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Research Article

Selenium-Chitosan Treatment Affects Amino Acid Content and Volatile Components of Red Globe Grape during Storage

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Flavor is an essential attribute of grapes, but it quickly deteriorates and loses its quality. This study examined the effects of the selenium-chitosan treatment on the amino acid content and volatile components of freshly harvested grapes stored at 0°C. The amount and composition of precursors such as fatty acids and amino acids have an important influence on the formation of aroma compounds. In this article, the amino acids, volatile components, and some enzyme activities of different treated grapes were analyzed. The results of the analysis of free amino acid composition indicated that the selenium-chitosan treatment significantly reduced the loss of amino acid content by inhibiting the activities of glutamate oxaloacetate transaminase (GOT), glutamate pyruvate transaminase (GPT), and pyruvate dehydrogenase (PDH). The analysis also revealed that the significant differences in alcohol and aldehyde compounds primarily accounted for the variation in volatile components between treatments. The selenium-chitosan treatment slowed the decline in the content of aldehyde compounds and inhibited the increase in the range of alcohol compounds. These findings demonstrated that treatment with 25 mg L^{-1} selenium mixed with 1.0% chitosan solution has a positive effect on maintaining the flavor of Red Globe grapes. This treatment is worthy of future promotion.

1. Introduction

Grapes (*Vitis vinifera* L.), a deciduous vine with origins dating back to ancient times, are one of the oldest fruits in the world [1]. Extensive research has shown that grapes possess a wide range of biological activities, including antioxidant, anticancer, and cardiovascular disease prevention properties [2–4]. Over 800 volatile compounds have been identified in grapes [5], with terpenes and lipids playing a critical role in grape aroma and floral characteristics [6, 7]. Meanwhile, alcohols and C6-aldehydes contribute to herbaceous aromas [8], and phenolic compounds like tannins can cause an astringent sensation [9]. Grapes are a highly sought-after fruit by consumers, largely due to their excellent nutritional profile and unique taste. However, grapes are susceptible to flavor deterioration during storage, leading to losses of amino acids and volatile substances. As a result, there has been a growing interest in developing new technologies to combat this problem. One recent study found that a combination treatment of girdling and foliar fertilization with potassium (K_2O) was effective in increasing the concentration of volatile compounds in grapes [5]. Other studies have also shown promising results with 1-methylcyclopropene (1-MCP) and ethanol (10–20%) treatments, which significantly inhibited grape berry decay during early postharvest storage. Preharvest sprays of 1.0% $CaCl_2$ were also found to be effective in controlling postharvest rot in grapes [10–12]. Jia et al. [13] improved the traditional treatment method of the MAP +SO_2 pad, and the quality of Red Globe grapes could be maintained for 240 days by using regular SO_2 fumigation.

Selenium is an essential trace element with a range of regulatory, immunologic, and antioxidant functions in the human body [14–16]. Presently, the application of selenium in fruit and vegetable production mainly focuses on two aspects. Firstly, selenium is used to improve postharvest fruit quality through the use of artificial selenium fertilizers or leaf spraying [17, 18]. For example, selenium fertilizers have been found to improve the content of total soluble solids and

vitamin C in tomatoes, while selenium spraying increased the concentrations of solution sugar and lycopene. This is because selenium treatment enhanced the plant's uptake of sulfur in soil, which in turn promoted glutathione synthesis [19]. Additionally, selenium has been shown to increase the activity of nitrate reductase and reduce the accumulation of nitrate in tomatoes [19]. Foliar selenium application has also been found to improve fruit quality by increasing the content of soluble solids [20]. Secondly, selenium is applied to maintain the storage quality in postharvest fruits and vegetables. Lv et al. [21] reported that selenium treatment has a positive effect on maintaining quality and enhancing the sensory quality of broccoli. Whether applied preharvest or postharvest, selenium can modulate amino acids [22–24]. Selenium fertilizer has also been found to significantly improve the content of arginine, serine, and histidine in the growth of potatoes and lettuce. Studies have shown that these enhancements in amino acid metabolism are closely related to selenium's participation in plant stress resistance [23, 25].

Chitosan is a commonly used substance in the postharvest storage of fruits and vegetables, primarily due to its antimicrobial and antioxidant activities, as well as its biocompatibility and nontoxicity [26, 27]. Many studies have demonstrated that chitosan coatings can enhance the flavor of fruits and vegetables. For instance, chitosan has been shown to increase the levels of ethyl butanoate and ethyl hexanoate in strawberries, thereby improving their taste [28]. Additionally, Zhang et al. [29] found that combining chitosan with ε-polyline was an effective preservation method for Chinese shrimp, as it inhibited the production of off-odor substances such as hypoxanthine adenosine and hypoxanthine, thus maintaining the shrimp's flavor.

In this study, the effectiveness of coapplying selenium and chitosan in improving the flavor of the Red Globe grape during storage was evaluated, and the preservation potential of selenium and chitosan on other fruits was also explored. The study conducted by Choudhary and Jain [30] suggested that the application of selenium and chitosan can preserve membrane integrity by inhibiting the activity of the LOX enzyme in guava. However, this method has not been tested on grapes. As a result, the present study investigated the effect of coapplying selenium and chitosan on the amino acids and volatile components of Red Globe grapes.

2. Materials and Methods

2.1. Plant Materials and Treatments. Red Globe grapes were collected from the Fruit and Vegetable Institute of Shanxi Agricultural University. The soluble solid content of the grapes was measured using a handheld refractometer, and grapes were randomly collected from ten trees when soluble solid content reached 16% in October. Fresh grapes with uniform size, bright color, and no visible damage were carefully selected as spare materials for further experimentation.

A total of 100 Kg of grape samples were divided into four equal parts, each of which was subjected to a different treatment. The first part was immersed in water, serving as the control group. The second part was treated with 25 mg L^{-1} selenite (Se treatment), while the third part was treated with 1.0% chitosan (CS treatment), and the fourth part was treated with a solution consisting of 1.0% chitosan compound mixed with 25 mg L^{-1} selenite (Se+CS treatment). The soaking time for all treatments was two minutes. After treatment, the grapes were air-dried and placed in low-density polyethylene bags with a thickness of 0.04 mm. The bags were then stored at 0°C.

2.2. Decay Rate. To investigate the grape decay rate, the number of rotten grapes was recorded every six days at 0°C, and the decay rate was calculated using the following formula [31]:

$$\text{Decay rate}\,(\%) = \left(\frac{\text{number of rotten grapes}}{\text{total number of grape}}\right) \times 100. \quad (1)$$

2.3. Glutamate Oxaloacetate Transaminase (GOT) Activity. To detect GOT activity, approximately 0.1 g of grape that had been frozen at -80°C two months prior was weighed and ground in an ice bath with 1 mL of the extraction solution that was provided in the GOT kit (Solarbio, China). The mixture was then centrifuged at 3500 g and 4°C for 10 minutes, and the resulting supernatant was collected for analysis. The GOT activity was determined using a kit from Solarbio (China), following the manufacturer's instructions. In brief, reagents, supernatant, and standard solutions were added sequentially to an EP tube, and the absorbance was measured at 505 nm using a spectrophotometer. The test was repeated three times, and the enzyme activity was presented as U/g. A standard curve was established using the kit reference, with the following equation: $y = 0.726x + 0.0204$ (y: absorbency value; x: concentration; $R^2 = 0.9964$).

2.4. Glutamate Pyruvate Transaminase (GPT) Activity. The experimental method was the same as the above. All the required reagents came from a GPT kit (Solarbio, China), and the operation was performed according to the standard procedures. The equation is as follows: $y = 0.5682x + 0.0171$ (y: absorbency value; x: concentration; $R^2 = 0.9962$).

2.5. Pyruvate Dehydrogenase (PDH) Activity. To prepare the samples, 0.1 g of the grape was ground and transferred to an EP tube containing the extract. The mixture was then centrifuged at 11000 g and 4°C for 10 min, and the supernatant was collected. Then, 50 μL of the supernatant was mixed with 900 μL of working fluid, and the absorbance was recorded at 470 nm at 10 s and 70 s. The difference between the two measurements was calculated as ΔA. A blank was prepared using distilled water instead of the sample, and the measured value was recorded as ΔB. Enzyme activity was calculated using the following formula:

$$\text{PDH activity} = \frac{913.81\,(\Delta A - \Delta B)}{0.1}. \quad (2)$$

The test was repeated for three times to obtain the average value. Enzyme activity units were presented as U/g.

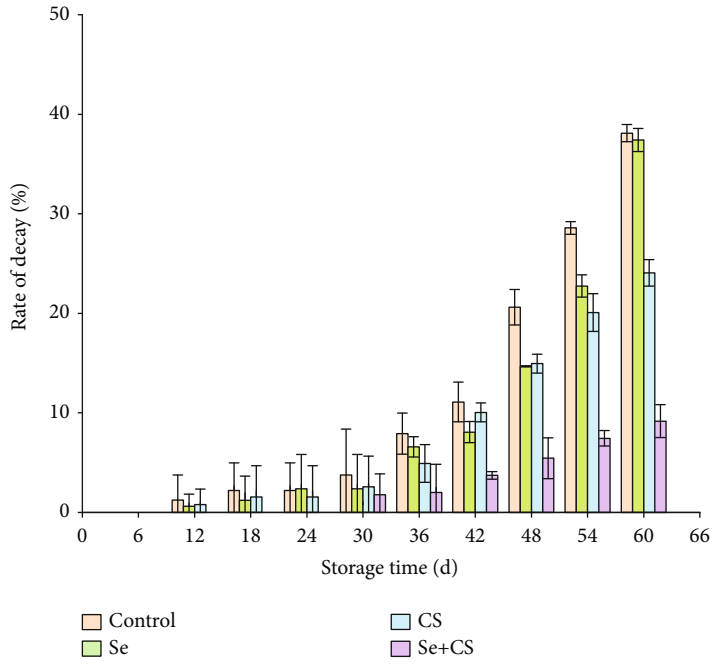


FIGURE 1: Analysis of decay rate of grape. Different letters represent significant differences in the same group during storage ($P < 0.05$) by Duncan's multiple range tests.

2.6. Amino Acid Content. The amino acid analysis of grape samples was conducted in accordance with the Chinese National Food Safety Standard method GB 5009.124-2016. The amino acid content was analyzed using an amino acid analyzer (Biochrom 30+, DKSH, UK) based on ion exchange chromatography with postcolumn ninhydrin derivatization. The results were reported as g kg^{-1}.

2.7. Volatile Components. A 5.0 g grape sample was placed in a 15 mL solid-phase microextraction (SPME) vial with 1.0 g of NaCl. The vial was equilibrated for 20 min and then extracted for 40 min at 50°C. The analysis of volatile compounds was performed using a GC-MS apparatus (GC-MS3100, EWAI, China).

GC Conditions: the analytes extracted from the fiber were desorbed at 250°C and separated on a 57298-U column (DVB/CAR/PDMS) using the following temperature program: 40°C for 3 min, increased to 150°C at a rate of 5°C/min, then increased to 220°C at a rate of 10°C/min, and held for 10 min.

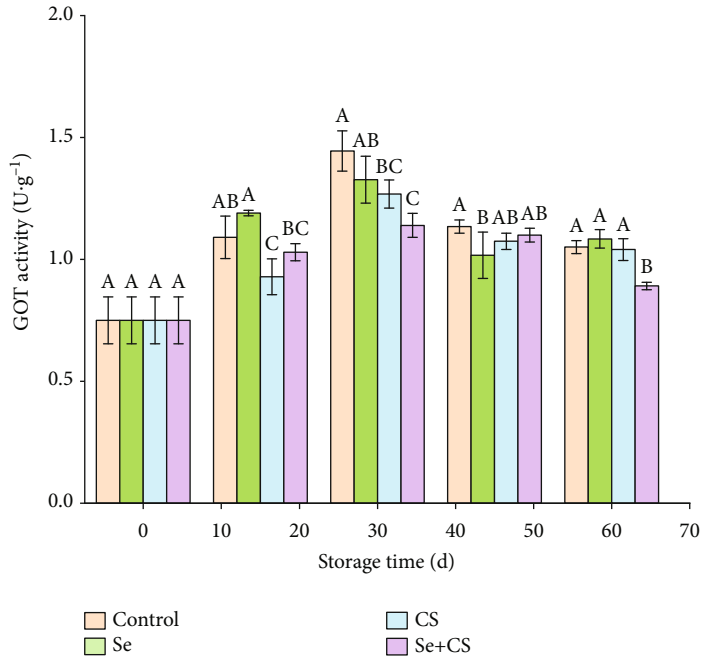
MS Conditions: the electron ionization source temperature was set at 250°C, and mass scanning was performed over a range of 35 to 500 m/z. Helium was used as the carrier gas with a flow rate of 1.0 mL/min.

2.8. Statistical Analysis. Statistical analysis was performed using OriginPro 2021 (Origin Lab Inc., Northampton, Massachusetts, USA) and SPSS v. 20 software (SPSS Inc., Chicago, Illinois, USA). Standard deviation, one-way ANOVA, and Pearson's correlation analysis were calculated using SPSS. The experiments were conducted in triplicate.

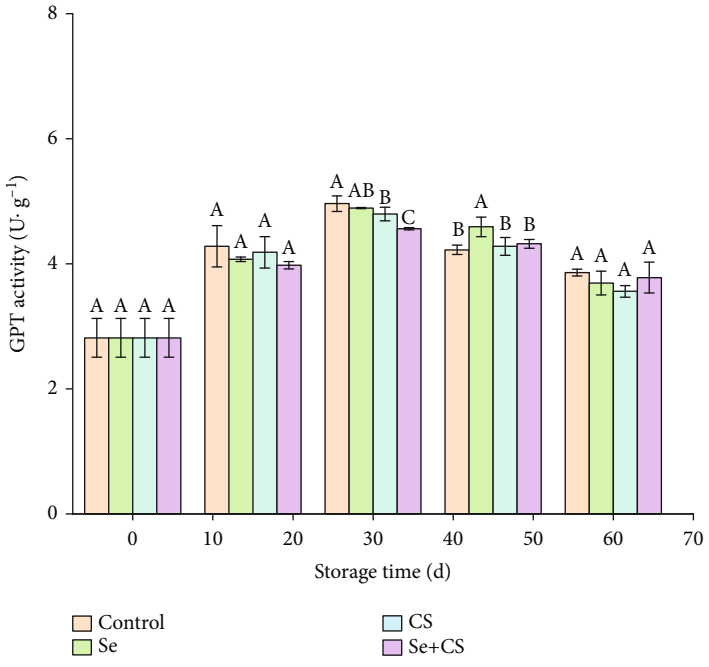
3. Results and Discussion

3.1. Analysis of Grape Decay Rate. The decay rate is an essential parameter to measure the quality of Red Globe grapes. As shown in Figure 1, the decay rate of both the experimental and control groups increased consistently with the extension of storage time. From 0 d to 30 d, there was no significant difference observed between the experimental and control groups. However, from 30 d to 60 d, the grape samples treated with Se+CS exhibited a lower decay rate as compared to the control, Se-treated, and CS-treated groups. Additionally, the grape samples treated with Se and CS individually also had a lower decay rate than the control group. This finding is consistent with previous reports, which showed that selenium and chitosan possess antimicrobial properties that can reduce fruit decay rate [32, 33]. Overall, these results suggested that the Se+CS treatment positively affected grape quality by inhibiting rot for a more extended period than the other treatments.

3.2. Analysis of Enzyme Activities. GOT is a widely distributed transaminase in plants that catalyzes the transfer of α-ketoacids and aspartate to glutamate and oxaloacetate [34, 35]. It is closely related to plant respiration, and GPT and PDH are both crucial enzymes in amino acid metabolism. According to He and Wu's [36] study, high activities of GPT and GOT can activate the catabolism of glutamate, alanine, and aspartate. As shown in Figure 2, the activities of GOT, GPT, and PDH showed a rising and falling trend, reaching their highest levels at 30 d. GOT activity was lower in the Se+CS-treated grapes than in other groups (Figure 2(a)). After the Se+CS treatment, GPT activity was significantly lower than other treatments at 30 d of storage,



(a)



(b)

Figure 2: Continued.

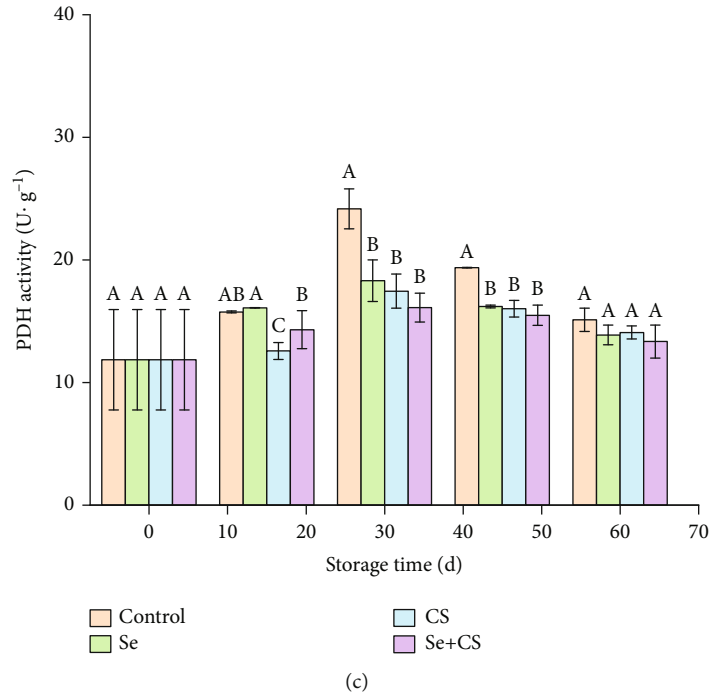


Figure 2: GOT, GPT, and PDH activities were validated. (a) GOT. (b) GPT. (c) PDH. Different letters represent significant differences in the same group during storage ($P < 0.05$) by Duncan's multiple range tests.

but no significant differences were observed between treatments before or after storage (Figure 2(b)). Therefore, based on these findings, it was tempting to speculate that an efficient accumulation of glutamate and aspartate could be achieved by inhibiting GOT and GPT activities with the Se +CS treatment. Interestingly, although the PDH activity of the treated groups was lower than that of the control group, there were no significant differences among the treated groups (Figure 2(c)).

3.3. Analysis of Amino Acid Content. The analysis of amino acid content in grapes has revealed that they possess antioxidant, antibacterial, and emulsifying properties, which can play a crucial role in improving food flavor and human physiological mobility [37].

In this study, fifteen individual amino acids were detected in Red Globe grapes, including six essential amino acid acids. As shown in Figure 3(a), the treated groups not only stimulated amino acid accumulation before day 30 but also inhibited amino acid degradation after day 30. Interestingly, the Se+CS treatment had a better effect than other treatments. Among all amino acids, glutamate and arginine were found to have the highest content (Table 1). Furthermore, nonessential amino acids like aspartic acid and glutamic acid had significantly higher content in the Se+CS groups on days 30 and 45. It has been reported that these amino acids, along with alanine, contributed to enhancing the flavor of food and imparting a pleasant sweet taste [38]. Thus, it is noteworthy that the Se+CS treatment could enhance the flavor by increasing the content of aspartic acid and glutamic acid. Interestingly, we also found that the Se treatment resulted in higher amino acid content than the single-chitosan treatment, which aligns with previous studies in heavy metal-treated plants [39] and selenium-treated Arabidopsis [40]. These findings highlight the potential of selenium-based treatments in enhancing the amino acid content of grapes and other plants, which could ultimately improve food quality and human health.

The human body cannot synthesize essential amino acids, and they must be obtained from food sources [41]. In this study, the Se+CS treatment demonstrated a protective effect on the essential amino acids of grapes (Figure 3(b)). Interestingly, essential amino acids have a specific impact on food flavor, with sweet amino acids like threonine and lysine contributing to a pleasant taste, while bitter amino acids like tryptophan, valine, isoleucine, leucine, and phenylalanine impart a bitter taste [42]. Surprisingly, in the Se+CS treatment of Red Globe grapes, the content of bitter amino acids was higher than that of sweet amino acids among the critical amino acids, indicating that the increase in essential amino acids may have a negative influence on the flavor of the Red Globe grapes. However, the total of threonine and lysine was much higher than the crucial amino acids, suggesting that the negative effect on flavor may be canceled out.

In addition to flavor, the increase in arginine content in grapes can also enhance their anticancer efficacy and cardiovascular disease inhibition. Studies have confirmed that arginine improved microcirculation in cerebral blood flow and reduced the frequency of stroke-like episodes [43]. Further, arginine not only improves the anticancer effect but also enhances the efficacy of other anticancer therapeutics [44].

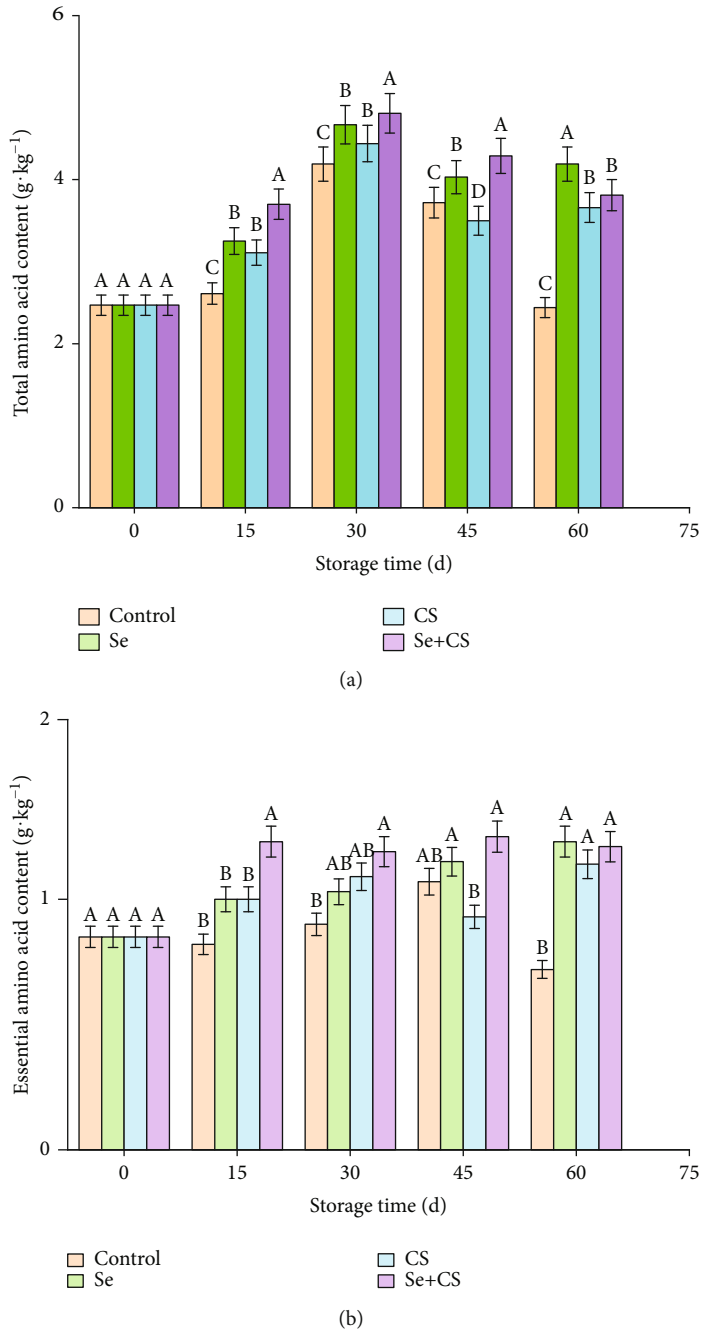


Figure 3: The content of total amino acid and essential amino acid with Se+CS treatment during storage. Different letters represent significant differences in the same group during storage ($P < 0.05$) by Duncan's multiple range tests.

Therefore, the increase in arginine content in grapes through the Se+CS treatment has significant potential health benefits for humans.

In summary, the Se+CS treatment demonstrated a significant increase in the content of total amino acids and essential amino acids in the Red Globe grape. The increase in threonine and lysine content was particularly noteworthy, as it contributed to the umami taste of the grapes. Additionally, the Se+CS treatment showed potential for improving the anticancer efficacy and preventing cardiovascular disease in grapes due to the increase in arginine content. Overall, the Se+CS treatment has the potential to enhance both the nutritional value and flavor of grapes while also providing significant health benefits for human consumption.

3.4. Analysis of Volatile Components. After using HS-SPME, the volatile compounds were separated by column and identified through GC-MS analysis, and a total of forty volatile compounds were identified in the Red Globe grape, including aldehyde, alcohol, phenol, and acid. The highest concentration was found to be of aldehydes, followed by alcohols (Table 2). It was noteworthy that the Se+CS treatment

Table 1: Amino acid content of grape with Se+CS treatment during storage.

Amina acids	Storage 0 d	Storage 15 d				Storage 30 d				Storage 45 d				Storage 60 d			
		Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS
Aspartic	0.26	0.25	0.34	0.34	0.29	0.32	0.29	0.27	0.35	0.30	0.31	0.24	0.36	0.29	0.37	0.27	0.30
Threonine	0.13	0.14	0.17	0.16	0.16	0.17	0.16	0.15	0.17	0.18	0.17	0.14	0.18	0.14	0.18	0.18	0.14
Serine	0.14	0.15	0.18	0.17	0.18	0.18	0.17	0.16	0.18	0.19	0.19	0.15	0.18	0.15	0.18	0.16	0.15
Glutamate	0.40	0.45	0.67	0.55	0.43	0.49	0.42	0.46	0.51	0.39	0.44	0.40	0.48	0.34	0.46	0.41	0.50
Proline	0.15	0.19	0.19	0.18	0.19	0.19	0.19	0.19	0.19	0.15	0.20	0.18	0.23	0.17	0.17	0.16	0.11
Glycine	0.13	0.14	0.17	0.17	0.17	0.18	0.16	0.15	0.18	0.19	0.18	0.14	0.18	0.16	0.18	0.16	0.15
Alanine	0.17	0.18	0.20	0.19	0.21	0.20	0.20	0.22	0.19	0.21	0.24	0.18	0.22	0.16	0.20	0.17	0.20
Valine	0.15	0.15	0.18	0.18	0.17	0.18	0.18	0.15	0.24	0.21	0.19	0.16	0.22	0.15	0.21	0.20	0.15
Isoleucine	0.10	0.11	0.14	0.14	0.13	0.13	0.13	0.11	0.15	0.16	0.15	0.12	0.16	0.23	0.15	0.16	0.10
Leucine	0.18	0.18	0.22	0.23	0.20	0.21	0.21	0.27	0.17	0.16	0.23	0.19	0.25	0.12	0.25	0.22	0.17
Phenylalanine	0.11	0.10	0.12	0.11	0.10	0.14	0.13	0.18	0.17	0.16	0.16	0.12	0.16	0.12	0.16	0.18	0.12
Histidine	0.15	0.011	0.15	0.15	0.15	0.19	0.18	0.16	0.20	0.18	0.19	0.19	0.24	0.14	0.24	0.25	0.22
Lysine	0.18	0.14	0.17	0.18	0.18	0.27	0.22	0.23	0.29	0.28	0.25	0.20	0.28	0.057	0.26	0.20	0.20
Arginine	0.11	0.21	0.23	0.25	0.24	1.20	1.10	1.20	0.93	0.86	1.02	1.00	1.07	0.023	1.10	0.83	1.20
Tryptophan	0.11	0.11	0.12	0.11	0.90	0.14	0.93	0.54	0.89	0.10	0.11	0.089	0.08	0.19	0.08	0.11	0.10

Table 2: Volatile components of grape with Se+CS treatment during storage.

Volatile components	Relative content (%)																
	Storage 0 d	Storage 15 d				Storage 30 d				Storage 45 d				Storage 60 d			
		Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS
Pentanal	—	0.08	0.14	—	0.13	0.09	—	—	0.12	—	0.01	—	—	—	—	—	—
Hexanal	36.23	31.20	33.19	30.26	31.99	21.60	31.99	26.05	34.98	30.95	37.82	36.62	39.63	33.43	38.06	41.30	41.92
Heptanal	0.17	0.33	0.14	—	0.19	0.14	—	—	0.12	0.20	0.24	0.14	0.21	—	0.24	0.16	0.19
Octanal	0.29	0.55	0.29	0.21	0.53	0.21	0.18	0.30	0.18	0.42	0.45	0.37	0.46	0.51	0.59	0.32	0.39
Nonanal	0.42	0.39	0.46	0.49	1.03	0.51	0.34	0.53	0.31	0.47	0.77	0.58	0.58	0.57	1.08	0.37	0.44
Decanal	0.11	0.31	0.08	0.11	0.17	0.08	—	0.04	0.06	—	—	0.04	—	0.14	0.10	0.02	0.02
2-Hexenol	0.34	0.13	0.18	0.28	0.12	0.32	0.15	0.71	0.31	1.05	1.25	0.81	1.03	0.21	0.44	0.85	0.48
Benzaldehyde	—	—	0.14	0.21	—	0.95	0.38	0.84	0.85	—	—	—	—	0.24	1.22	—	1.15
β-Cyclocitral	—	—	0.05	0.04	—	—	—	0.03	0.05	—	0.06	—	—	—	—	—	—
Trans-2-hexenal	54.33	56.27	56.73	57.15	57.95	50.40	56.05	55.49	56.37	46.85	49.97	50.94	54.13	46.60	48.12	49.87	50.83
2,4-Bis(1,1-dimethylethyl)-5-methyl-phenol	0.04	0.10	0.13	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—
2,6-Di-tert-butyl-4-methylphenol	—	—	—	—	—	—	—	—	—	0.04	—	—	0.05	0.04	0.06	0.02	0.02
Pentanoate	—	—	—	0.11	—	1.59	—	—	—	—	0.01	0.03	—	—	—	1.54	0.01
Acetic acid	0.05	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Propanoic acid	0.04	—	0.02	—	—	—	—	1.11	—	—	—	1.12	0.27	—	1.34	0.01	0.14
3-Aminoisobutyric acid	—	—	—	—	1.18	0.01	1.35	0.04	—	0.42	—	—	—	—	—	0.01	0.93
n-Hexanol	6.21	5.00	6.90	7.55	4.17	11.04	3.97	11.65	2.00	9.00	4.00	9.00	2.87	5.55	3.00	3.06	1.00
2-Aminoethanol	0.01	—	—	—	—	2.62	1.74	1.66	1.34	1.90	0.03	—	—	—	—	—	—
α-Cadinol	—	—	—	—	—	—	0.04	—	—	—	0.02	0.03	—	—	—	—	—
Cis-4-methylcyclohexanol	—	—	—	—	—	—	—	—	—	—	—	—	0.11	0.10	0.08	0.09	—
Cis-2-hexen-1-ol	—	0.00	0.31	0.29	—	—	—	—	—	—	—	—	—	—	—	—	—
Trans-2-hexen-1-ol	—	2.17	—	—	—	1.32	0.70	0.50	—	—	—	—	—	8.14	0.81	—	—
Trans-2-methylcyclopentanol	—	0.00	—	—	0.06	—	—	0.04	—	—	—	—	—	0.16	—	—	—
3,7-Dimethyl-2,6-octadienyl-3-ol	—	0.03	—	—	0.02	—	—	0.02	0.04	—	—	—	—	—	—	—	—
(-)-Limonene	—	—	0.42	—	—	—	—	—	—	—	0.23	—	0.20	0.35	0.29	0.21	0.22
1-Caryophyllene	—	—	—	—	—	0.36	0.25	—	0.11	0.43	0.91	—	—	—	—	—	—
β-Caryophyllene	—	—	—	—	—	—	0.37	—	0.07	—	0.58	—	—	—	—	—	—
(+)-Limonene	0.21	0.89	—	0.65	0.43	—	0.27	0.24	0.32	0.75	—	—	—	—	—	—	—
Camphor	0.03	0.04	0.07	0.06	0.07	0.03	—	—	0.05	—	—	—	0.04	—	0.05	0.04	0.03
β-Damascone	0.06	0.21	0.17	—	0.34	0.11	—	0.11	0.17	0.05	0.25	0.14	0.28	0.20	0.02	0.12	0.21
Methylheptenone	—	0.33	0.50	0.44	0.14	0.31	—	0.24	0.31	—	—	—	—	—	—	—	—
2,2,6-Trimethylcyclohexanone	—	—	—	—	0.03	—	—	—	0.02	0.01	0.04	0.03	0.02	—	—	0.01	0.02
Isoamyl isobutyrate	—	—	—	—	—	1.33	0.24	0.30	0.26	—	—	—	—	—	—	—	—
Bornyl isovalerate	0.01	—	0.02	—	0.03	0.02	—	—	0.01	—	—	—	0.03	—	0.01	0.01	—

Table 2: Continued.

Volatile components	Relative content (%)																
	Storage 0 d	Storage 15 d				Storage 30 d				Storage 45 d				Storage 60 d			
		Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS	Control	Se	CS	Se+CS
Camphor	—	—	—	—	—	—	0.04	0.04	—	—	—	—	—	0.04	—	—	—
2-Ethyl-1,3-hexanediol	—	—	—	—	—	—	—	—	—	0.07	0.10	0.10	0.06	0.10	0.07	0.04	0.10
Toluene	—	0.03	0.05	—	0.05	0.02	0.04	0.02	—	0.06	—	—	0.01	—	—	0.02	0.03
Hydroxyurea	1.44	—	—	1.62	1.34	1.82	—	—	1.68	1.94	—	—	—	—	1.70	1.86	1.84
Semicarbazide	—	0.22	—	—	0.02	2.53	1.64	—	0.04	1.48	1.81	—	—	—	—	—	—
2-Hydroxypropionamide	—	1.35	—	—	—	2.55	—	—	0.21	3.21	1.02	—	—	3.44	2.54	—	—
Aldehydes	91.90	89.26	91.40	88.76	92.12	74.29	89.10	84.00	93.36	79.94	90.57	89.50	96.04	81.70	89.86	92.90	95.43
Alcohols	6.22	7.21	7.21	7.84	4.25	14.98	6.44	13.88	3.39	10.91	4.06	9.03	2.97	13.96	3.90	3.14	1.00
Phenols	0.04	0.10	0.13	—	—	0.05	—	—	—	0.04	—	—	0.05	0.04	0.06	0.02	0.02
Acids	0.09	0.02	0.02	0.11	1.18	1.60	1.35	1.15	—	0.42	0.01	1.15	0.27	—	1.34	1.56	1.08
Alkenes	0.21	0.89	0.42	0.65	0.43	0.36	0.89	0.24	0.50	1.19	1.72	—	0.20	0.35	0.29	0.21	0.22
Ketones	0.09	0.58	0.74	0.49	0.58	0.45	—	0.36	0.55	0.06	0.29	0.17	0.34	0.20	0.07	0.18	0.27
Lipids	0.01	—	0.02	—	0.03	1.35	0.24	0.30	0.27	—	—	—	0.03	—	0.01	0.01	—
Other	1.44	1.60	0.05	1.62	1.41	6.92	1.71	0.07	1.94	6.77	2.93	0.10	0.07	3.59	4.31	1.92	1.97

Table 3: Pearson's correlation coefficients (r) for correlations between the measured parameters in early stage (days 0 to 30) and late stage (days 30 to 60).

(a) All subjects

	GOT	GPT	PDH	Amino acids	Aldehydes	Alcohols
GOT	1					
GPT	0.971**	1				
PDH	0.989**	0.974**	1			
Amino acids	0.928*	0.984**	0.955*	1		
Aldehydes	0.332	0.468	0.381	0.511	1	
Alcohols	-0.521	-0.708	-0.566	-0.779	-0.728	1

(b) Early stage

	GOT	GPT	PDH	Amino acids	Aldehydes	Alcohols
GOT	1					
GPT	0.999*	1				
PDH	0.987	0.994	1			
Amino acids	0.977	0.987	0.999*	1		
Aldehydes	0.808	0.839	0.893	0.916	1	
Alcohols	-1.000*	-1.000*	-0.990	-0.981	-0.822	1

(c) Late stage

	GOT	GPT	PDH	Amino acids	Aldehydes	Alcohols
GOT	1					
GPT	0.998*	1				
PDH	1.000*	0.997	1			
Amino acids	0.954	0.971	0.948	1		
Aldehydes	-0.520	-0.573	-0.502	-0.752	1	
Alcohols	0.997*	0.990	0.998*	0.928	-0.453	1

Note: ** indicates that the correlation was significant at the 0.01 level (two tailed), while * indicates that the correlation was significant at the 0.05 level (two tailed).

significantly promoted the accumulation of aldehydes, specifically trans-2-hexenal ($C_6H_{10}O$) and hexanal ($C_6H_{12}O$). Conversely, other treatment groups showed the opposite effects. Moreover, the Se+CS treatment inhibited the increase of alcohols, and the content of alcohols was lower than that of the control group during storage, mainly due to the decrease in n-hexyl alcohol.

Previous studies had reported that hexanal and trans-2-hexenal are strongly associated with the flavor of fruits, such as apple, pear, and cherry [45–47]. These compounds are known to have fatty–grassy and green–fruity notes, respectively [48]. In the control group, a decreasing trend of hexanal and trans-2-hexenal was observed during storage, which was consistent with the findings of Buvé et al. [49]. However, the content of hexanal and trans-2-hexenal in the grapes treated with Se+CS was higher than that in other treatment groups, suggesting that the Se+CS treatment could improve the flavor of the grape. In addition, hexanal has been shown to extend the shelf life of perishable products [50], and thus, we can speculate that the delay in the rotting of grapes with the Se+CS treatment is likely due to the increased content of hexanal.

It has been reported that alcohols can be produced in fruits through the transamination, decarboxylation, and reduction/oxidation of amino acids under the action of various enzymes [51]. A previous study has described n-hexanol as having a green scent [52], which can contribute to the unique flavor of some fruits and vegetables. However, the content of n-hexanol was reduced by the Se+CS treatment in grapes, indicating that this volatile compound may have a limited effect on the overall aroma contribution to the flavor of grape fruits.

3.5. Analysis of the Correlation. Table 3 summarizes the correlation analysis between measured parameters after the Se +CS treatment. In Table 3(a), the amino acid level was found to be positively correlated with the activities of GOT, GPT, and PDH. Interestingly, the alcohol level showed a negative correlation with the activities of GOT and GPT from day 0 to day 30 ($r = -1.000$ and -1.000, $P < 0.05$), while it was

positively correlated with the activities of GOT and PDH from day 30 to day 60 ($r = 0.997$ and 0.998, $P < 0.05$). However, no significant correlation was observed between the levels of aldehydes and alcohols and the levels of amino acids.

4. Conclusions

In conclusion, the combined application of 25 mg L^{-1} selenium and 1.0% chitosan was effective in improving the flavor of a Red Globe grape by promoting total amino acids and aldehyde components while reducing the activities of the GOT, PDH, and GPT enzymes, as well as alcohol components. These findings suggested that the coapplication of selenium and chitosan can be a practical approach for enhancing the flavor of Red Globe grapes. The results of this research provided a sustainable, ecofriendly, safe, and efficient way to enhance grape quality, amino acids, and flavor.

Data Availability

Data is not applicable to this study.

Conflicts of Interest

There is no conflict of interest to declare.

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