, bud fruitfulness was also distributed unevenly along the shoot, with the highest value (88.4%) recorded in the 5th bud. In addition, the 6th and 7th buds exhibited high fruitfulness values ranging between 82.6% and 82.4%. No cluster development was observed in the 11th–13th buds, while fruitfulness declined to zero after the 16th bud. In the Michele Palieri cultivar, the proportion of actually fruitful buds was evaluated at 83.9%, indicating a comparatively high level of bud fruitfulness. The authors reported that bud fruitfulness was distributed unevenly along the shoot, with the principal fruit-bearing zone located in the median portion of the cane. Fruitfulness was lower in the basal buds and higher in the median nodal positions. In this cultivar, a general correspondence between potential and actual fruitfulness was observed [14].

In the Novrast cultivar, the highest bud fruitfulness (45.5%) was recorded in the 4th bud. In addition, fruitfulness values of 32.5% were observed in the 3rd and 9th buds, while the 6th bud exhibited 25.8% fruitfulness. In the upper portion of the shoot, fruitfulness values in the 17th–20th buds were considerably lower, ranging between 0.4% and 5.0%. In the Chahrayi kishmish cultivar, the fruit-bearing zone was concentrated between the 2nd and 7th buds, with the highest fruitfulness value (57.7%) observed in the 6th bud. Furthermore, the 4th and 5th buds exhibited comparatively high fruitfulness values of 53.8% and 50.0%, respectively. No cluster formation was observed in the 16th bud, while fruitfulness values in the 17th–20th buds ranged between 0% and 3.8%. In the Gara kishmish cultivar, bud fruitfulness was mainly observed between the 1st and 13th buds, with the highest value (72.2%) recorded in the 3rd bud. In addition, the 2nd and 4th buds each exhibited 45.5% fruitfulness. In the upper portion of the shoot, no cluster development was observed after the 14th bud. In the Gara Kechimemesi cultivar, bud fruitfulness was mainly concentrated in the basal and median portions of the shoot. A high fruitfulness value of 77.5% was recorded in the 1st bud. In addition, fruitfulness values of 71.6% and 57.5% were observed in the 3rd, 2nd, and 5th buds, respectively, while the 11th bud exhibited 49.2% fruitfulness. In the upper portion of the shoot, no cluster development was observed after the 13th bud. In the Gara khatyny cultivar, the fruit-bearing zone was mainly concentrated between the 4th and 7th buds, with the highest fruitfulness value (88.6%) recorded in the 7th bud. In addition, the 6th and 5th buds exhibited comparatively high fruitfulness values of 84.3% and 62.6%, respectively. No cluster formation was observed after the 14th bud. In the Garabag Gyrmyzy Uzumu cultivar, bud fruitfulness was mainly concentrated between the 7th and 10th buds. The highest values were recorded in the 9th and 10th buds, reaching 58.7% and 58.6%, respectively. In addition, the 7th and 8th buds exhibited fruitfulness values ranging between 48.2% and 50.6%. In the upper portion of the shoot, no cluster development was observed after the 16th bud. In the Cardinal cultivar, productive buds were concentrated between the 4th and 10th nodal positions. The highest fruitfulness value (60.4%) was recorded in the 5th bud. In addition, fruitfulness values of 47.1% and 50.0% were observed in the 9th and 10th buds, respectively. In the upper portion of the shoot, no cluster formation was observed after the 13th bud. In the Kehraba cultivar, bud fruitfulness was mainly concentrated between the 5th and 9th buds. The highest value (86.8%) was recorded in the 7th bud, while the 6th and 8th buds exhibited fruitfulness values of 78.6% and 56.4%, respectively. In the distal portion of the shoot, no cluster development was observed after the 11th bud. In the Kechimemesi cultivar, the fruit-bearing zone was mainly concentrated between the 4th and 7th buds. The highest fruitfulness value (60.0%) was recorded in the 7th bud. In addition, the 6th bud exhibited 42.6% fruitfulness, while the 4th and 5th buds each showed 40.6% fruitfulness. In the upper portion of the shoot, no cluster formation was observed after the 17th bud.

In our investigations, the Crimson Seedless cultivar exhibited an uneven distribution of bud fruitfulness along the shoot. The highest fruitfulness values were recorded in the 8th (88.6%), 9th (88.4%), 10th (76.6%), and 11th (88.2%) buds. Toward the distal portion of the shoot, no cluster development was observed after the 14th bud. Ferrara and Mazzeo [14] evaluated bud fruitfulness in the Crimson Seedless cultivar as moderate. The authors noted that a proportion of the buds in this cultivar may remain unfruitful. Nevertheless, higher fruitfulness was observed in the median bud positions, while overall productivity exhibited a relatively stable pattern.

In the Ichkimar cultivar, productive buds were mainly concentrated between the 3rd and 7th nodal positions, with the highest fruitfulness value (71.4%) recorded in the 3rd bud. In addition, fruitfulness values of 28.5% were observed in the 4th–6th buds, while the 7th bud exhibited 42.8% fruitfulness. Toward the distal portion of the shoot, no cluster formation was observed after the 10th bud.

In the Italia cultivar, bud fruitfulness along the fruiting canes displayed a relatively stable distribution between the 1st and 8th buds. The highest fruitfulness value (47.5%) was recorded in the 5th bud. In addition, fruitfulness values of 38.7% and 45.0% were observed in the 3rd–4th buds and the 6th bud, respectively. In the upper portion of the shoot, no cluster development was observed after the 16th bud. Ferrara and Mazzeo [14], while evaluating potential and actual fruitfulness in the Italia cultivar, reported that the percentage of potentially fruitful buds was extremely high (95.5%), whereas fruitfulness values throughout the shoot exceeded 1.0. The bud fruitfulness coefficient, expressed as the number of clusters per bud, was comparatively high in the Italia cultivar. Buds located in the median portion of the shoot exhibited higher productivity, whereas comparatively lower values were recorded in the basal positions. In general, a close correspondence between potential and actual fruitfulness was observed.

In the Huseini cultivar, the fruit-bearing zone was mainly concentrated between the 5th and 7th buds, with the highest fruitfulness value (76.7%) recorded in the 7th bud. In addition, fruitfulness values of 36.7% and 26.7% were observed in the 6th and 5th buds, respectively. In the upper portion of the shoot, cluster formation was almost absent after the 8th bud. In the Yumru kishmish cultivar, bud fruitfulness was predominantly concentrated in the median portion of the shoot. The highest value (66.6%) was recorded in the 8th bud. In addition, fruitfulness values of 39.4% and 34.9% were observed in the 6th and 9th buds, respectively. Toward the distal portion of the shoot, fruitfulness declined sharply after the 15th bud, and no fruitfulness was recorded in the 20th bud.

In the Red Globe cultivar, the fruit-bearing zone was concentrated between the 5th and 7th buds. The highest fruitfulness value (72.6%) was recorded in the 6th bud. In addition, the 7th and 5th buds exhibited fruitfulness values of 68.4% and 34.8%, respectively. Toward the distal portion of the shoot, fruitfulness declined after the 10th bud, and no cluster development was observed after the 13th bud. Odabaşoğlu [1] reported that, in the Red Globe cultivar cultivated under the ecological conditions of Adıyaman, Türkiye, the bud fruitfulness coefficient along the fruiting cane varied considerably from the basal to the distal positions. The corresponding values were 0.33% in the 1st bud, 1.0% in the 2nd bud, 8.67% in the 3rd bud, 35.67% in the 4th bud, 67.67% in the 5th bud, 35.67% in the 6th bud, 6.67% in the 7th bud, 1.67% in the 8th bud, and 1.0% in the 9th bud, whereas the 10th bud remained unfruitful. In contrast, under Absheron conditions, the highest bud fruitfulness in the Red Globe cultivar was observed in the 6th and 7th buds, averaging 68.4–72.6%, whereas under the ecological conditions of Adıyaman, Türkiye, the highest value (67.67%) was recorded in the 5th bud. In comparative evaluations of the Red Globe cultivar, Ferrara and Mazzeo [14] reported that the percentage of actually fruitful buds reached 76.4%, whereas potential fruitfulness was estimated at 81.0%. The fruit-bearing zone was mainly concentrated in the median portion of the shoot. In addition, the occurrence of blind buds (5.5%) was observed in the basal nodal positions of the shoots. In the Prima cultivar, bud fruitfulness was mainly concentrated between the 6th and 8th buds. The highest value (50.2%) was recorded in the 8th bud, while fruitfulness values of 43.7% and 40.8% were observed in the 6th and 7th buds, respectively. In the upper portion of the shoot, fruitfulness declined after the 15th bud, and no clusters were recorded in the 20th bud.

In the Təbrizi cultivar, bud fruitfulness remained relatively stable along the shoot. The highest fruitfulness value (53.1%) was observed in the 4th bud. In addition, fruitfulness values ranging between 48.7% and 49.8% were recorded in the 3rd and 6th buds. Toward the distal portion of the shoot, fruitfulness declined after the 15th bud and reached only 0.9% in the 20th bud. In the Kishmish Sogdiana cultivar, the fruit-bearing zone was mainly concentrated between the 2nd and 9th buds. The highest fruitfulness values were recorded in the 2nd (63.8%), 3rd (69.4%), and 9th (58.3%) buds. In the upper portion of the shoot, no cluster development was observed after the 16th bud. In the Superior Seedless cultivar, bud fruitfulness was higher in the 3rd–4th buds, ranging between 55.6% and 66.7%. In addition, comparatively high fruitfulness values of 50.0% were recorded in the 7th and 8th buds. No cluster development was observed after the 18th bud.

In the Sultanina cultivar, the fruit-bearing zone was mainly concentrated between the 6th and 8th buds. The highest fruitfulness values were recorded in the 6th (78.8%), 7th (92.4%), and 8th (96.4%) buds. No cluster formation was observed after the 12th bud. Ferrara and Mazzeo [14] reported that bud fruitfulness in the Sultanina cultivar was mainly concentrated in the median portion of the shoot. According to bud dissection analyses, the number of inflorescence primordia in this cultivar was moderate. Since the fruitfulness of basal buds was relatively low, the authors suggested that long pruning systems are more suitable for this cultivar. Certain differences between potential and actual fruitfulness were also observed.

In the Zeynabi cultivar, bud fruitfulness was mainly concentrated between the 3rd and 8th buds. The 4th bud exhibited the highest value (86.6%), while the 5th and 6th buds showed fruitfulness levels of 58.2% and 56.4%, respectively. Toward the distal portion of the shoot, no cluster formation was observed after the 16th bud. In the Veles cultivar, productive buds were mainly concentrated between the 4th and 6th nodal positions. Fruitfulness values of 52.5%, 62.5%, and 71.9% were recorded in the 4th, 5th, and 6th buds, respectively. In the upper portion of the shoot, fruitfulness values in the 17th–20th buds ranged between 1.9% and 5.4%. The generalization of the obtained results demonstrated that both technical and table grape cultivars exhibit significant differences in maximum bud fruitfulness levels and in the localization of fruit-bearing zones along the shoots. In technical cultivars, the fruit-bearing zone was mainly concentrated between the 2nd and 7th buds, and in certain cultivars, fruitfulness exceeded 99%. In table grape cultivars, however, the fruit-bearing zone was generally concentrated in the median portion of the shoots, particularly between the 4th and 8th buds, where the highest fruitfulness values were recorded. In some cultivars, the relatively low productivity of basal buds resulted in the displacement of the fruit-bearing zone toward the median nodal positions.

3.3 Comparative analysis of wine and table grape varieties

As shown in the figure, technical grape cultivars consistently exhibited considerably higher fruitfulness in the 1st–7th buds compared with table grape cultivars. In table grape cultivars, comparatively higher fruitfulness was more frequently observed in the 8th–9th buds. This phenomenon is associated with the biological characteristics of table grape cultivars. The average fruitfulness values of buds along fruiting shoots (buds 1 through 20) in table and wine grape varieties were compared using the U-factor. It was found that the values for buds 1 through 5 were statistically significant at the $p < 0.05$ level. The difference for buds 6 through 20 on the fruiting shoots of the studied grape varieties was not significant ($p > 0.05$) (Figure 1).

During the study, buds were classified into basal, median, and apical groups, and average values were calculated for each category. In technical grape cultivars, bud fruitfulness in the basal portion varied from 8.6% in the Meleyi cultivar to 83.0% in Merlot. In the median portion, fruitfulness ranged from 21.2% in Sykh Gara to 99.2% in Merlot. In the apical portion, fruitfulness values in the 7th–10th buds varied between 22.5% in Arayatly Gara Uzum and 94.0% in Merlot, whereas in the 11th–15th buds the corresponding values ranged from 5.1% in Gara Uzum to 39.8% in Cabernet Sauvignon.

Similarly, substantial differences were observed among basal, median, and apical buds in table grape cultivars. In the Mahmudu, Zeynabi, Prima, Yumru kishmish, İchkimar, Cardinal, Garabag Gyrmyzy Uzumu, Arna-grna, Meleyi, and Veles cultivars, fruitfulness in the basal buds was extremely low, varying between 0% and 9.5%, and was markedly lower compared with the remaining cultivars.

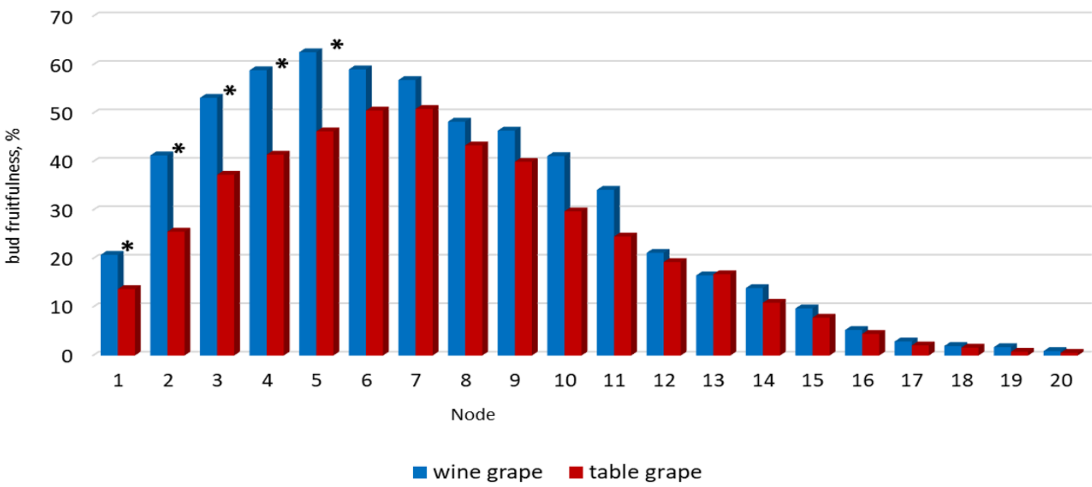
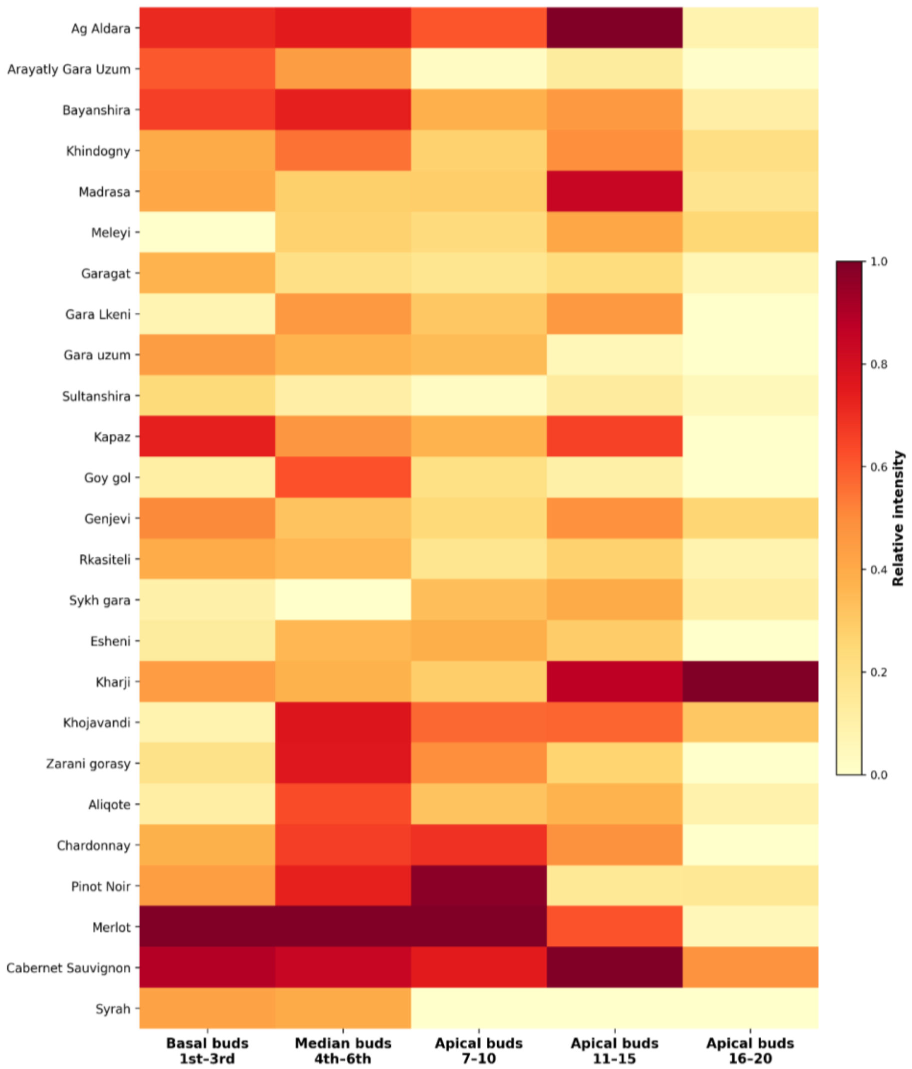


Figure 1. Bud fruitfulness characteristics of buds along the fruiting canes of wine and table grape cultivars
Note: *Level of statistical significance at $p < 0.05$.



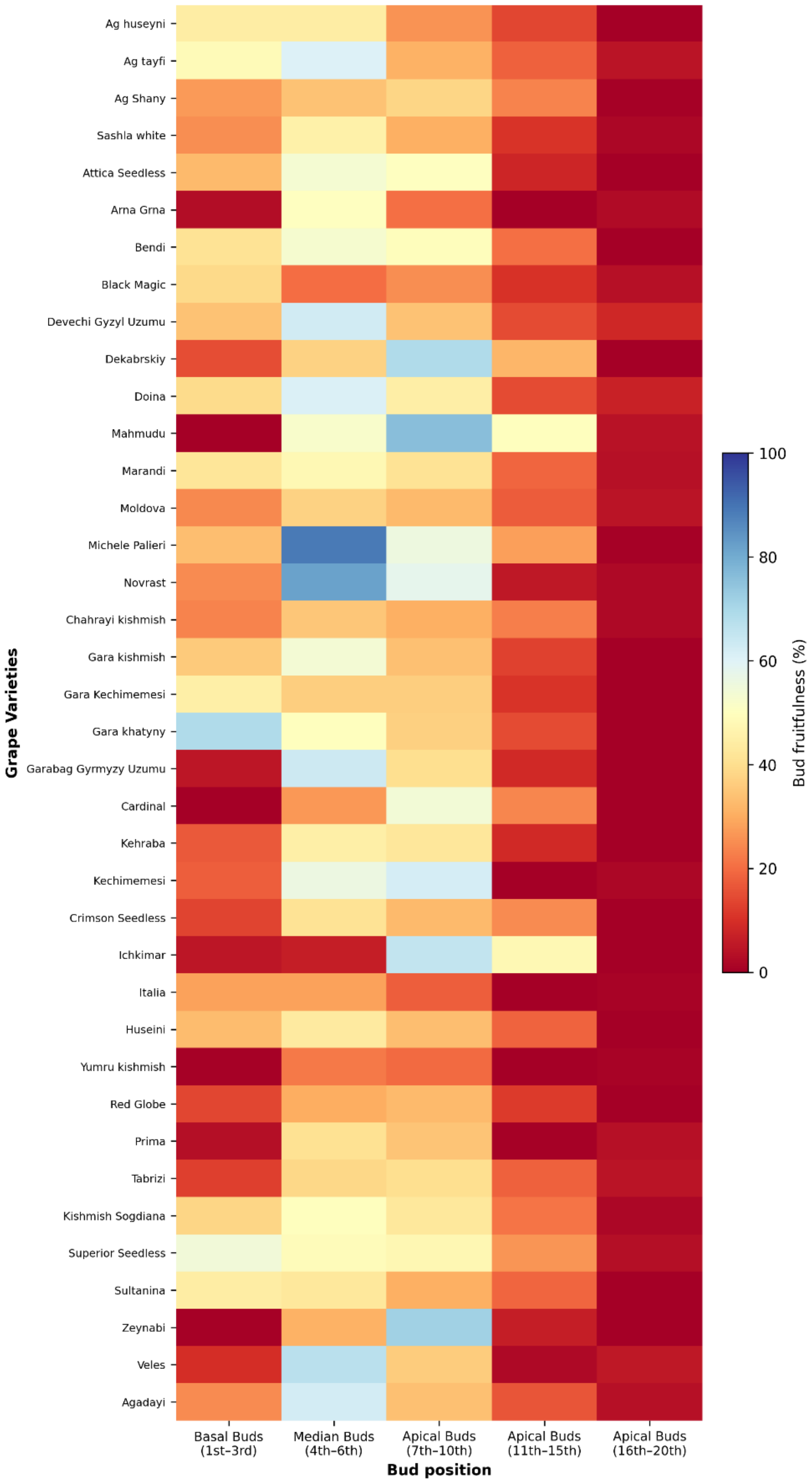


Figure 2. Bud fruitfulness distribution along the shoots of the investigated grape varieties (basal, median, and apical portions)

Fruitfulness of the table grapes' median buds also varied within a broad range, from 6.3% in İchkimar to 88.7% in Michele Palieri. In the apical portion, fruitfulness values in the 6th–10th buds ranged between 17.8% in Italia and 75.9% in Mahmudu, whereas fruitfulness in the 11th–15th buds varied from 0.3% in Arna-grna to 47.9% in Mahmudu. In the Kechimemesi, Italia, and Yumru kishmish cultivars, no cluster formation was observed in the terminal 11th–15th buds.

The investigations further revealed that, in addition to the general differences between table and technical grape varieties, each variety exhibited distinct bud fruitfulness characteristics. In most cases, the varieties did not replicate one another with respect to this parameter. Thus, no cluster formation was observed in the first basal bud in seven technical grape varieties and in fifteen table grape varieties. In both technical and table grape varieties, the principal fruiting zone was mainly concentrated between the 4th and 10th buds along the shoots (Figure 2).

The average fruitfulness values of basal, median, and apical buds were determined separately for technical and table grape varieties and comparatively evaluated. The results demonstrated that, on average, the fruitfulness of basal, median, and apical buds in technical grape varieties was higher than that observed in table grape varieties (Figure 3).

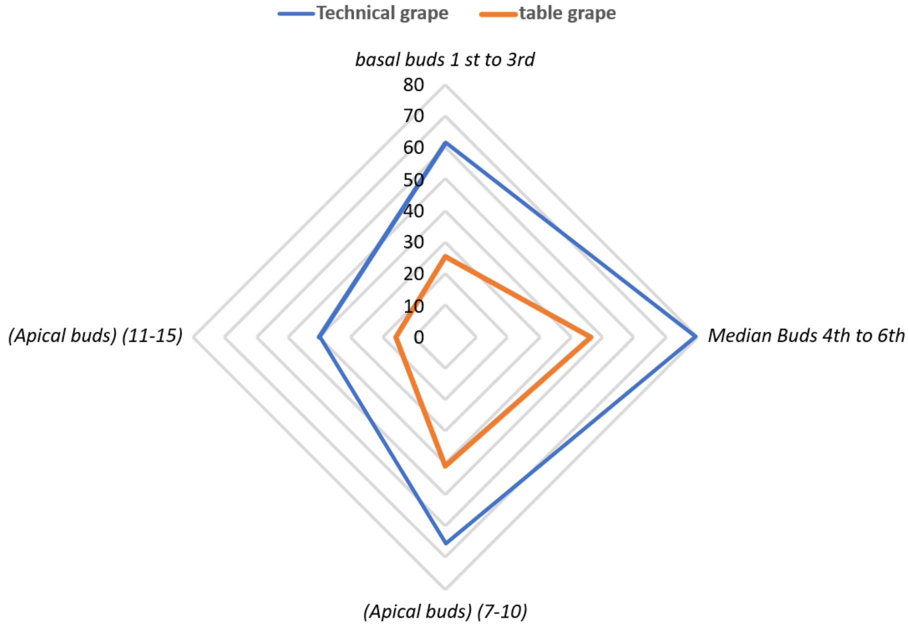


Figure 3. Comparative bud fruitfulness of basal, median, and apical buds in the investigated table and technical grape varieties

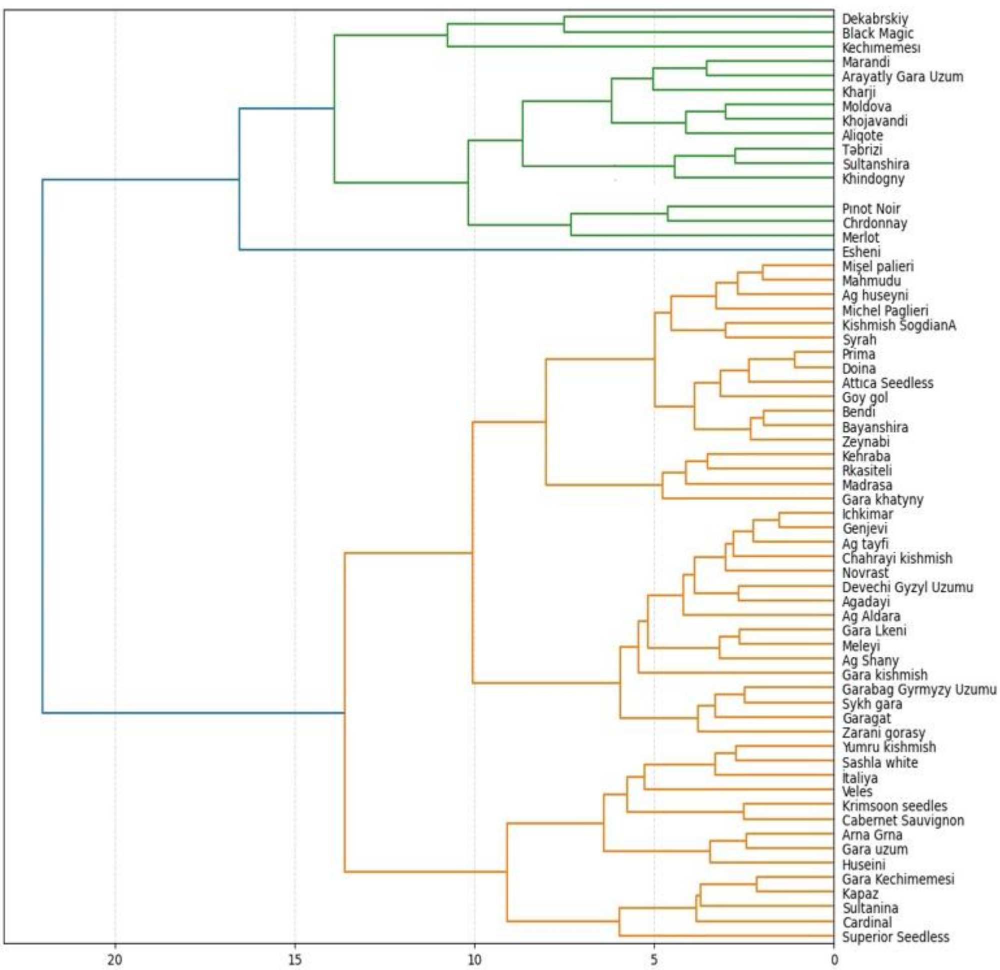


Figure 4. Grouping of grape varieties according to the fruitfulness characteristics of basal, median, and apical buds across 20 bud positions along the fruiting canes

3.4 Cluster analysis and grouping of varieties

Cluster analysis of the bud fruitfulness coefficients (%) of the fruiting canes in 63 investigated grape genotypes was performed using Ward's method, and the resulting dendrogram was constructed to distinguish genotypes with similar and contrasting characteristics was divided into two major groups. The first group, which contained 47 grape varieties, represented the largest cluster of genotypes. Based on the similarity of the investigated trait, this group was further divided into two major clusters consisting of 14 and 33 varieties, respectively (Figure 4).

Within the first cluster, five varieties localized in the initial subcluster exhibited high similarity according to the average values of bud fruitfulness; however, Superior Seedless was distinguished by a lower number of unfruitful shoots and therefore formed a separate sister subcluster. Among the nine genotypes included in the second subcluster, three varieties (Arna Grna, Gara Uzum, and Huseini) were positioned relatively close to one another and were characterized by low to moderate fruitfulness values. Nevertheless, the Huseini variety differed from the remaining two genotypes by having a greater number of buds with a fruitfulness coefficient equal to zero, which resulted in its placement within a separate sister cluster.

As shown in the dendrogram, the second cluster was also divided into two major subclusters containing 16 and 17 grape varieties, respectively. Among the four varieties included in the first subcluster (Garabag Gyrmyzy Uzumu, Syrah, Garagat, and Zarani gorasy), Zarani gorasy was distinguished by the occurrence of unfruitful buds in the first nodal positions and by higher fruitfulness percentages in several buds, resulting in its separation into an individual sister cluster. Within the second subcluster, which contained 13 genotypes, the Gara kishmish variety was particularly distinguished. Among these varieties, the highest bud fruitfulness coefficient after Ag Aldara was recorded in Gara kishmish. In addition, compared with the remaining varieties of the same subcluster, a larger number of buds with zero fruitfulness values were observed in this genotype. The Kahraba, Rkasiteli, Madrasa, and Gara khatyny varieties formed a separate sister cluster due to their comparatively higher similarity relative to the remaining genotypes within the same subcluster. Among these, Gara khatyny was distinguished by the absence of fruitfulness in the first two buds and by exhibiting the highest fruitfulness percentages among the fruiting canes within the same cluster. As demonstrated by the analysis, the second major group of the dendrogram consisted of 16 genotypes. Among them, the Esheni variety differed considerably from the remaining varieties in this group by exhibiting comparatively moderate average values for the investigated trait. In addition, the larger number of buds with fruitfulness coefficients equal to zero caused this variety to form a separate cluster. The second cluster, consisting of 15 grape genotypes, was further divided into two subclusters containing 3 and 12 varieties, respectively. The sister clusters included within the first subcluster combined 3 and 9 varieties, among which Pinot Noir, Chardonnay, and Merlot were clearly distinguished by exhibiting the highest bud fruitfulness coefficients. In the second subcluster, formed by the Kechimemesi, Black Magic, and Dekabrskiy varieties, certain buds of the fruiting canes displayed relatively high fruitfulness; however, the overall bud fruitfulness coefficients were characterized by moderate and low values, resulting in the formation of a separate grouping.

The final evaluation of the cluster analysis demonstrated that the varieties included in the first major group of the dendrogram possessed a considerable number of unfruitful buds. In particular, three genotypes (Huseini, Sultanina, and Kehraba) ranked first according to the number of unfruitful buds. However, based on the average values of the investigated trait, the highest fruitfulness percentages were observed in the Merlot and Pinot Noir varieties located in the second major group of the dendrogram.

3.5 Practical implications for pruning

Based on the applied cluster analysis, it was determined that the various grape cultivars were differentiated into two main groups, not only according to their botanical characteristics but also based on the spatial distribution of productive zones along the shoot. The first group comprises wine (technical) cultivars and several native cultivars characterized by high bud fertility in both basal (nodes 1–5) and mid-shoot (nodes 6–12) positions. The low incidence of barren (unproductive) nodes in these cultivars allows for the application of short to medium pruning (8–12 nodes). Conversely, cultivars in the second group of the dendrogram exhibited low basal bud fertility and a higher proportion of barren nodes. Since productivity was primarily concentrated in the mid-shoot nodes (nodes 6–12), long pruning (12–14 or more nodes) is considered essential for the cultivars in this group.

4. CONCLUSIONS

Technical grape varieties exhibited a distinct distribution pattern of bud fruitfulness compared with table grape varieties and, in certain cases, demonstrated greater stability. In technical varieties, the fruiting zone was distributed across a broader nodal interval. Therefore, during dormant pruning, short pruning (up to 4–5 buds), medium pruning (6–8 buds), and long pruning (more than 9 buds) may be considered appropriate depending on varietal characteristics. In table grape varieties, the comparatively lower fruitfulness of basal buds requires the application of medium and long pruning systems. Bud fruitfulness represents not only an important indicator of agrobiological characteristics, but also a key factor in the formation of productivity structure. This parameter has substantial practical significance for the selection of pruning systems, optimization of vine load, and maintenance of commercial fruit quality characteristics.

Thus, the application of differentiated agrotechnical approaches according to ecological zones, together with the selection of pruning length based on the localization of the fruit-bearing zone in each variety, enables the efficient realization of the commercial potential of both local and introduced grape varieties. The actual fruitfulness of buds located along the fruiting canes of 25 technical and 38 table grape varieties investigated under Absheron conditions over a three-year period was determined. These findings will provide a basis for establishing the optimal pruning length of fruiting canes during dormant pruning for each investigated variety.

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APPENDIX

Table A1. The fruitfulness coefficient of the buds on the fruiting shoots (fruiting canes) of the studied grape varieties 1

No.	Cultivar Name	Number of Fruiting Shoots	Proposed Pruning Length by Bud Count	Number of Buds	NODE									
					1	2	3	4	5	6	7	8	9	10
1	Ag Aldara	3	16.1	48.4	0.0	92.3	92.3	84.6	76.9	76.9	76.9	69.2	61.5	53.8
2	Arayatly Gara Uzum	3	15.4	46.2	30.8	60.8	68.8	70.3	82.4	15.2	19.5	38.7	16.6	15.0
3	Bayanshira	5	12.4	62.4	48.0	58.9	65.7	75.8	80.9	79.4	71.1	47.9	41.8	33.2
4	Khindogny	4	14.6	58.6	19.5	45.0	49.6	45.2	72.0	75.6	44.1	37.7	45.7	34.0
5	Madrasa	4	12.2	48.7	40.6	30.7	46.9	38.5	53.6	36.9	44.6	27.6	45.3	46.9
6	Meleyi	4	11.5	46.3	0	11.2	14.6	50.6	25.8	50.6	65.3	25.2	25.2	33.4
7	Garagat	4	12.1	48.4	35.2	33.5	39.7	27.2	33.5	50.0	33.5	35.7	35.2	27.2
8	Gara Lkeni	5	12.4	62.2	14.3	0.0	28.6	71.4	57.1	42.9	42.9	28.6	57.1	42.9
9	Gara uzum	4	12.2	48.8	24.8	58.5	41.8	50.1	41.8	58.3	50.1	48.6	49.8	33.5
10	Sultanshira	4	12.0	48.3	25.6	23.6	29.5	29.5	29.5	29.5	25.6	25.6	27.5	11.8
11	Kapaz	4	13.1	52.4	18.1	90	81.8	36.3	63.6	72.7	36.3	36.3	54.5	63.6
12	Goy gol	4	13.1	52.5	11.5	13.3	26.3	35.6	86.6	86.2	66.4	33.2	30.2	12.5
13	Genjevi	5	12.8	64.3	41.3	45.3	51.9	47.1	42.9	48.1	43.5	40.8	42.3	26.1
14	Rkasiteli	4	11.5	46.2	25.0	36.5	51.8	51.8	50.6	45.3	42.4	34.4	30.2	25.4
15	Sykh gara	3	12.9	38.7	11.3	11.3	25.6	25.6	11.4	26.6	90.3	38.6	12.5	38.6
16	Esheni	3	12.8	38.5	0.0	3.2	52.1	52.1	43.4	52.1	56.5	52.1	43.4	43.4
17	Kharji	3	13.6	40.8	32.4	56.2	37	48.3	60.7	41.5	25	51.7	39.2	49.4
18	Khojavandi	5	12.9	64.5	5.5	11.1	27.8	72.2	94.4	77.8	77.8	66.7	61.1	44.4
19	Zarani gorasy	4	9.7	38.8	0.0	20.6	48.2	80.6	86.0	76.0	80.2	60.4	60.2	25.4
20	Aliqote	3	10.8	32.6	0.0	25.6	25.8	75.2	85.5	50.6	50.2	50.4	25.7	48.8
21	Chrdonnay	3	11.5	34.7	0.0	42.4	67.8	69.2	72.5	76.4	72.3	70.2	74.5	68.2
22	Pinot Noir	3	12.1	36.5	32.4	54.6	72.4	70.8	71.4	98.6	95.6	98.4	96.5	77.4
23	Merlot	3	10.9	32.7	64.4	87.2	97.4	98.7	99.2	99.6	94.8	96.7	95.3	89.2
24	Cabernet Sauvignon	3	12.1	36.3	38.4	87.6	98.4	96.6	88.8	75.4	74.2	78.6	76.5	72.4
25	Syrah	3	13.4	40.4	0.0	33.3	87.6	68.4	54.2	34.0	42.4	13.3	12.6	12.8
26	Agadayi	5	14.1	70.6	38.3	40.5	54.8	51.6	41.6	40.4	23.3	25.4	28.3	27.2
27	Ag huseyni	5	14.1	70.8	9.1	54.5	81.8	54.5	72.7	54.5	36.3	18.1	45.4	27.2
28	Ag tayfi	5	14.5	72.6	16.0	22.0	43.0	35.0	35.0	32.0	41.0	46.0	38.0	27.0
29	Ag Shany	5	8.5	42.5	11.1	30.6	33.8	46.8	41.7	48	50.1	27.3	28.9	15.5
30	Sashla white	3	12.1	38.8	13.4	21.95	62.6	43.5	51.85	65.05	56.5	37.4	58.7	50.4
31	Attıca Seedless	5	13.3	66.8	0.0	1.44	7.66	34.6	69.67	46.67	32.48	26.5	22.4	1.33
32	Arna Grna	5	12.4	62.4	18.7	56.5	48.5	59.1	45.1	54.8	52.2	49.8	57.3	38.1
33	Bendi	5	11.7	58.7	41.6	58.3	16.6	18.6	16.6	25.2	25	25	37.5	12.5
34	Black Magic	5	12.5	62.6	25.6	30.8	46.2	38.5	83.6	65.9	46.2	33.3	28.2	28.2

35	Devechi Gyzyl Uzumu	4	10.5	42.3	0.0	22.4	23.3	26.0	35.0	50.6	76.7	66.2	66.7	66.7
36	Dekabrskiy	4	9.6	38.5	0.0	48.8	68.5	75.2	54.6	52.6	52.2	52.2	48.4	26.6
37	Doina	4	9.6	38.5	0.0	0.0	0.0	25.8	42.7	88.6	88.4	86.6	78.2	50.6
38	Mahmudu	5	8.5	42.6	31.6	42.1	52.7	51.8	48.6	46.5	47.7	42.7	40.0	34.7
39	Marandi	5	14.8	74.4	16.0	25.7	31.1	37.5	38.5	36.2	37.1	33.8	32.3	27.1
40	Moldova	5	10.0	50.4	15.4	33.2	51.2	82.8	92.0	91.4	92.6	41.0	44.5	45.2
41	Mişel palieri	5	9.7	48.8	0.0	0.0	74.6	74.6	88.4	82.6	82.4	66.4	48.2	35.6
42	Novrast	5	12.5	62.5	18.9	20.2	32.5	45.5	34.1	25.8	35.0	25.1	32.5	29.7
43	Chahrayi kishmish	5	13.7	68.5	15.3	42.3	50	53.8	50	57.7	46.1	30.7	34.6	23.0
44	Gara kishmish	5	13.7	68.5	18.1	45.5	72.2	45.5	36.4	27.3	36.4	45.5	27.3	36.4
45	Gara Kechimemesi	5	14.8	74.4	77.5	57.5	71.6	43.3	57.5	49.1	45	36.6	32.5	34.1
46	Gara khatyny	4	10.5	42.3	0.0	0.0	14.3	42.9	62.6	84.3	88.6	42.9	14.3	14.3
47	Garabag Gyrmyzy Uzumu	4	11.1	44.4	0.0	0.0	0.0	25.4	26.7	28.8	50.6	48.2	58.7	58.6
48	Cardinal	4	10.6	42.5	0.0	20.6	30.8	40.2	60.4	35.4	30.4	40.2	47.1	50
49	Kehraba	5	9.3	46.6	0.0	26.6	26.8	36.8	52.4	78.6	86.8	56.4	53.2	50.6
50	Kechımemesı	5	10.5	52.4	0.0	20.3	20.3	40.6	40.	42.6	60.0	30.0	30.3	10.0
51	Krimsoon seedles	5	13.7	68.7	0.0	0.0	14.6	4.3	6.14	8.6	7.3	88.6	88.4	76.6
52	Ichkimar	5	12.9	64.7	0.0	14.2	71.4	28.5	28.5	28.5	42.8	14.2	14.2	0.0
53	İtaliya	5	14.5	72.5	25	35	38.7	38.7	47.5	45	32.5	37.5	35.2	28.7
54	Huseini	5	15.3	76.5	0.0	0.0	1.4	2.8	26.7	36.7	76.7	1.4	1.2	0.0
55	Yumru kishmish	4	13.1	52.5	15.3	13.1	12.8	21.4	29.7	39.4	16.3	66.6	34.9	13.4
56	Red Globe	5	13.7	68.4	0.0	0.76	9.68	14.6	34.87	72.6	68.42	36.33	28.6	5.42
57	Prima	4	9.6	38.5	0.0	12.7	25.2	34.6	37.5	43.7	40.8	50.2	34.3	34.6
58	Təbrizi	5	14.5	72.4	26.5	39.2	48.7	53.1	46.4	49.8	48.08	44.3	42.7	36.1
59	Kishmish Sogdiana	5	14.1	70.4	30.5	63.8	69.4	41.6	48.6	56.9	47.2	41.6	58.3	43.0
60	Superior Seedless	5	14.1	70.4	38.9	38.9	55.6	66.7	38.9	22.2	50	50	11.1	11.1
61	Sultanina	5	14.9	74.4	0.0	1.8	0.0	0.0	14.6	78.8	92.4	96.4	62.4	34.6
62	Zeynabi	3	12.9	38.7	0.0	0.0	28.6	86.6	58.2	56.4	52.6	48.2	36.4	7.8
63	Veles	5	13.8	68.8	18.1	29.8	26.5	52.5	62.5	71.9	39.7	39.1	38.4	18.7

Table A2. The fruitfulness coefficient of the buds on the fruiting shoots (fruiting canes) of the studied grape varieties 2

No.	Cultivar Name	Number of Fruiting Shoots	Proposed Pruning Length by Bud Count	Number of Buds	NODE									
					11	12	13	14	15	16	17	18	19	20
1	Ag Aldara	3	16.1	48.4	53.8	46.2	46.2	38.5	15.4	7.7	0.0	0.0	0.0	0.0
2	Arayatly Gara Uzum	3	15.4	46.2	12.3	10.8	10.1	4.3	1.4	0.0	0.7	0.0	0.0	0.0
3	Bayanshira	5	12.4	62.4	31.5	26.3	17.9	12.7	10.5	4.9	3.6	0.5	0.5	0.3
4	Khindogny	4	14.6	58.6	30.0	30.4	18.8	17.9	8.3	5.9	4.6	3.34	2.9	2.2
5	Madrasa	4	12.2	48.7	56.8	24	33.8	22.9	32.8	11.5	3.1	1.5	0.0	0.0
6	Meleyi	4	11.5	46.3	22.4	21.5	11.8	24.3	11.0	12.5	10.6	0.0	0.0	0.0
7	Garagat	4	12.1	48.4	14.7	6.2	6.2	14.7	14.7	6.2	0.0	0.0	0.0	0.0
8	Gara Lkeni	5	12.4	62.2	42.9	42.9	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	Gara uzum	4	12.2	48.8	8.5	0	0	8.5	8.5	0.0	0.0	0.0	0.0	0.0
10	Sultanshira	4	12.0	48.3	11.8	11.8	11.8	0	3.9	0	0	1.9	1.3	1.2
11	Kapaz	4	13.1	52.4	54.5	18.1	18.1	27.2	18.1	0.0	0.0	0.0	0.0	0.0
12	Goy gol	4	13.1	52.5	12.5	12.3	6.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0
13	Genjevi	5	12.8	64.3	36.5	23	18.4	11.0	16.1	2.8	7.2	6.3	6.4	0.5
14	Rkasiteli	4	11.5	46.2	19.8	19.8	13.0	8.4	4.4	3.6	2.7	0.8	0.4	0.3
15	Sykh gara	3	12.9	38.7	11.6	10.6	22.3	22.3	22.3	11.3	0.0	0.0	0.0	0.0
16	Esheni	3	12.8	38.5	34.7	17.3	8.6	8.6	0.0	0.0	0.0	0.0	0.0	0.0
17	Kharji	3	13.6	40.8	65.9	47.1	25.6	18.7	18.7	21.0	18.7	18.7	16.5	16.5
18	Khojavandi	5	12.9	64.5	38.9	22.2	27.8	16.7	16.7	16.7	0	5.6	5.6	0
19	Zarani gorasy	4	9.7	38.8	22.6	21.3	10.5	9.5	0.0	0.0	0.0	0.0	0.0	0.0
20	Aliqote	3	10.8	32.6	42.5	11.4	10.4	9.6	9.2	4.8	3.2	0.0	0.0	0.0
21	Chrdonnay	3	11.5	34.7	40.4	26.7	22.4	11.4	3.4	0.0	0.0	0.0	0.0	0.0
22	Pinot Noir	3	12.1	36.5	25.6	12.4	11.8	14.7	6.4	6.2	7.8	0.0	0.0	0.0
23	Merlot	3	10.9	32.7	74.5	24.2	12.8	14.3	3.6	3.2	0.6	0.4	0.3	0.3
24	Cabernet Sauvignon	3	12.1	36.3	79.6	38.7	34.6	28.6	17.7	13.2	9.6	9.8	9.2	1.6
25	Syrah	3	13.4	40.4	10.6	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	Agadayi	5	14.1	70.6	25.4	15.0	14.8	8.32	5.6	11.1	3.3	3.3	1.2	0.6

27	Ag huseyni	5	14.1	70.8	18.1	36.3	18.1	9.1	9.1	0.0	0.0	0.0	0.0	0.0
28	Ag tayfi	5	14.5	72.6	35.0	30.0	24.0	19.0	11.0	8.0	3.2	3.0	5.2	3.2
29	Ag Shany	5	8.5	42.5	24.2	15.2	6.4	4.6	3.7	1.8	0.9	0.0	0.0	0.0
30	Sashla white	3	12.1	38.8	18.1	7.3	3.65	3.65	9.55	9.55	0.0	0.0	0.0	0.0
31	Attıca Seedless	5	13.3	66.8	1.33	0.34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	Arna Grna	5	12.4	62.4	32.8	23.1	22.5	9.8	14.9	4.7	2.8	1.9	1.6	0.9
33	Bendi	5	11.7	58.7	12.5	25	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	Black Magic	5	12.5	62.6	23.1	12.8	17.7	15.1	5.4	5.5	4.1	3.1	3.0	2.6
35	Devechi Gyzyl Uzumu	4	10.5	42.3	33.2	42.6	33.8	33.0	16.2	14.6	0	16.2	6.7	3.7
36	Dekabrskiy	4	9.6	38.5	25.4	22.3	11.5	11.0	3.4	0.0	0.0	0.0	0.0	0.0
37	Doina	4	9.6	38.5	48.8	47.2	49.5	52.2	50.8	21.4	10.3	4.6	0.0	0.0
38	Mahmudu	5	8.5	42.6	22.9	22.7	22.1	15.7	11.3	9.1	5	2.5	3.1	1.5
39	Marandi	5	14.8	74.4	27.4	20.8	15	12.7	10.7	6.4	6	3.0	1.6	1.5
40	Moldova	5	10.0	50.4	41.9	30.5	27.5	19.2	20.2	12.2	7.6	0.8	0.1	0.0
41	Mişel palieri	5	9.7	48.8	0.0	0.0	0.0	14.6	11.3	3.33	0.0	0.0	0.0	0.0
42	Novrast	5	12.5	62.5	31.1	26.9	32.0	17.3	6.3	3.4	5	1.6	1.1	0.4
43	Chahrayi kishmish	5	13.7	68.5	26.9	19.2	11.5	3.8	3.8	0	3.8	3.8	0	3.8
44	Gara kishmish	5	13.7	68.5	27.3	18.1	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	Gara Kechimemesi	5	14.8	74.4	49.2	14.1	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	Gara khatyny	4	10.5	42.3	14.3	16.2	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	Garabag Gyrmyzy Uzumu	4	11.1	44.4	27.5	26.6	22.8	21.4	22.7	0.0	0.0	0.0	0.0	0.0
48	Cardinal	4	10.6	42.5	16.4	14.2	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	Kehraba	5	9.3	46.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	Kechımemesı	5	10.5	52.4	32.6	20.6	30.3	30.0	10.2	9.4	0.0	0.0	0.0	0.0
51	Crimsoon seedles	5	13.7	68.7	88.2	78.3	66.4	3.3	3.0	0.0	0.0	0.0	0.0	0.0
52	Ichkimar	5	12.9	64.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	İtaliya	5	14.5	72.5	21.3	32.5	20	12.5	6.3	2.5	2.5	0	0	0
54	Huseini	5	15.3	76.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	Yumru kishmish	4	13.1	52.5	22.3	10.0	13.9	6.9	6.3	0.8	2.3	0.6	1.1	0
56	Red Globe	5	13.7	68.4	1.36	1.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	Prima	4	9.6	38.5	37.5	15.8	25	12.5	0	6.5	6.5	6.5	0.0	0.0
58	Təbrizi	5	14.5	72.4	29.6	27.1	23.1	18.7	8.3	9.5	4.6	4.9	2.6	0.9
59	Kishmish Sogdiana	5	14.1	70.4	38.8	19.4	25	29.1	19.4	8.3	0.0	0.0	0.0	0.0
60	Superior Seedless	5	14.1	70.4	22.2	16.7	22.2	16.7	15.6	10.2	5.6	0.0	0.0	0.0
61	Sultanina	5	14.9	74.4	32.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	Zeynabi	3	12.9	38.7	3.6	2.5	2.2	0.6	0.5	0.0	0.0	0.0	0.0	0.0
63	Veles	5	13.8	68.8	20.3	22.3	15.5	12.8	11.0	11.1	5.4	5.2	2.1	1.9