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# The Impact of Bud Load on Berry Quality, Yield, and Cluster Compactness in H4 Strain Grapevines

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**Abstract:** The Thompson Seedless (Sultanina) seedless variety of grapes is an important crop in Egypt, both for local consumption and export. In recent years, the H4 strain of this grape variety has gained popularity due to its high productivity. However, a drawback of this strain is that the grape clusters become densely packed, resulting in small berries and reduced overall quality. A study was conducted to investigate the impact of pruning severity and bud load on the growth, yield, and quality of H4 grapes. The study included several different treatments, namely T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds), T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), and T9: (12 canes × 13 buds). The behavior of the buds, vegetative growth, yield, and quality of the grapes were analyzed. The results showed that pruning of the H4 strain with either 8 canes and 10–12 buds per cane, or 6 canes with 13 buds, produced the best results in terms of managing excessive fruit production, achieving a balance between vegetative growth and yield, and improving the physical and chemical characteristics of the grape clusters and berries. Overall, maintaining 8 canes with 10–12 buds per cane or 6 canes with 13 buds is recommended for obtaining maximum crop yield and quality.

**Keywords:** *Vitis vinifera* L.; pruning severity; bunch; canes; buds

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## 1. Introduction

H4 strain grapevines are a strain of Thompson Seedless grape that was developed in Egypt in the early 2000s [1]. It has quickly become one of the most popular grape varieties in the world, due to its high yield and large clusters [2]. However, this strain produces clusters with high compactness and small berries, thus negatively affecting the cluster's quality during marketing [3].

Pruning is one of the most important horticultural processes in viticulture due to its impact on fruit yield and quality [4]. Pruning includes the selective removal of canes, shoots, leaves, and other vegetative parts of the grapevine [5]. The goal of pruning is to manage the vine's shape, size, and vigor, which ultimately influences crop yield and quality [6]. The pruning process mainly depends on the fertility of the basal buds of the cultivar, which could be detected in the previous growing season [7]. Previous studies have helped forecast the pruning recommendations, fruitfulness, and potential yield [8].

Bud load is the number of buds left on a grapevine after pruning [9]. The ideal bud load for a grapevine depends on the variety of grape, the growing conditions, and the desired yield [10]. In general, a bud load of 60–80 buds per vine is a good starting point for bud burst number and percentage of grapevines [11]. However, it may be necessary to adjust the bud load up or down depending on the bud fruitfulness in order to meet the productive objective [12,13].

Abdel-Mohsen [14] investigated the effect of the cane length of Crimson Seedless grapes on bud behavior under Egyptian conditions. The results showed that bud behavior was significantly affected by cane-length treatments. Long cane pruning (10 buds/cane) recorded the highest bud fertility percentage and the lowest bud burst percentage. Ghobrial [15] studied the effect of bud load on the bud behavior of the Autumn-Royal seedless grape cultivar. The length of the fruiting canes was 6, 8, 10, 12, and 15 buds per cane. The results showed that bud behavior measurements expressed as bud burst percentage and bud fertility coefficient were significantly increased by increasing cane lengths. The longest canes (15 buds per cane) resulted in the highest bud burst percentage, followed by 12 buds cane length without any significant differences between them. In comparison, 6 buds cane length induced the lowest percentage of this parameter. Regarding bud fertility, the highest value resulted from 15 buds, followed by 12, but the 6 buds/cane length had the least value of bud fertility.

Khamis et al. [16] evaluated the effect of different cane bud loads (8, 10, and 12 buds/cane) on the vegetative growth of Superior grapevines represented by shoot length, shoot diameter, the number of leaves/shoot, and the leaf area. They reported insignificant differences among the tested bud loads concerning shoot length and the number of leaves/shoot. However, the shortest cane (8 buds/cane) treatment resulted in superior values for both shoot diameter and leaf area compared to the 10 and 12 buds/cane treatments. Bassiony [17] tested different bud load levels of Flame seedless grapevines (20, 30, and 40 buds per kilogram of pruning weight). The author reported that internodes length, diameter, the total length of laterals, coefficient of wood ripening, and leaf area significantly increased due to the effect of bud load treatments. Bud load of 20 followed by 30 and 40 gave the highest values of all vegetative growth parameters. The potential yield and quality of several raisin grapes subjected to different pruning severities were determined by Fidelibus et al. [18]. They tested four varieties: 'Thompson Seedless', 'DOVine,' 'Fiesta,' and 'Selma Pete', and two pruning treatments: 8 or 6 canes at 15 nodes on each cane retained 120 or 90 nodes per vine. They reported that Thompson seedless resulted in the fewest clusters, indicating that it had the lowest basal bud fertility of the varieties tested. Moreover, vines pruned at eight canes had about 33% more nodes than vines with six canes. The number of canes per vine did not affect the berry quality parameters except for acidity. Increasing the number of canes from six to eight represented a 33% increase in the number of nodes, increased yield by 10%, regardless of the variety, and increased the number of clusters accounting by 22% only. H4 is a strain of Thompson seedless. It has spread widely in recent years and the demand on this strain for cultivation has become great due to the high yield of vines as well as increase in the weight of clusters. Therefore, the main target of this experiment was to evaluate the effect of different cane numbers with constant buds and constant canes number with different buds on vegetative growth, yield, and quality of (H4 strain) grapevines to determine the appropriate bud load which can be recommended for a pruning system. The available literature reveals that little work has been done on the effect of bud load on berry quality, yield, and cluster compactness of H4 strain grapevines. Therefore, the aim of the present work was to elucidate the effect of pruning severity (bud load) on vegetative growth parameters, yield, and berry quality and cluster compactness of H4 strain grapevines.

## 2. Materials and Methods

### *2.1. Plant Material and Field Conditions*

The study was conducted over two consecutive seasons, specifically in 2018 and 2019. We utilized Thompson seedless cultivar (H4 strain) grapevines (*Vitis vinifera* L.) that were grafted onto Freedom rootstock (1613C × V. champini), which is known for its high resistance to *phylloxera* and nematodes. This rootstock also enhances the vigor of scions [19]. The grapevines were grown in a private orchard located in the El-Khatatba region of Minufiya Governorate, with coordinates of 30°21′ N 30°49′ E. The weather conditions in the experimental area can be seen in Figure 1 and Table 1. The vines were arranged in a north–south row orientation. They were consistently healthy and exhibited uniform vigor, planted approximately 2 × 3 m apart in sandy soil. A drip irrigation system was employed for irrigation. The irrigation program was applied 100% of reference evapotranspiration ($ET_0$), with irrigation rate 1505 $m^3$/ha/year as calculated using Class A pan evaporation data according to Penman [20]. Cane pruning techniques, as well as the quadrilateral cordon trellis system and Spanish Parron system (as described by Chacon [20]), were utilized for training and supporting the vines. The experimental vines received standard agricultural practices commonly implemented in commercial vineyards, including organic and mineral fertilizers, as well as pest control methods recommended by the Ministry of Agriculture in Egypt.

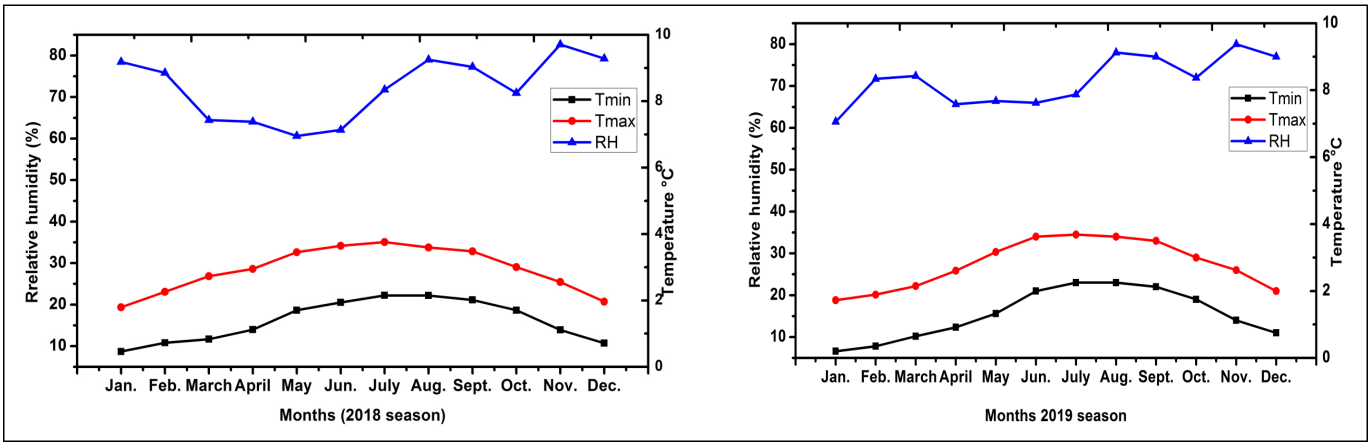



**Figure 1.** Climatic data of El-Khatatba region—monthly means of 2018 and 2019.

**Table 1.** Precipitation and wind speed of El-Khatatba, Minufiya, Egypt as the average of the 2018 and 2019 seasons.

| | Rainfall (mm·month$^{-1}$) | Wind Speed (km·h$^{-1}$) |
|---|---|---|
| Winter | 4.7 | 14.0 |
| Spring | 3.3 | 15.6 |
| Summer | 0.0 | 14.5 |
| Fall | 2.3 | 13.0 |

The experiment was arranged in Randomized Complete Block Design (RCBD) with three replicates represented by three trees for each replicate. The experiment was carried out on 81 fruited vines arranged in 9 treatments per block.

The tested treatments in the experiment were arranged as displayed in Table 2.

**Table 2.** The pruning treatments in the experiment on Thompson seedless cultivar (H4 strain) grapevines.

| Treatments | Description |
|---|---|
| T1 | Control: 10 canes with 12 buds = 120 buds/vine |
| T2 | 8 canes × 6 buds = 48 buds/vine |
| T3 | 8 canes × 8 buds = 64 buds/vine |
| T4 | 8 canes × 10 buds = 80 buds/vine |
| T5 | 8 canes × 12 buds = 96 buds/vine |
| T6 | 6 canes × 13 buds = 78 buds/vine |
| T7 | 8 canes × 13 buds = 104 buds/vine |
| T8 | 10 canes × 13 buds = 130 buds/vine |
| T9 | 12 canes × 13 buds = 156 buds/vine |

All treatments were applied in winter on dormant vines in the last week of January in the two growing seasons of the study.

### *2.2. Measurement of Experimental Data*

To study the responses of vines to different treatments, some parameters were measured as follows.

#### 2.2.1. Bud Behavior Parameters

In both seasons, during pruning time and after the bud break phenological stage, the bud behavior per vine was recorded with respect to the following parameters:

Bud burst % = (number of burst buds per vine divided by total number of buds per vine $\times$ 100).

Bud fertility % = (the number of clusters per vine divided by total number of buds per vine $\times$ 100).

#### 2.2.2. Vegetative Growth Parameters

To determine the vegetative growth parameters during both seasons after the fruit set stage, four labeled branches at four different tree original directions were used to estimate the following characteristics:

Average shoot length (cm): It was calculated by measuring the average length of four shoots per vine.

Average shoot diameter (cm): It was calculated by measuring the average diameter of four shoots (middle portion of shoot) per vine by using a digital vernier caliper.

Number of leaves/cane: Leaves were counted for each labeled shoot and the average number of leaves per vine was calculated.

#### 2.2.3. Total Leaf Chlorophyll Content

Total leaf chlorophyll content (SPAD units): Leaf content of total chlorophyll were taken in June at veraison [21] measured by using the nondestructive Konica Minolta chlorophyll meter SPAD 502 Plus Osaka, Japan according to Wood et al. [22] on the apical 5th leaf of the shoot according to Federica et al. [23]. On each vine, 8 fully expanded leaves were carefully selected and inserted in a symmetrical manner, positioned opposite to the basal bunches on the main shoots.

#### 2.2.4. Yield and Its Components

At harvest, six clusters per replicate (18 bunches/treatment) were randomly harvested when the average total soluble solids content percentage in berry juice attained about 16–17% in the untreated vines and taken to measure the yield components as follow:

Yield component:

Total number of clusters: It was calculated by counting the clusters at harvest time on each individual vine.

Cluster weight (g): It was calculated by weight a representative sample of six clusters per replicate.

Yield (kg/vine): six clusters from each replicate were weighted and the average of cluster weight was multiplied by number of clusters/vine to calculate the average yield as kg/vine. Percentage was calculated by using the equation in El-Naby et al., 2019 [24].

$$\text{Yield increasing } (\%) = \frac{\text{Yield (treatment)} - \text{yield (control)}}{\text{yield (control)}} \times 100$$

Total yield (ton per ha):

During both seasons, the average yield as tons per (ha) was measured by using yield per vine and the number of vines per (ha) (1667 vines).

2.2.5. Physical Characteristics of Clusters

Actress random samples of 6 bunches per replicate were harvested at ripening when total soluble solids content (TSS) reached about 16–17%. The following characteristics were determined.

Average cluster weight (g). It was estimated by weighting six clusters from each replicate to the nearest gram using an electrical sensitive balance. Moreover, bunch dimensions (length and width from the middle portion) (cm) were determined using a measuring tape and the average of fruit length and width were recorded.

Compactness coefficient: It was calculated by dividing the number of cluster berries by the cluster length, Winkler et al. (1974) [25].

2.2.6. Physical Characteristics of Berries

A random sample of 100 berries was collected from replicate sources to measure the following parameters:

Weight of 100 berries (g): It was estimated in grams by using an electrical sensitive balance (SF-400A-Generic).

Volume of 100 berries ($cm^3$): This parameter was determined by immersing 100 berries sample in water in a graduated glass cylinder containing water to a certain level, and then the bumped water was measured.

Berry dimensions (length and diameter) (cm). Both the length and the diameter of 10 berries were measured using a vernier caliper and the average of fruit length and diameter were recorded. Moreover, berry shape index was calculated by dividing berry length by berry diameter.

Compression Force ($kg/cm^2$). It was measured using a pressure tester (Force-Gauge Model LGV-USA Shimpo instruments, New York, NY, USA).

Pedicle length (mm).

2.2.7. Chemical Characteristics of Berries

Total soluble solids content (TSS %): It was estimated by Carl Zeiss hand refractometer (Carl Zeiss, Oberkochen, Germany).

Total titratable acidity (%): It was determined by titrating 5 mL juice from each sample against NaOH (0.1 N) using phenolphthalein as indicator. The acidity was expressed as tartaric acid (%).

TSS/acid ratio: Total soluble solids content (TSS)/acid ratio was calculated for all the samples.

*2.3. Chemicals*

Sigma-Aldrich, Taufkirchen, Germany provided the chemicals used in the study.

*2.4. Statistical Analyses*

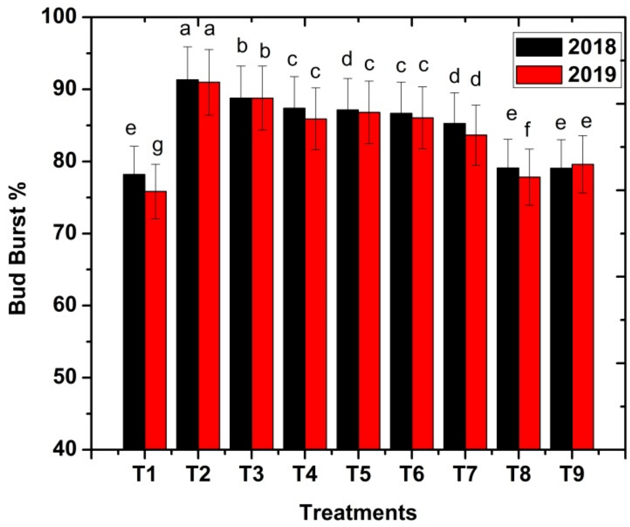
The differences between the tested treatment groups and the control group were analyzed in a completely randomized block design according to the method described by Gomez and Gomez [26]. The obtained data from both seasons were subjected to analysis of variance using the CoStat Version 6.4 Computer Software program. The treatment means were compared using Duncan's multiple range test with a probability of 0.05, according to Duncan [27].

## 3. Results

*3.1. Effect on Bud Behavior*

Figure 2A,B show the parameters related to bud behavior, including the number of dormant and burst buds, as well as the percentages of bud burst and bud fertility. These parameters were analyzed under various levels of pruning severity. Among the different pruning treatments, vines pruned at 12 canes with 13 buds per cane (156 buds/vine—T9) had the highest number of dormant buds. Conversely, vines pruned at 8 canes with 6 buds per cane (48 buds/vine—T2) had the lowest number of dormant buds in both seasons of the study. Furthermore, the data presented in Figure 2A reveal that the percentage of bud burst exhibited an inverse relationship with the pruning severity. The treatment with the lowest bud load (48 buds/vine—T2) showed the highest percentage of bud burst. The pruning severity of the treatment with 64 buds/vine, T3, followed closely in terms of bud burst percentage in both seasons. There were no significant differences in bud burst percentage between treatments of vines pruned at 8 canes with 10 or 12 buds/vine, and those pruned at 6 canes with 13 buds/cane, T6. Similarly, vines pruned at 10 or 12 canes with 12 and 13 buds/cane (120, 130, and 156 buds/vine—T1, T8, and T9) recorded the lowest bud burst percentage, with no significant differences, especially in the first season. Regarding bud fertility percentage, the findings in Figure 2B indicate that the effect of bud load on bud fertility follows the same pattern as the bud burst percentage. In other words, the treatment with the highest pruning severity (48 buds/vine—T2) resulted in the highest percentage of bud fertility, 56.25% and 56.42%, in the 2018 and 2019 seasons, respectively. There were insignificant differences in bud fertility percentages among treatments with medium pruning severity (64, 78, and 80 buds/vine), particularly in the 2019 season. However, the lowest bud fertility was observed in vines subjected to the light pruning severity treatment (156 buds/vine—T9).

(**A**) (**B**)



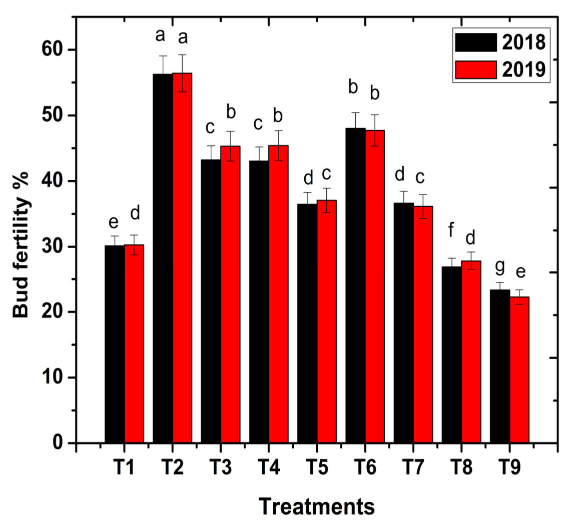




**Figure 2.** Effect of bud load on bud behavior: (**A**) bud burst % and (**B**) bud fertility of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds) and T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

### *3.2. Effect on Vegetative Growth Parameters*

The results depicted in Figure 3A–C for the examined bud load treatments in both seasons clearly demonstrate that the treatment with the fewest number of buds per vine (48 buds/vine—T2) yielded the highest vegetative growth parameters, including shoot length, shoot diameter, and number of leaves per shoot. In the 2018 and 2019 seasons, vines pruned at 8 canes with 6 buds per cane (T2) exhibited an average shoot length of 184.63 cm and 192.71 cm, respectively. Conversely, the shortest shoot length was observed in vines pruned at 10 canes with 12 buds per cane (T1) throughout both seasons. Similarly, Figure 2B illustrates that the trend observed for shoot length also applies to shoot diameter. The pruning severity showed an inverse correlation with both shoot length and shoot diameter. Vines pruned at 8 canes with 6 buds per cane (T2) displayed the highest shoot diameter, while the lowest value was recorded in vines pruned at 10 canes with 12 buds per cane (T1). Furthermore, Figure 3C demonstrates the impact of different bud loads on the number of leaves per shoot. The number of leaves exhibited a similar trend to that observed for shoot length and shoot diameter. The results indicate that all tested bud loads significantly influenced the number of leaves. The highest number of leaves was observed in vines pruned at 8 canes with 6 buds per cane, followed by those pruned at 8 canes with 8 buds per cane (T8) in both seasons. Conversely, the lowest number of leaves occurred in vines pruned at 10 canes with 12 buds per cane—T1. Additionally, Figure 3D highlights the significant effect of pruning severity on the chlorophyll content in the leaves of Thompson seedless (H4 strain) grapevines throughout the study.

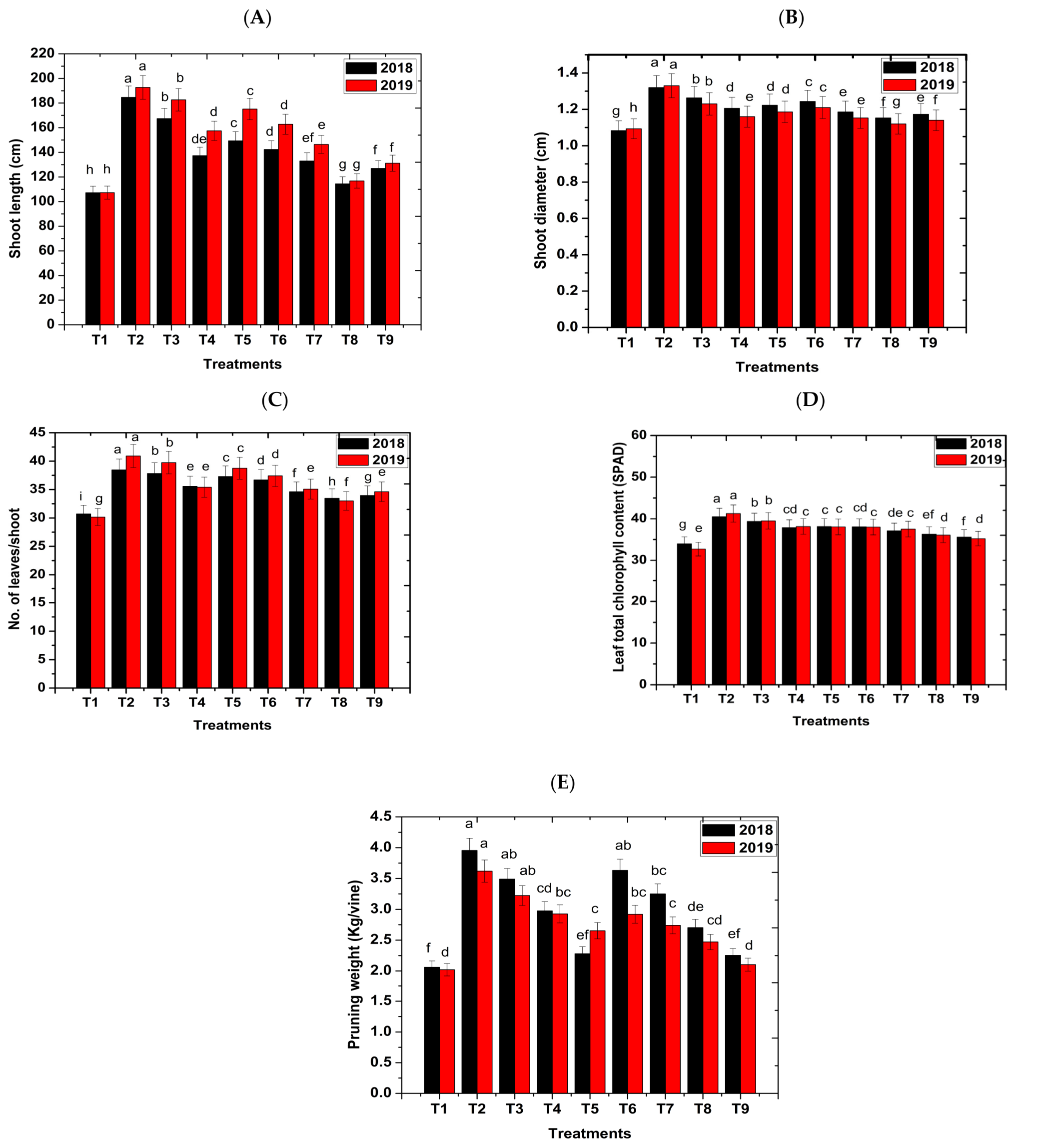



**Figure 3.** Effect of bud load on vegetative growth parameters: (**A**) shoot length, (**B**) shoot diameter, (**C**) No. of leaves/shoot, (**D**) leaf total chlorophyll content (SPAD), and (**E**) pruning weight (kg/vine) of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds) and T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

The SPAD units representing chlorophyll content ranged from 41.25 to 32.69 across different treatments, and these values were significantly higher compared to the control. Among the treatments, the highest chlorophyll content was observed in vines pruned at 8 canes with 6 buds, followed by those pruned at 8 canes with 8 buds. However, the control had the lowest chlorophyll content, significantly lower than all other treatments. The medium bud load treatments (80, 96, 78, and 104 buds/vine, T4, T5, T6, and T7) did not exhibit significant differences in leaf chlorophyll content. Regarding the impact of pruning severity on pruning weight, data from the same figure (Figure 3E) indicate that vines pruned at 8 canes with 6 buds and 8 canes with 8 buds treatments yielded the highest pruning weight in both seasons. Conversely, vines pruned at 120, 130, and 156 buds/vine, T1, T8, and T9, exhibited the lowest pruning weight.

### *3.3. Effect on Yield and Its Components*

The data presented in Figure 4A–F show the average yields and yield parameters of Thompson seedless grapevines (H4 strain) under different pruning severity treatments during the 2018 and 2019 seasons. The number of bunches per vine was found to be less significantly affected by the bud load treatments. The highest number of bunches was observed in vines pruned at 6 canes × 13 buds (T6) and 10 canes × 13 buds (T8) treatments, followed by the control treatment of 8 canes × 12 buds (T1), in both seasons. On the other hand, the lowest number of bunches was obtained from vines pruned at 8 canes × 6 buds (T2) and 8 canes × 8 buds (T3), with no significant differences between these treatments. The number of bunches from treatments T4, T5, T6, T7, T8, and T9 showed insignificant values compared to the control treatment (T1), especially in the second season, which may be attributed to the number of canes left on the vines. Regarding the bunch weight characteristic, the data in Figure 4B indicated that vines pruned at 8 canes × 8 buds resulted in the heaviest bunches, with values of 862.41 g and 832.46 g in the 2018 and 2019 seasons, respectively. However, the bunches from vines pruned at 12 canes × 13 buds treatment recorded the lowest weights. In other words, the results suggest that cluster weight is influenced by pruning severity, with both severe and light pruning negatively affecting the weight of clusters. When 8 canes were left on the vine with 10, 12, or 13 buds in each treatment, and also with treatments T2, T6, and T8, no significant differences were found in terms of the bunch weight characteristic during the two seasons.

Regarding the yield per vine, the results depicted in Figure 4C demonstrate that the T4 pruning treatment (8 canes × 10 buds) exhibited higher values compared to the T6 pruning treatment (6 canes × 13 buds), and T4 also displayed higher values compared to the other treatments. However, there were no significant differences between the T4 treatment and the 6 canes × 13 buds treatment in the two seasons of study. On the other hand, the lowest vine yield was observed in the severe pruning treatment with 8 canes × 6 buds and the light pruning treatment with 12 canes × 13 buds. Figure 4C–E reveal that different bud loads significantly affected bunch weight, yield per vine, yield per hectare, and the percentage of yield increase above the control in both seasons. Regarding the effect of cane length on bunch weight, the data indicate that vines pruned at 8 canes × 8 buds (64 buds/vine) treatment resulted in the highest bunch weight, followed by vines pruned at 6 canes × 13 buds (78 buds/vine) treatment. It is also evident that vines with the highest bud load (156 buds/vine) treatment had the lowest bunch weight. The data in Figure 4D for the estimated yield in tons per hectare, as affected by the studied pruning severity treatments, generally followed the same trend as the yield in kilograms per vine. The highest yield (45.65 and 46.69 tons) was recorded with the 8 canes × 10 buds (T4) in both seasons, followed by the 6 canes × 13 buds (T6). Conversely, the lowest yield (31.92 and 33.82 tons) resulted from vines with the highest bud load treatment (12 canes × 13 buds—T9).

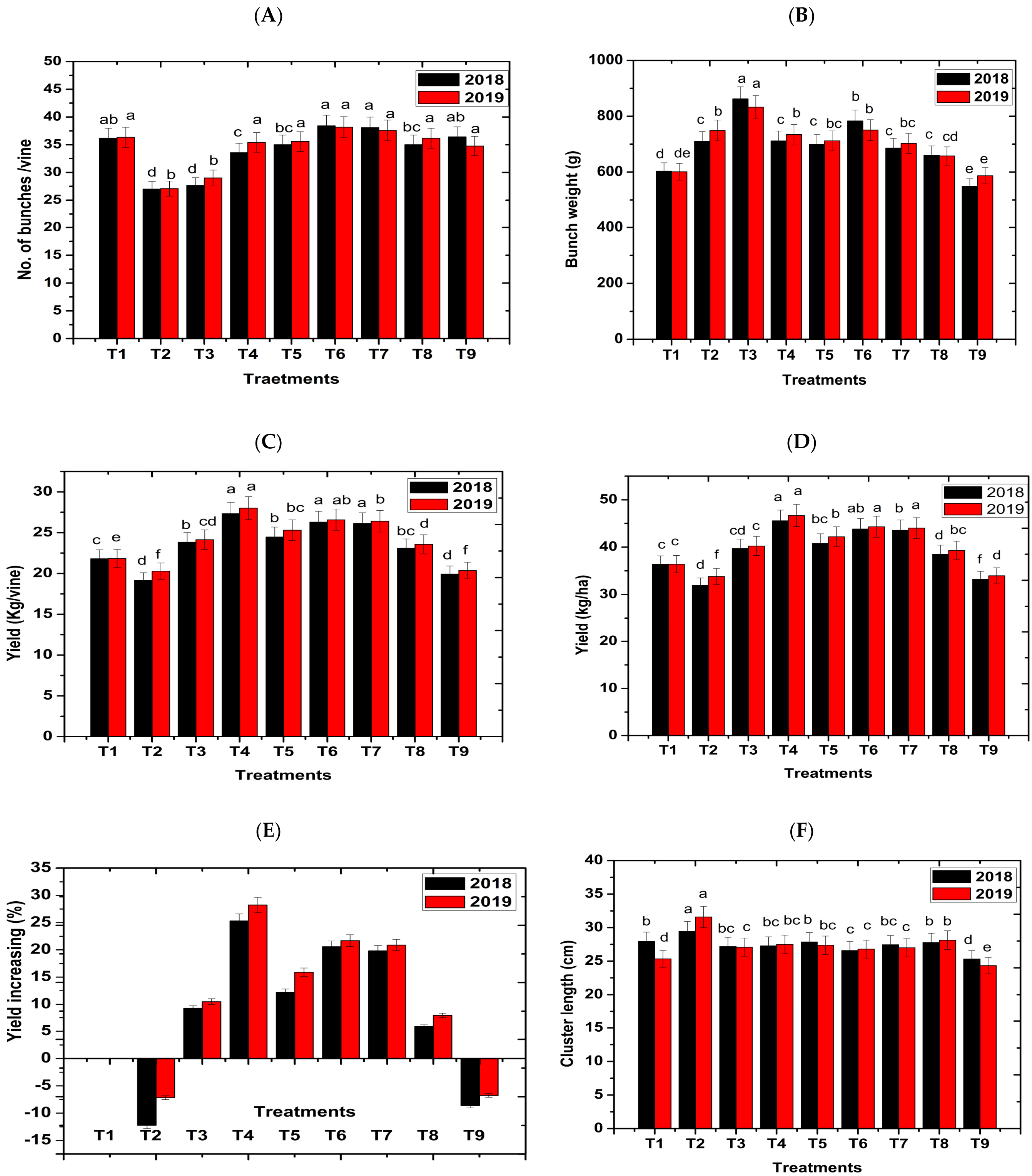



**Figure 4.** Effect of bud load on (**A**) number of bunches, (**B**) bunches weight (g), (**C**) yield (kg/vine), (**D**) yield (ton/ha), (**E**) yield increasing (%), and (**F**) cluster length (cm) of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds) and T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

The results presented in Figure 4E provide evidence that pruning severity treatments significantly influence the percentage of yield increase above the control. Specifically, both the highest and lowest bud loads had a negative impact on the percentage of yield increase compared to the control treatment. However, the remaining pruning severities had a positive effect on the percentage of increase above control. The vines pruned at 8 canes × 10 buds (80 buds/vine—T4) treatment exhibited the highest percentage of increase, 25.33% and 28.23%, in the first and second seasons, respectively. This was followed by the vines pruned at 6 canes × 13 buds (78 buds/vine—T6) treatment, which recorded a percentage of increase of 20.59% and 21.69% in the respective seasons. In contrast, the vines pruned at 8 canes × 6 buds (48 buds/vine—T2) treatment and those pruned at 12 canes × 13 buds (156 buds/vine—T9) displayed the lowest percentages of increase, −12.22% and −7.16% and −8.62% and −6.76%, respectively, compared to the control in both seasons. Furthermore, the results indicate that the vines pruned at 8 canes with 6 buds (48 buds per vine T2) resulted in the longest cluster length (Figure 4F). Conversely, the vines with the highest bud load, pruned at 12 canes with 13 buds (156 buds per vine—T9), exhibited the shortest cluster length. The remaining bud load treatments showed intermediate values in terms of cluster length, with less significant effects observed, particularly in the first season.

### *3.4. Effect on Bunch Physical Quality Characteristics*

Figures 5 and 6 explain the effect of pruning severity on the physical properties of clusters and berries. The data in Figure 5A also show the relationship between the pruning severity and the cluster width. The results clearly indicated that the highest cluster width (15,670 and 21,500 cm) resulted from vines pruned at 8 canes × 8 buds and 8 canes × 6 buds treatments in the 2018 and 2019 seasons, respectively. On the other side, the lowest cluster width resulted from vines pruned at 12 canes × 13 buds treatment.

As for the number of berries per cluster, the results in Figure 5B show the effect of tested pruning severity in both seasons of study. The results revealed that vines that received the intermediate pruning severity (8 canes with 12 buds) treatment produced the highest number of berries. Vice versa, the lowest number of berries was obtained from vines pruned at 12 canes with 13 buds. In addition, the vines pruned at treatments 6 canes × 13 buds, 8 canes × 10 buds, 8 canes × 13 buds, 10 canes × 13 buds, and 8 canes × 6 buds (T2) did not show any significant difference in the number of berries in the two seasons. The data in Figure 5C show the pedicle length as affected by pruning severity treatments. There are no significant differences among all tested treatments. Figure 5D also shows the effect of different bud loads on the compression force as a physical quality parameter of grape berries. The obtained results clearly show that the treatments loads resulted in the highest compression force in both seasons for treatments T5 and T6; (T4 and T7 in 2018); 96, 78, 80, and 104 buds/vine respectively. The lowest compression force was for treatments T2, T3, T8, and T9; 48, 64, 130, and 156 buds/vine respectively, in both seasons. Moreover, no significant differences were observed among vines pruned at 6 canes × 13 buds, 8 canes × 13 buds, and 10 canes × 13 buds treatments in the first season. On the other hand, the lowest compression force recorded with the berries resulted from vines pruned at 12 canes × 13 buds treatment.

### *3.5. Effect on Berries Physical Properties*

Other studied physical quality characteristics represented by the weight of 100 berries and the volume of 100 berries are shown in Figure 6A,B. The lightest 100 berries weight was recorded with vines of control treatment and those that were pruned at 8 canes with 12 buds treatment in the two seasons. However, the heaviest 100 berries resulted from vines pruned at 8 canes with 8 buds treatment. Otherwise, the best treatments of bud load were gained by control and 8 canes with 12 buds treatments with regard to 100 berry weight, especially in the second season. According to the 100 berries volume, data in Figure 6B also show that all bud load treatments were significantly effective. The highest volume of berries was obtained from vines pruned at 8 canes with 8 buds and 8 canes with 6 buds treatments in the first and second seasons, respectively. The lowest volume resulted from vines pruned at 8 canes with 12 buds in the two seasons. The values of 100 berries volume in the first season were higher than second season with all tested bud load treatments except the 12 canes with 13 buds treatments.

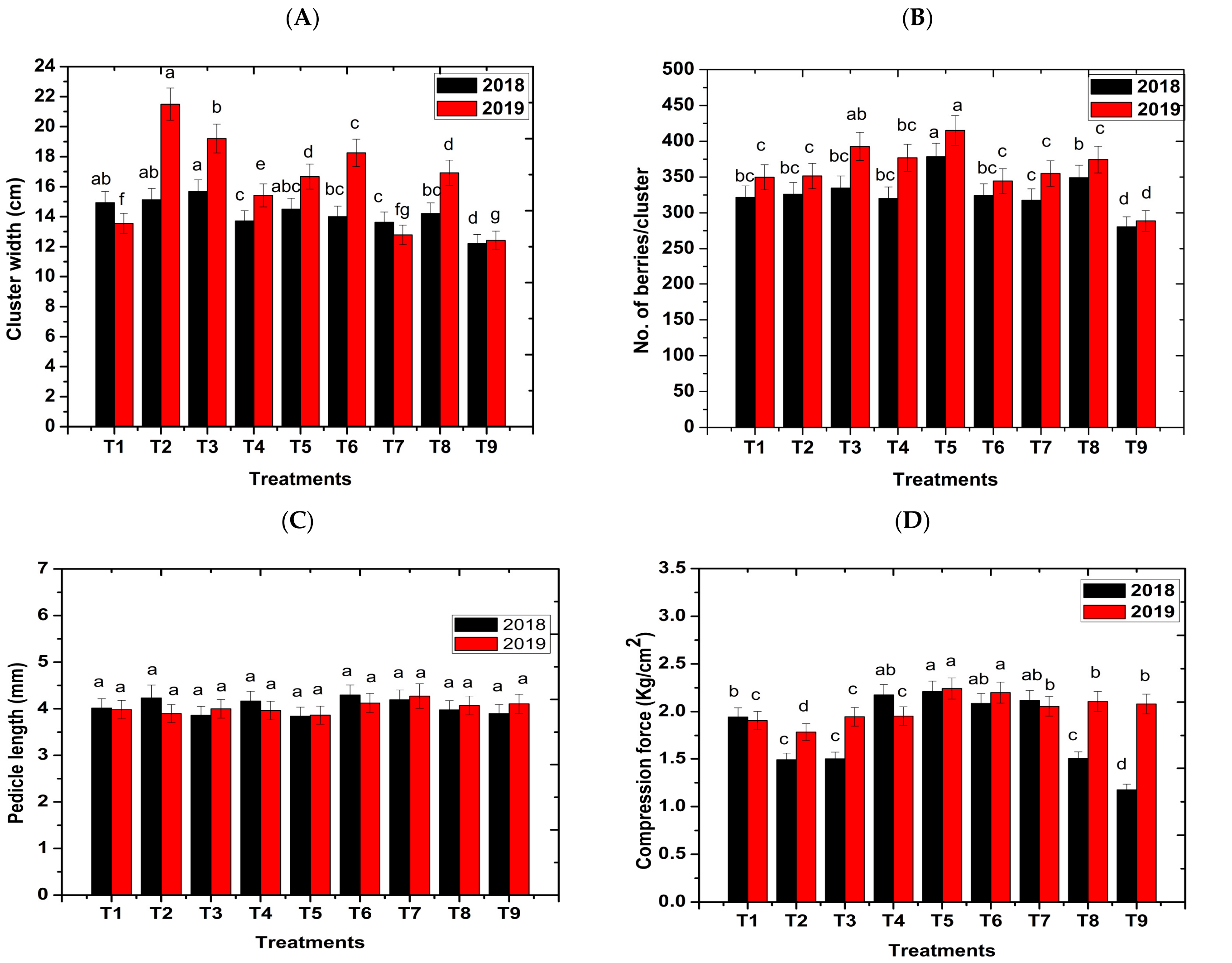



**Figure 5.** Effect of bud load on bunch physical characteristics: (**A**) cluster width (cm), (**B**) No. of berries/cluster, (**C**) pedicle length (mm), and (**D**) compression force (kg/cm$^2$) of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds) and T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

The results in Figure 7A–D display the effect of bud load on compactness of clusters and some physical properties of berries, i.e., berry length, berry diameter, and berry shape index. The vines pruned at 8 canes with 12 buds (T5) produced the highest value of cluster compactness; however, changes among all treatments were less significant in the first season than the second one. The lowest value of cluster compactness resulted after pruning vines at 12 canes with 13 buds on each cane in both studied seasons (Figure 6A).

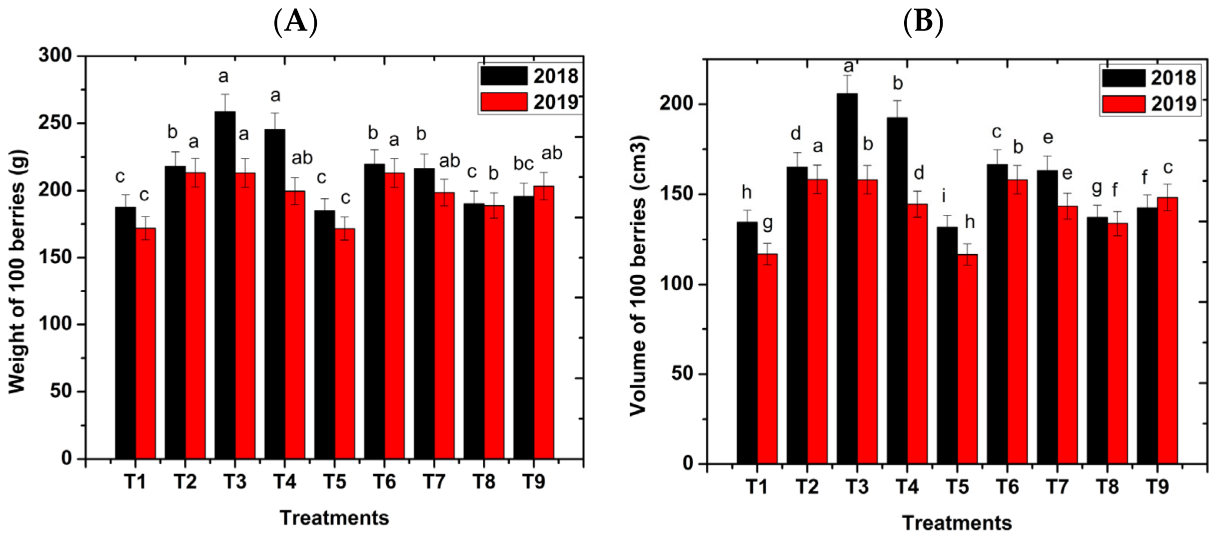



**Figure 6.** Effect of bud load on berries physical characteristics: (**A**) weight of 100 berries (g) and (**B**) volume of 100 berries ($cm^3$) of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds), T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

As for the berry length parameter, the results in Figure 7B also revealed that vines pruned at 8 canes with 12 buds resulted in the longest berries (20.720 mm) in the second season. The high and medium pruning severity treatments produced berries longer than the low pruning severity treatment and control in the two seasons. Looking at the results in the same figure, it can be noted that the berries resulted from vines pruned at T4 (8 canes × 10 buds) recorded the highest length in the first season, whereas the shortest berries resulted from the vines received the lightest pruning severity in the first season and from control in the second season.

The data in Figure 7C are also concerned with the effect of bud load on berry diameter as a physical quality parameter of Thompson seedless (H4 strain) grapevines. No clear trend can be observed for the effect of different pruning treatments on berry diameter trait. Generally, it can be said that the control treatment led to obtaining the highest berry diameter but the highest bud load treatment (156 buds/vine–T9) resulted in the lowest berry diameter in the first season. However, treatments of vines pruned at 8 canes with 8 buds (T3) or with 12 buds (T5) along with control produced the highest berry diameter without significant differences among them in the second season.

Regarding the effect of tested pruning severity on berry shape index, the data in Figure 7D clearly show that all treatments affected the shape index. Both treatments of vines pruned at T2 (8 canes × 6 buds) and T4 (8 canes × 10 buds) resulted in highest values of berry shape index in both seasons of study. Such results indicated that the lowest shape index value resulted from the control treatment.

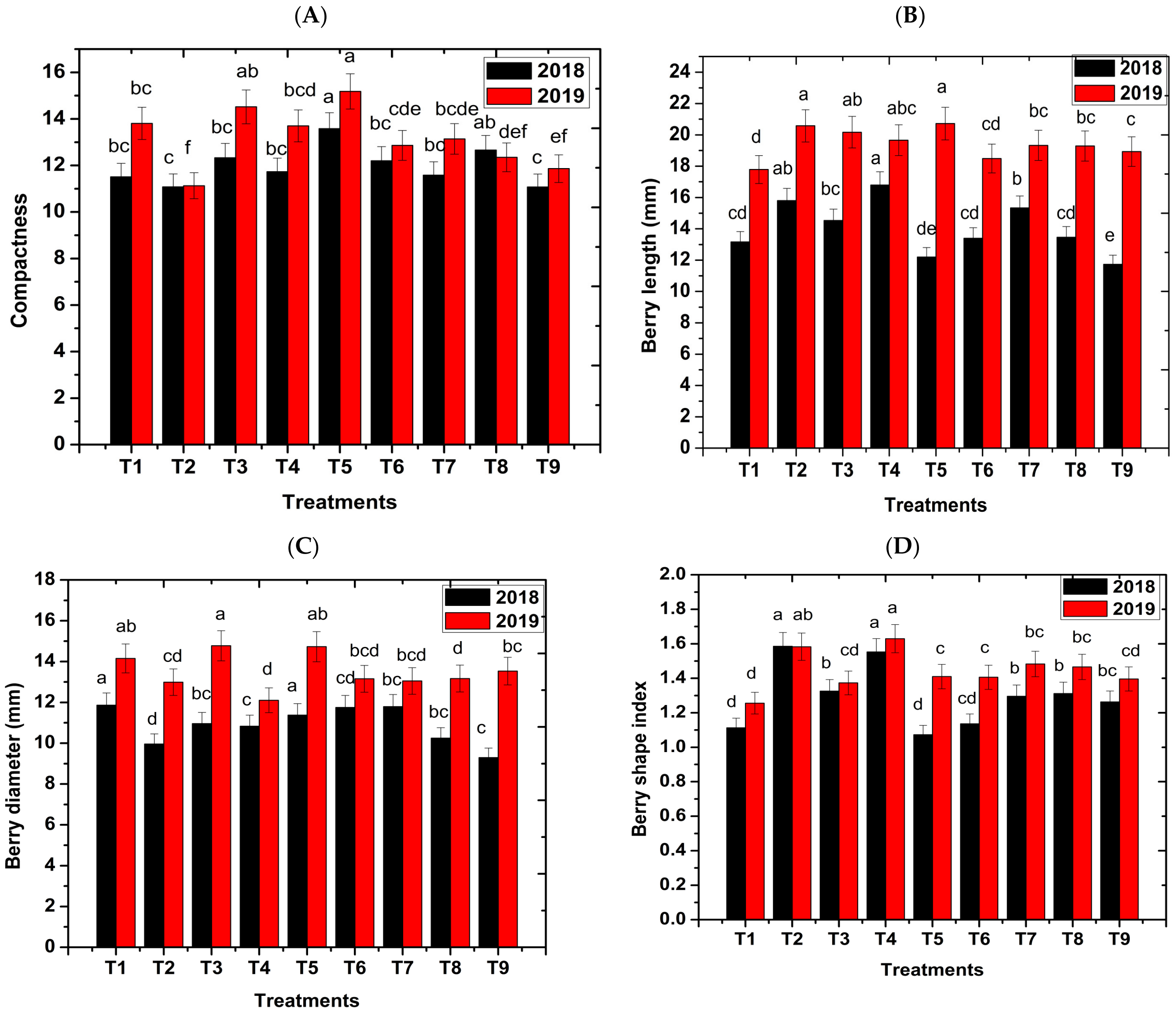



**Figure 7.** Effect of bud load on berry physical characteristics. (**A**) Compactness, (**B**) berry length, (**C**) berry diameter, and (**D**) berry shape index of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds), T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

### *3.6. Effect on Some Biochemical Characteristics*

It is obvious from Figure 8A–C that vines pruned at 6 canes with 13 buds (78 buds/vine) T6 resulted in the highest values of TSS followed by those pruned at 8 canes with 10 buds (80 buds/vine) T4 and those pruned at 8 canes with 12 buds (96 buds/vine) T5. Moreover, pruning vines at 8 canes with 13 buds (104 buds/vine) T7 gave a higher TSS values than those pruned at 10 canes with 13 buds (130 buds/vine) T8. The treatment of 12 canes with 13 buds (156 buds/vine) T9 gave the lowest value of TSS, less than the 10 canes with 12 buds (120 buds/vine) of the control treatment (Figure 8A). With regard to the effect of bud load treatments on total acidity, Figure 8B shows that control vines (10 canes with 12 buds—T1) and 12 canes with 13 buds (T9) treatments gave the highest values of total acidity. Furthermore, vines pruned at 6 canes with 13 buds (T6) gave the lowest value of total acidity. Generally, the total acidity percentage takes an opposite direction with total soluble solids percentage.

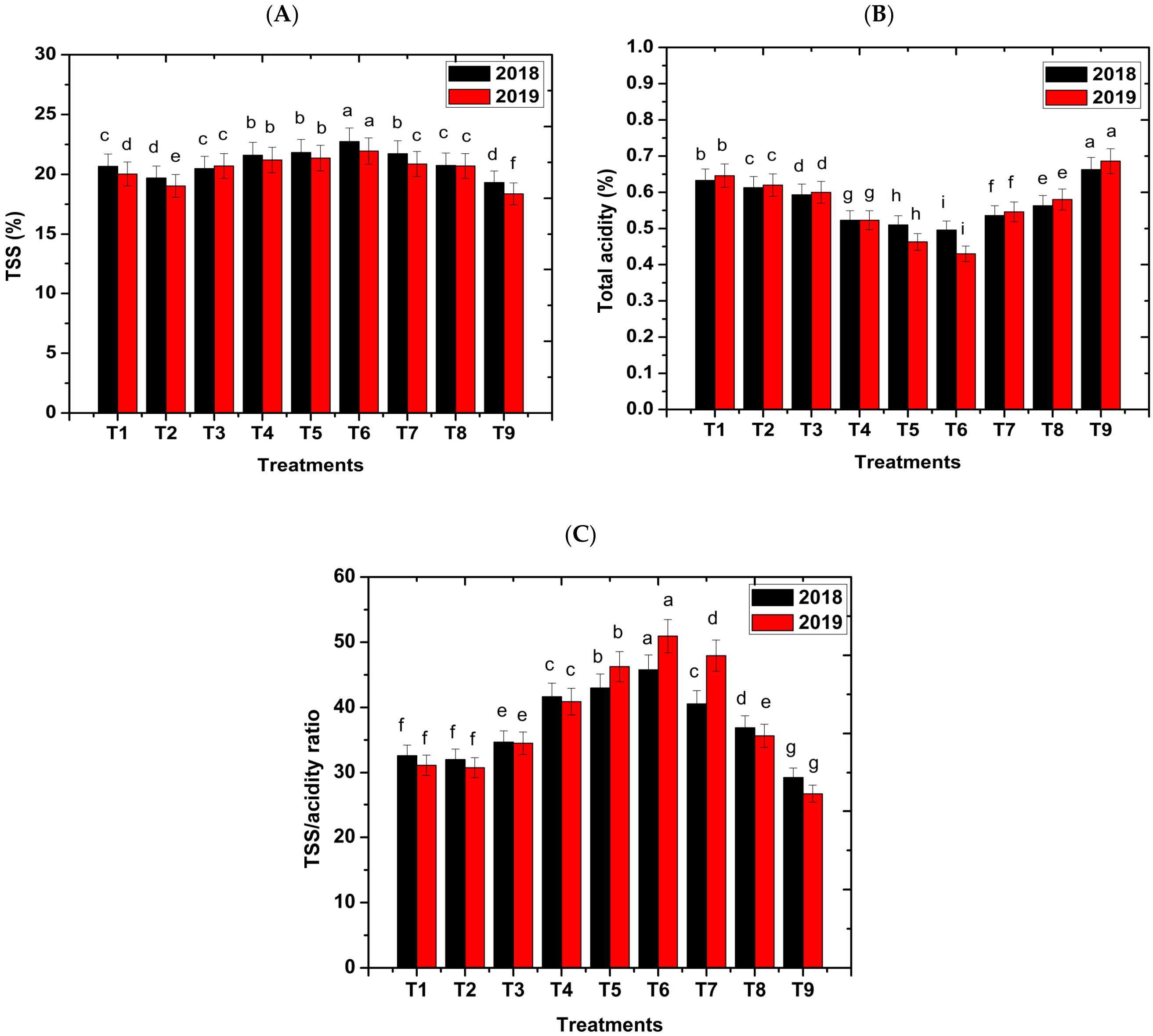



**Figure 8.** Effect of bud load on berry chemical characteristics: (**A**) TSS (%), (**B**) total acidity (%), and (**C**) TSS/acidity ratio of Thompson seedless grapevines (H4 strain) in seasons 2018 and 2019. T1 Control: (10 canes × 12 buds), T2: (8 canes × 6 buds), T3: (8 canes × 8 buds), T4: (8 canes × 10 buds), T5: (8 canes × 12 buds), T6: (6 canes × 13 buds), T7: (8 canes × 13 buds), T8: (10 canes × 13 buds), T9: (12 canes × 13 buds). Bars indicate mean values ± SE ($n$ = 9). Different letters above columns indicate significant differences among bud load treatments at $p \leq 0.05$ according to Duncan's test.

Concerning the effect of pruning severity on TSS/acid ratio, data in Figure 8C revealed that a similar trend was found due to those treatments on the TSS percentage. The medium pruning severity treatment with 6 canes and 13 buds (T6) ranked in the first order with respect to TSS/acid ratio in the two studied seasons, while the lowest ratio of TSS/acidity resulted from vines that received light pruning when pruned at 12 canes with 13 buds (T9).

## 4. Discussion

The findings presented in Figure 2 regarding the impact of bud load on bud behavior, specifically bud burst and bud fertility percentages, align with previous research conducted by Ahmad et al. [28] on the Perlette cultivar. Their study indicated that severe pruning resulted in a higher percentage of bud burst, which was inversely proportional to the number of nodes. Similarly, Samra et al. [29] observed a reduction in bud burst percentage with an increase in the number of buds per cane in Superior seedless grape. This increase in bud burst percentage can be attributed to the release of stored nutrients in the vines. However, an increase in bud load led to a decrease in bud burst due to a decrease in the amount of nutrients available for each bud to burst.

Regarding bud fertility percentage, our findings are consistent with the research conducted by Rizk et al. [30] on Thompson Seedless grapes, where an increase in bud fertility percentage was associated with a lower number of buds under the same number of canes per vine. Fawzi et al. [31] also arrived at similar conclusions with Crimson seedless grapevines, noting a decrease in bud fertility with an increase in bud load. The highest bud fertility was observed in vines pruned at a rate of 78 buds per vine, while the lowest bud fertility percentage was recorded in vines pruned at a rate of 143 buds per vine. Furthermore, the findings illustrated in Figure 2 also support the research conducted by Sabry [32], which highlighted the influence of varying cane numbers and lengths, while maintaining a constant number of buds per vine, on bud burst and bud fertility. The study found a significant and gradual increase in both bud burst and bud fertility percentages as the cane length decreased and the number of canes per vine increased in Red Globe grapevines. It is worth noting that Red Globe grapevines possess fertile basal buds starting from the fifth bud of the cane.

The findings depicted in Figure 4 demonstrate the impact of bud load on vegetative growth, specifically in terms of shoot length, shoot diameter, and the number of leaves per shoot. Based on the results obtained, it can be inferred that all vegetative growth parameters were diminished as the bud load increased. These observations align with the research conducted by Khamis et al. [16] on Superior grapevines and Ghobrial [15] on Autumn Royal grapevines, which indicated that pruning severity positively influenced vegetative growth parameters. The study found that vines pruned with a cane length of 6 buds exhibited significantly higher values of shoot length, whereas those pruned with a cane length of 15 buds displayed the lowest values. In other words, an increase in bud load per vine led to a decrease in shoot length, which can be attributed to the competition between shoots with higher bud loads. These findings are consistent with the research conducted by Benismail et al. [33] on grape cv. Cardinal, where they observed a reduction in maximum shoot growth with an increase in bud load. The effect of bud load on vegetative growth highlights the positive impact of lower bud loads on the vigor of grapevines. Additionally, Ali et al. [34] demonstrated that increasing vine loads from 62 to 102 eyes per vine resulted in a decrease in shoot length and the number of leaves per shoot in Superior grapevines.

Furthermore, Bassiony et al. [17] demonstrated that the vegetative growth parameters, specifically shoot length and leaf area, of Flame seedless grapevines exhibited a significant increase when the bud load was decreased. The treatment with the lowest bud load yielded the highest values for these growth parameters. The positive impact of pruning severity on vegetative growth can be attributed to an enhanced or more efficient translocation of photosynthates towards the main shoot. This, in turn, reduces competition among different parts of the canopy, promoting growth and leaf expansion.

In relation to the discussion on yield and its components, the findings presented in Figure 4 align with those of Fawzi et al. [31]. Their study clearly demonstrated that the number of bunches per vine in Crimson seedless grapevines significantly increased with an increase in bud load. However, the weight of each bunch decreased as the bud load increased. Similar results were observed in [35] with Autumn Royal grapevines, where an increase in bud load led to a significant reduction in yield per vine. Specifically, leaving 60 buds per vine resulted in a lower yield per vine, while leaving 42 buds per vine led to the highest increase in yield per vine. The decrease in yield was attributed to a decrease in cluster weight caused by an increase in bud load. These findings regarding the positive impact of bud load on cluster weight, number, and yield are consistent with the results obtained by Ali et al. [34]. Their study revealed that increasing vine loads from 62 to 102 buds per vine significantly enhanced the yield in terms of cluster weight and number per vine in Superior grapevines. Similar results were observed by Devi et al. [36] in Thompson Seedless vines, where the maximum number of bunches, highest bunch weight, and total yield per vine were recorded with a pruning severity of 10 buds per cane. Furthermore, these findings align with Fawzi et al. [37], who reported that, in Superior grapevines, an increase in bud load per vine resulted in a higher number of bunches. However, the lowest bunch weight and yield per vine values were recorded at lower and higher bud loads.

The results obtained can be explained based on the findings of Bassiony [17]. According to their study, the cluster number and total yield of Flame seedless grapevines increased as the bud load increased up to a certain point. However, when the vines became overloaded, the total yield eventually decreased. On the other hand, the cluster weight showed a negative trend with the level of bud load, as the highest values were recorded in vines with lighter pruning. Similar findings were observed in Superior grapevines by Khamis et al. [16]. They found that the highest yield and number of clusters per vine were achieved with the highest load of buds per cane (12 buds per cane). This gradual and significant increase in yield was observed in terms of both weight and number of clusters per vine. Additionally, they reported that different pruning treatments had no significant effect on the number of clusters per vine.

Our findings align with a previous study conducted on grapevines [38], which found that vines with longer canes had fewer clusters compared to vines with shorter canes. This observation helps explain why the number of clusters did not increase proportionately with the number of canes and nodes. In contrast, another study [39] reported that the yield, cluster number, and berry number increased with the node level. However, cluster weight, berries per cluster, berry weight, and fruit soluble solids decreased. On the other hand, Badr et al. [40] conducted a study on Niagara's grapevines and found that cluster weight decreased as the number of nodes retained increased, while the cluster number increased. They concluded that retaining 80 fixed nodes resulted in sustainable production. Furthermore, Feitosa et al. [41] studied the vine cultivar Sugrathirteen (Midnight Beauty) and discovered a significant interaction between bud load and yield. They observed an increasing trend in cluster weight with a decrease in bud load. Additionally, Abdle Hamid et al. [35] demonstrated that increasing bud load significantly reduced the yield per vine. This decrease in vine yield may be attributed to a reduction in the weight of clusters per vine in Autumn Royal seedless grapes.

In terms of the impact of bud load on the physical characteristics of grape bunches, our findings support the research conducted by Ghobrial [15]. They found that vines subjected to severe pruning treatments with a cane length of 6 and 8 buds exhibited the highest bunch length and width. Similarly, Farag [42] investigated the effects of different bud load levels on Autumn Crisp grapevines and observed that cluster length and width were influenced. Vines pruned to 62 buds per vine showed the highest values, while high bud load levels resulted in the lowest values. Regarding the number of berries in a bunch, Devi et al. [36] discovered significant variations influenced by pruning severity. The highest number of berries per bunch in Thompson Seedless grapes was recorded with a pruning severity of 10 buds per cane.

Furthermore, Ali et al. [43] conducted a study on the Melody syn. Blagratwo grape variety and found that the variation in the number of berries per bunch could be attributed to differences in berry size and diameter. They associated the decrease in the number of berries with increased length and diameter of the berries, as well as efficient nutrient utilization. These differences may be influenced by the genetic characteristics of the variety, the number of canes, and the size of the berries. Abo-Elwafa [44] investigated Early sweet grapevines and reported that lower bud load resulted in higher cluster length and width compared to higher bud load, which exhibited the lowest values. Similarly, Bassiony [17] observed that reducing bud load levels led to increased cluster length and width in Flame seedless grapevines. Regarding the effects of bud load on berry characteristics, Bassiony [17] found that severe and moderate pruning levels yielded the highest weight values for 100 berries. Additionally, the bud load treatments at levels T3 (8 canes × 8 buds), T4 (8 canes × 10 buds), and T5 (8 canes × 12 buds) showed the highest values for the volume of 100 berries compared to other pruning levels. On the other hand, the lowest values for these characteristics were recorded with T5 (8 canes × 12 buds) and the control T1. The positive impact of severe pruning on berry characteristics may be attributed to the reduction in the number of clusters per vine, which reduces competition among clusters. Khamis et al. [16] demonstrated that the weight and volume of 100 berries increased as the number of buds per cane decreased. Conversely, high bud load treatments resulted in the lowest values for 100 berries.

The results obtained in T2 and T8 align with the findings of Belal et al. [3], who observed that leaving a higher number of canes per vine resulted in greater cluster length, berry width, berry length, and berry diameter compared to a lower number of shoots. No significant differences were observed between the two conditions. Additionally, Bondada et al. [45] reported that shoot pruning, particularly under severe pruning treatments, led to a decrease in cluster compactness. This pruning practice had noticeable effects on cluster and berry morphology, resulting in looser clusters. These findings are consistent with the research conducted by Intriglio et al. (2014) [46], where severe pruning, involving the removal of the eight basal leaves during fruit set, significantly reduced cluster compactness and resulted in looser clusters. Furthermore, Fawzi et al. [37] indicated that increasing the bud load per vine in superior grape varieties significantly increased the compactness coefficient. This increase in compactness may be attributed to the shorter length of the bunch. Abo-Elwafa [44] also revealed that pruning the vines at 48 buds per vine yielded the highest values for berry weight, size, width, and length compared to other treatments.

These findings align with the research conducted by Farag [42], who observed that vines subjected to long pruning exhibited significantly lower juice total soluble solids (TSS) percentages, higher TSS/acid ratio contents, and lower total acidity contents compared to vines with short pruning. Furthermore, Ghobrial (2018) [15] found that vines that underwent severe pruning, with cane lengths of 6 buds and 8 buds, respectively, yielded the highest significant values of TSS and TSS/acid ratio content in the berries, while exhibiting the least significant acidity. No discernible differences were observed between the two cane lengths in terms of TSS and TSS/acid ratio content. On the other hand, the cane length of 15 buds notably demonstrated the lowest values for these parameters, except for acidity, which followed the opposite pattern. Parthiban and Sangeetha [47] demonstrated that vines subjected to more severe pruning produced higher TSS, a lower TSS/acid ratio, and less acidity. This could be attributed to reduced competition for metabolites among the fewer bunches, increased availability of photosynthetic energy, enhanced vigor, and improved physiological activities, all contributing to the growth of total soluble solids and the TSS/acid ratio.

## 5. Conclusions

Conducting the winter pruning of the Sultanina grape vines (H4 breed) by leaving 8 canes with a length of 13 buds may overcome the problem of over-yield to balance the vegetative growth and yield, as well as improving the compactness of the berries.

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