Journal of the American Pomological Society 74(5): 274-283 2020

Yield and fruit quality evaluation of 'Yueguangwuhe' grapes *(Vitis vinifera* x *V. labrusca)* grafted on different rootstocks

Nan Jia, Yonggang Yin, Minmin Li, Junwei Yuan, Changjiang Liu, Bin Han, Yan Sun, Shengjian Zhao, and Zijuan Guo[1]

Additional index words: table grape, grafting, yield factor, fruit quality parameters, comprehensive evaluation

Abstract

The purpose of this study was to evaluate fruit yield and berry quality parameters of 'Yueguangwuhe' grapevines grafted on eight rootstocks (SO4, 101-14M, 3309C, 188-08, 110R, 5C, 5BB and Beta, with own root as control) over three consecutive years. The results revealed that the greatest difference of fruit yield existed between vines on SO4 and 5BB which were both notably different from control. Vines on 101-14M produced the highest fruit berry weight, berry vertical diameter, berry horizontal diameter, total soluble solids concentration (TSS) and pressure resistance and the lowest values of titratable acidity (TA) and pulling resistance. The highest values of cluster weight and flesh firmness were obtained with SO4. Overall, SO4 and 101-14M performed better than all other rootstocks and control. These results could provide a valuable reference for cultivation of table grapes.

Grape (*Vitis vinifera* L.) is one of the most important fruits in the world. China has the largest number of table grape growers worldwide and around 2.9 million farmers grow table grapes on 540 thousand hectares (Wang et al., 2017). Now, with the improvement of people's living standard and the change of ecological environment, there are many challenges in grape production such as different climate and soil types, high-quality fruits demanded by consumers, the instability of production and the decreasing area of cultivated land. Grafting is an effective way to adapt to the environment including biological stresses such as nematodes and phylloxera (Smith et al., 2017) and abiotic stresses such as drought, poor pH, saline-alkali soil, wet soil and limestone soil (Bavaresco et al., 2003; Elaidy et al., 2019; Soylemezoglu et al., 2009). Moderate vigor rootstocks may improve the grape yield and fruit quality (da Silva et al., 2018; Tecchio et al., 2020). However, many researchers paid more attention to the yield and quality of wine grape berries grafted on different rootstocks (Ozden et al., 2010; Pulko et al., 2012; Wooldridge et al., 2010) and fewer rootstock trials have been performed with table grapes (Chou and Li, 2014).

'Yueguangwuhe' (*Vitis vinifera* x 'Kyoho'), a seedless purple black table grape, is a triploid hybrid from 'Muscat Hamburg' x 'Kyoho' bred in China. It has a unique fruit taste with sweet flavor, crunchy flesh and strawberry aroma which are preferred by Chinese consumers (Cao et al., 2014; Zhou et al., 2015). Nevertheless, its yield and quality on non-grafted vines needs to be further improved in some growing areas, which makes it necessary to select proper rootstocks that could help to produce vines with higher yield and better fruit quality. Yet, our knowledge about the performance of the grafted table grapes is still very poor. Therefore, fruit

[1] Changli Research Institute of Fruit Trees, Hebei Academy of Agricultural and Forestry Sciences, Changli, Hebei, 066600, China
Corresponding author: grapesworks@outlook.com
The authors thank for the support from the China Agriculture Research System for Grape Industry (CARS-30) and Natural Science Foundation of Hebei Province (C2019301034 andC2019301115)

Table 1. The genetic origin of eight grape rootstocks and degree of tolerance to phylloxera, drought, cold hardiness, and salinity.

Usual name	Genetic origin	Phylloxera	Drought	Cold hardiness	Salinity
5BB	*V. berlandieri* × *V. riparia*	high	low	high	sensitive
5C	*V. berlandieri* × *V. riparia*	high	low	-	medium
101-14 M	*V. riparia* × *V. rupestris*	high	very low	medium	high
SO4	*V. berlandieri* × *V. riparia*	high	low	high	sensitive
110 R	*V. berlandieri* × *V. rupestris*	high	high	medium	medium
188-08	*V. berlandieri* × *V. riparia*	-	-	-	sensitive
Beta	*V. riparia* × *V. labrusca*	-	-	high	medium
3309 C	*V. riparia* × *V. rupestris*	high	very low	medium	medium

yield and berry quality related traits of 'Yueguangwuhe' grapevines grafted on different rootstocks were determined to provide experimental evidence for the use of rootstocks for table grapes.

Materials and Methods

Grapevine materials and experimental design. 'Yueguangwuhe' scion was grafted onto eight rootstocks (Beta, 101-14M, 5BB, SO4, 3309C, 110R, 188-08, and 5C) and nongrafted vines, defined as own-rooted vines, were used as a control. The main characteristics including the genetic origin (Riaz et al., 2019), and tolerance to phylloxera (Whiting, 2005), drought (Dry, 2007), salinity (Yuan et al., 2019), cold hardiness (Gao et al., 2014) of the rootstocks are shown in Table 1. The scions were grafted on hardwood cuttings in early April 2010. Grafted and own-rooted vines were grown in a nursery for almost a month until they were transplanted in the field. The five-year-old grapevines were used in this trial.

Vines planting and management. The experiment was conducted in an experimental vineyard located in Kongzhuang, Changli City (39°78'N, 119°20'E) northeast of Hebei Province, China. Changli is one of the main table grape producing areas with a temperate subhumid continental climate. The climate conditions, including temperature, sunshine duration, rainfall, are showed in table 2. The vines were planted on a typical loamy soil with the pH of 6.82 and 1.68% soil organic matter. Vines were planted at a spacing of 0.7x4.0 m and trained to a single wire trellis system with a height of 1.8m. The experiment was a randomized block design with three replications. Each replication consisted of 10 vines. The vines were pruned leaving 6-8 fruiting shoots with 2-3 nodes. Inflorescence was treated with a dip of 20 mg/L GA3 during blossom and the same treatment was repeated 15 days later. Irrigation was mainly in dry season from Oct. to Mar. and fertilization was based on the critical phenological period. Black plastic film mulch provided weed control and a polyethylene screen was used to prevent bird attack.

Fruit yield. The fruits were harvested in late Aug. for three consecutive years (2015-2017). Bunches per vine and average cluster weight were recorded. Yield/vine was deter-

Table 2. Meteorological data of the experimental field 'Yueguangwuhe' vines from Apr. to Oct. in 2015-2017.

Year	Mean air temperature (℃)	Total precipitation (mm)	Total sunshine duration (h)	Soil temperature(℃)		
				0 cm	10 cm	20 cm
2015	20.4	560.3	1815.8	22.7	21.5	21.3
2016	20.5	831.9	1731.8	23.1	21.7	21.5
2017	20.9	572.0	1599.2	24.1	22.2	21.9

mined as number of bunches per vine x average cluster weight.

Fruit quality. Twenty clusters were randomly sampled from each replication and weighted using an electronic balance of 0.1 g accuracy. A total of 200 berries were randomly sampled from the shoulder, middle and tail of weighted clusters. Ten berries from each replication were used to measure berry weight with a scale of one-percent accuracy. The berry vertical diameter and berry horizontal diameter of 10 berries from each repetition were determined with a digital caliper. Fifteen berries from each replication were juiced with a fresh squeeze juicer to determine the total soluble solids concentration (TSS) and titratable acid (TA). The TSS and TA were analyzed using a digital refractometer (PAL-1, Atago, Tokyo, Japan) and fruit acidity meter (GMK-835F, G-WON Hitech Co., Ltd, Seoul, Korea), respectively. TSS was expressed in units of %. TA was expressed as percentage of citric acid. Flesh firmness of ten berries from each replication was tested at the center of the peeled berry side with a fruit hardness tester (KM-1, Takemura Electric Works, Tokyo, Japan) equipped with a 5 mm-diameter cylinder tip (5mm). Pressure resistance and pulling resistance were measured using a fruit pressure-tension tester (NK-30, Algol Instrument, CO., LTD, Taiwan, China) and each indexes used ten berries in each replication.

Statistical analysis. Data were analyzed by analysis of variance using SPSS software (version 20.0). The comparison of means was by Duncan's multiple range test at $P < 0.05$. Principal component analysis (PCA) was applied to all measured attributes via XLSTAT statistical software version 2019 (Addinsoft, Boston, USA). Additionally, the influence on yield and fruit quality of 'Yueguangwuhe' grafted on different rootstocks was assessed using the subordinate function value method (Hou et al., 2010; Shen et al., 2010; Yang et al., 2015). This method is used to calculate the evaluation value of each index of each treatment (rootstock-scion combination), and then the evaluation value is accumulated to obtain the comprehensive evaluation value of the treatment.

Membership function value was determined by the formula (1):

$$X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \times \alpha + (1 - \alpha) \quad (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (1)$$

In this formula, X'_{ij} was membership function value; X_{ij} was the raw data value of the j[th] index from the i[th] treatment; (X_i) was the minimum value of the j[th] index; $\max(X_i)$ was the maximum value of the j[th] index; α was the efficacy coefficient (= 0.6).

Weight value was determined by the formula (2), (3) and (4):

$$f_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}}, i = 1,2,\dots,m; j = 1,2,\dots,n \quad (2)$$

$$H_j = -\frac{1}{\ln m}\sum_{i=1}^{m} f_{ij} \ln f_{ij} \quad (3)$$

$$W_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j} \quad (4)$$

In this formula, H_i was the entropy value of the j[th] index. H_i was the weight value of j[th] index.

Comprehensive evaluating value by the formula (5):

$$R_i = \sum_{j=1}^{n} X'_{ij} W_j \quad (5)$$

In this formula, R_i was the comprehensive evaluation value.

The comprehensive results were ranked by the evaluation value. The higher comprehensive evaluating value represented the better comprehensive performance of the rootstock-scion combination.

Results

Fruit yield. Both the rootstocks and harvest year, but not their interaction, had a significant impact on fruit yield (Table 3). Yield increased year by year from 2015 to 2017 (Table 3). The three-year average yields (2015-2017) are presented in Table 3. The highest yield was produced by SO4 (4.96 kg/vine) while 5BB had the lowest yield (3.48 kg/vine). Yield for both of these rootstocks

Table 3. Yield and fruit characteristics of 'Yueguangwuhe' table grape berries as influenced by 8 rootstocks over three years (2015-2017) [z].

Rootstock	Yield (kg/vine)	Cluster weight (g)	Berry weight (g)	Berry vertical diameter (mm)	Berry horizontal diameter (mm)
Own root	3.72 e	478.3 def [y]	6.73 c	24.86 c	21.43 c
Beta	4.61 b	575.8 b	6.82 bc	24.89 c	21.47 c
101-14M	4.02 d	506.3 cd	7.23 a	26.06 a	22.29 a
5BB	3.48 f	460.5 f	6.78 c	24.92 c	21.68 bc
SO4	4.96 a	624.6 a	7.08 ab	25.35 bc	22.05 ab
3309C	4.38 c	581.7 b	7.20 a	25.73 ab	22.24 a
110R	4.13 d	525.2 c	7.09 ab	25.34 bc	22.03 ab
188-08	3.68 ef	473.9 ef	7.25 a	26.21 a	22.48 a
5C	3.74 e	500.3 cde	6.88 bc	25.01 c	21.73 bc
Year					
2015	3.92 c	505.3 b	7.07 a	25.80 a	22.02 a
2016	4.05 b	519.7 b	7.04 a	24.93 c	21.82 a
2017	4.27 a	550.6 a	6.90 b	25.39 b	21.96 a
Year (*P* value)	<.001	<.001	0.012	<.001	0.315
Rootstock (*P* value)	<.001	<.001	<.001	<.001	<.001
Year×Rootstock (*P* value)	0.613	0.887	0.157	0.210	0.917

[z] Yield and fruit quality data presented for individual rootstocks were averaged over years 2015–2017.
[y] Means within rootstocks and years followed by common letters do not differ by Duncan's multiple range test at P < 0.05.

differed significantly from the control (3.72 kg/vine). Yields for 188-08 and 5C and all the other rootstocks, 101-14M, 3309C, 110R and Beta, had higher yields than own rooted vines. In short, higher yield was obtained with SO4 and Beta, intermediate yield with 101-14M, 110R and 3309C, and lowest yield with 5BB, 188-08, 5C and control.

Fruit quality. Fruit quality parameters including cluster weight and berry size and internal quality parameters were evaluated for each harvest (2015-2017). Analysis of variance for main effects of harvest year and rootstock were highly significant for fruit quality parameters, including cluster weight, berry weight, berry vertical diameter, TSS and TA averaged over the three years (Tables 3 and 4). There was a significant interaction for year x rootstock for TSS and TA. Berry horizontal diameter, flesh firmness, pressure resistance and pulling resistance were significantly affected by only the rootstocks

Table 4. Internal berry quality of 'Yueguangwuhe' grapes as influenced by 8 rootstocks for three years (2015–2017) [z].

Rootstock	TSS (%) [y]	TA (%) [x]	Flesh firmness (kg/cm^2)	Pressure resistance（N）	Pulling resistance (N)
Own root	18.0 d [w]	0.81c	0.66 d	23.02 cd	5.36 cd
Beta	19.0 b	0.79 cd	0.67 d	23.32 bc	5.24 d
101-14M	19.4 a	0.78 d	0.85 b	25.67 a	4.74 e
5BB	18.1 d	0.88 b	0.95 a	22.87 cd	6.37 a
SO4	18.5 c	0.88 b	0.95 a	23.58 b	5.52 bc
3309C	17.7 e	0.89 b	0.67 d	25.54 a	5.65 b
110R	18.6 c	0.92 a	0.69 d	22.68 d	5.53 bc
188-08	18.6 c	0.93 a	0.84 b	23.00 cd	5.53 bc
5C	18.5 c	0.93 a	0.79 c	23.34 bc	5.50 bc
Year					
2015	18.6 a	0.90 a	0.78 a	23.81 a	5.55 a
2016	18.5 a	0.86 b	0.78 a	23.52 a	5.47 a
2017	18.4 b	0.85 c	0.79 a	23.68 a	5.47 a
Year (*P* value)	<.001	<.001	0.512	0.149	0.364
Rootstock (*P* value)	<.001	<.001	<.001	<.001	<.001
Year×Rootstock (*P* value)	<.001	<0.001	0.167	0.711	0.900

[z] Fruit quality data presented for individual rootstocks was averaged over years 2015–2017.
[y] TSS, total soluble solid.
[x] TA, titratable acidity.
[w] Means within rootstock and years followed by common letters do not differ at the 5% level by Duncan's multiple range test.

(Tables 3 and 4).

Vines on SO4 had the highest cluster weight (624.63 g), which was significantly higher than control (478.31 g), whereas 5BB (460.51 g) had the lowest cluster weight (Table 3). 3309C, Beta and 110R had higher cluster weight than control, whereas 101-14M, 188-08 and 5C had cluster weights similar to own rooted vines. The highest berry weight (7.25, 7.23 and 7.20 g, respectively) was obtained with 188-08, 101-14M and 3309C while own rooted vines and those on 5BB had the lowest berry weight (6.73 and 6.78 g, respectively). The other rootstocks had intermediate berry weight. The maximum difference in berry vertical diameter was between fruit produced on 188-08 (26.21 mm) compared with control (24.86 mm). A similar trend was found in berry horizontal diameter. All of the rootstocks except 188-08, 101-14M and 3309C did not severely alter the berry vertical diameter. Vines on Beta, 5BB and 5C showed no variation in the berry horizontal diameter and vines on the other five rootstocks significantly increased the berry horizontal diameter.

The TSS was highest (19.4 %) for vines on '101-14M' and lowest (17.7 %) for vines on 3309C which were both markedly different from own rooted (Table 4). All the rootstocks, except 3309C and 5BB, observably increased TSS. The TA ranged from a low of 0.78 % for fruit produced on 101-14M to a high of 0.93 % for fruit produced on 5C and 188-08. Beta had similar TA to own rooted, 101-14M reduced the value of TA and the other rootstocks had higher TA than own rooted. The highest flesh firmness was obtained with 5BB and SO4 (0.95 kg/cm^2) and was higher than for own rooted vines (0.66 kg/cm^2). Berries from 3309C, Beta and 110R had the lowest value of flesh firmness and did not differ from the control. Berries from 101-14M (25.67 N) and 3309C (25.54 N) had the highest pressure resistance, whereas the lowest was on 110R (22.68 N). Compared to own rooted, 101-14M, 3309C and SO4 had higher pressure resistance and the

Table 5. Factor loadings, eigenvalues and proportion of variation associated with two principal components (PC) of the PCA for 10 traits related to yield and fruit quality for 8 rootstocks plus own-root grapevines.

Traits [z]	PC1	PC2
YL	0.418	-0.596
CW	0.391	-0.524
BW	0.926	0.337
VD	0.878	0.405
HD	0.844	0.528
TSS	0.441	-0.345
TA	-0.073	0.775
FR	0.107	0.378
PR	0.717	-0.208
PU	-0.598	0.571
Eigenvalue	3.754	2.418
Variability (%)	37.538	24.181
Cumulative %	37.538	61.719

[z] Yield (YL), cluster weight (CW), berry weight (BW), berry vertical diameter (VD), berry horizontal diameter (HD), total soluble solid (TSS), titratable acidity (TA), flesh firmness (FR), pressure resistance (PR), pulling resistance (PU).

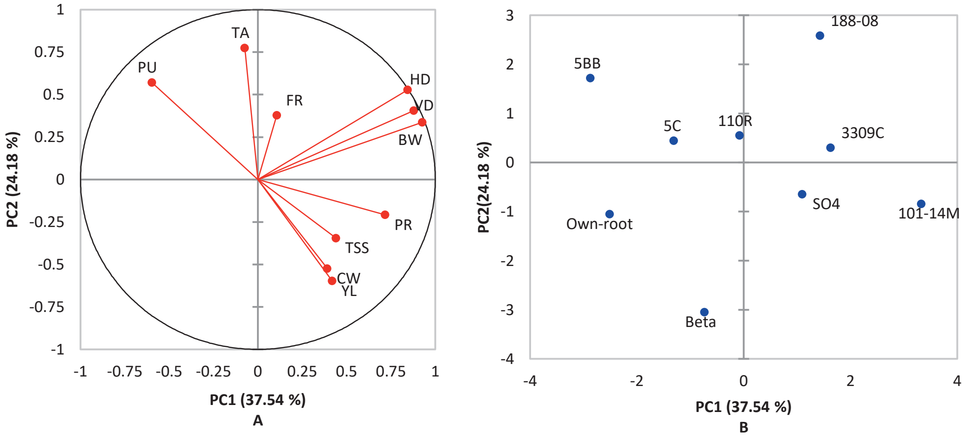

Fig.1. Plots of the principal component analysis of 10 yield and fruit quality traits in 8 scion-rootstock grapevines combinations. Scores plot (A) and loadings plot (B). The rootstock represented the scion-rootstock combination. See Table 5 for trait labels.

other rootstocks were similar to own roots. The greatest difference in pulling resistance was between vines on 5BB (6.37 N) and 101-14M (4.74 N) and both of them were significantly different from control (5.36 N). The other rootstocks, except 3309C, displayed no visible difference with control.

Principal components analysis. The data set of 8 scion-rootstock combinations and 10 traits was processed by principal component analysis (PCA) which provided overview visualization in a reduced dimension (Table 5). PC1 and PC2 were responsible for 61.72% of the total variation.

The PC1 explained 37.54% of the variability. Berry horizontal diameter (HD), berry vertical diameter (VD), berry weight (BW), pressure resistance (PR) and pulling resistance (PU) had higher weights in the separation of the samples along the axis 1. All these traits presented high positive loadings on PCA except for PU which presented negative loadings (Fig. 1A and Table 5). The PC2 accounted for 24.18% of the total variation, where TA, PU, HD, yield (YL) and cluster weight (CW) had a higher weights in the separation of the samples along the axis 2. TA, PU and HD were correlated with the PC2 with strong positive loadings (Fig. 1A and Table 5), and YL and CW were negatively correlated with the PC2 (Fig. 1A and Table 5).

Different scion-rootstock combinations were discriminated by the first two principal components (Fig. 1B). The PC1 was effective in separating the vines on 101-14M from the others, primarily from control and vines on 5BB (Fig. 1B). Vines on 101-14M had a higher value of HD, VD, PR and BW and lower value of PU than control (Fig. 1A and B). Vines on 188-08 and 5BB had a higher value of TA, PU and HD and lower values of YL and CW and were separated from others along the axis 2.

Comprehensive evaluation. Results of comprehensive evaluation based on subordinate function are shown in table 6. The top two values were gained by SO4 and 101-14M. SO4 performed best in yield, cluster weight and flesh firmness. 101-14M had the highest value for TSS and pressure resistance and the second highest value at berry weight, berry vertical diameter, berry horizontal diameter which were slightly inferior to 188-08. The lowest value was obtained with control, followed by Beta and values for the other rootstocks were intermediate.

Table 6. Subordinate function value analysis of eight rootstocks plus own roots effects on yield and fruit quality of 'Yueguangwuhe'.

Rootstock	Yield	Cluster weight	Berry weight	Berry vertical diameter	Berry horizontal diameter	TSS [z]	TA [y]	Flesh firmness	Pressure resistance	Pulling resistance	Comprehensive evaluation value	Rank
Own root	0.044	0.046	0.043	0.050	0.038	0.035	0.054	0.053	0.059	0.032	0.455	9
Beta	0.076	0.081	0.055	0.051	0.040	0.061	0.046	0.056	0.066	0.030	0.563	8
101-14M	0.055	0.056	0.106	0.116	0.085	0.071	0.042	0.106	0.125	0.021	0.782	2
5BB	0.036	0.039	0.050	0.053	0.052	0.039	0.083	0.133	0.055	0.051	0.591	7
SO4	0.089	0.099	0.087	0.077	0.072	0.047	0.083	0.133	0.073	0.035	0.795	1
3309C	0.068	0.083	0.102	0.098	0.082	0.028	0.087	0.056	0.122	0.038	0.765	4
110R	0.059	0.063	0.088	0.076	0.071	0.051	0.100	0.062	0.050	0.036	0.655	5
188-08	0.043	0.044	0.108	0.124	0.095	0.051	0.104	0.103	0.058	0.036	0.766	3
5C	0.045	0.054	0.062	0.058	0.054	0.049	0.104	0.089	0.067	0.035	0.617	6

[z] TSS, total soluble solid.
[y] TA, titratable acidity.

Discussion

Influences of rootstocks on fruit yield are well documented and results were inconsistent. Yields of grafted 'Cabernet Franc' and 'White Riesling' were much higher than the own-rooted vines (Ferree et al., 1996). 'Thompson Seedless' on Dogridge, 1103P and St. George were always less fruitful than the own-rooted vines (Jogaiah et al., 2014). For 'Chardonnay', rootstock had no obvious effect on yield when compared to the own-rooted vines (Boselli et al., 1992). In general, 3309C and 110R had higher yield (Li et al., 2019b; Loureiro et al., 2016), which was in agreement with our study (Table 3). In this paper, the highest yield was produced by SO4 while the lowest yield by 5BB which were both significantly different from own root (Table 3). Similar results for 'Summer Black' were reported by Jin et al. (2016a). However, 'Kishmish Chorni' on SO4 had lower yield than own root (Vijaya et al., 2019). The contradictory results may be due to site x rootstock interactions, and differences in scion cultivars and vine management. The annual yields increased from 2015-2017 (Table 3), which might be due to the rising soil temperature (Table 2).

Choosing suitable rootstocks is one of the paramount factors to achieve the best berry quality. Many studies have demonstrated that rootstocks could affect the fruit quality (Chou and Li, 2014; Jin et al., 2016a; Jin et al., 2016b; Li et al., 2019a; Li et al., 2019b; Loureiro et al., 2016; Satisha et al., 2010). Larger berries were produced by 'Thompson Seedless' vines grafted on Dogridge and 110R, while they were the smallest on own rooted vines (Satisha et al., 2010). 'Kyoho' on 1202C produced berries with higher TA compared to the own-rooted vines with the lowest TA (Chou and Li, 2014).

In this experiment, SO4 had the largest cluster weight and flesh firmness (Tables 3 and 4). The results were in line with those reported in a previous study on 'Summer black' vines (Jin et al., 2016a). Vines on 101-14M produced the highest TSS and TA (Table 4), which was coincident with the report for 'Marselan' vines (Li et al., 2019a). 'Summer Black' on 101-14M showed a similar results with our study in terms of berry weight, but results were opposite for TSS and TA (Jin et al., 2016a). We verified that vines on 5BB had cluster weight, berry weight and TSS similar to own roots (Tables 3 and 4). Similar results were found for 'Gold Finger' vines (Jin et al., 2016b) whereas 'Summer Black' on 5BB had lower values of TA (Jin et al., 2016a). 'Gold Finger' on 3309C improved the cluster and berry weights and impaired TSS (Jin et al., 2016b). These impacts of 3309C were also exhibited in this experiment. Our trial results clearly showed vines on Beta significantly increased the cluster weight and TSS (Tables 3 and 4) while 'Summer Black' on Beta was similar to own roots (Jin et al., 2016a). The reasons for the different results may be that the roots of different rootstocks by affecting water and mineral absorption eventually modify vine physiology (Keller et al., 2001; Romero et al., 2019; Satisha et al., 2007).

In this study, higher cluster weight and lower berry weight and TSS were obtained in 2017 (Tables 3 and 4), which might be due to less sunlight (Table 2). The interaction for year x rootstock had a significant impact on TSS and TA (Table 4), which indicated environment and rootstock influenced each other. Whether the interaction was positive or negative and which kind of environment factor interacts with rootstock needed to be further studied.

Different rootstocks have their own characteristics. In this study, the PCA analysis indicated that 101-14M had an advantage in pressure resistance, and berry weight and size over own roots (Fig. 1), which is consistent with the results by comprehensive evaluation based on subordinate function (Table 6). SO4 and 101-14M exhibited the better comprehensive performance (Table 6). This result was inconsistent with that of the study by Li et al. (2016b) who found 'Petit Verdot' on 3309C and 110R performed better. The different results above showed that the scion genetic traits might respond differently to the rootstock and environment (Bascuñán-Godoy et al., 2017; Kodur et al., 2013).

Conclusion

Our results revealed that the yield and berry quality of 'Yueguangwuhe' grapevines were greatly affected by the rootstocks being used. SO4 produced the highest average yield, cluster weight and flesh firmness. Vines on 101-14M produced the best fruit quality, including berry weight and size, TSS, and pressure resistance, and the lowest values for TA and pulling resistance. In this study, the order of different rootstocks by comprehensive evaluation for grapevines was SO4, 101-14M, 188-08, 3309C, 110R, 5C, 5BB, Beta and own root, respectively. The overall performance of grafted vines was better than that of own-rooted vines. SO4 and 101-14M were recommended for 'Yueguangwuhe' grapevines with obvious advantages compared to other rootstocks and control.

Literature Cited

Bascuñán-Godoy, L., N. Franck, D. Zamorano, C. Sanhueza, D.E. Carvajal, and A. Ibacache. 2017. Rootstock effect on irrigated grapevine yield under arid climate conditions are explained by changes in traits related to light absorption of the scion. Sci. Hortic. 218:284-292. http://doi.org/10.1016/j.scienta.2017.02.034.

Bavaresco, L., E. Giachino, and S. Pezzutto. 2003. Grapevine rootstock effects on lime-induced chlorosis, nutrient uptake, and source–sink relationships. J. Plant Nutr. 26:1451-1465. http://doi.org/10.1081/PLN-120021054.

Boselli, M., M. Fregoni, A. Vercesi, and B. Volpe. 1992. Variation in mineral composition and effects on the growth and yield of Chardonnay grapes on various rootstocks. Agric Ric. 14:138-139.

Cao, M., G. Chen, S. Xie, H. Li, J. Han, F. Pan, and X. Bai. 2014. Double-harvest-a-year cultivation technique of 'Yueguangwuhe' grape. Sino-Overseas Grapevine & Wine 000:37-38. https://doi.org/10.13414/j.cnki.zwpp.2014.06.009.

Chou, M. and K. Li. 2014. Rootstock and seasonal variations affect anthocyanin accumulation and quality traits of 'Kyoho' grape berries in subtropical double cropping system. Vitis 53:193-199.

da Silva, M.J.R., A.P.M. Paiva, A.P. Junior, C.A.P.C. Sánchez, D. Callili, M.F. Moura, S. Leonel, and M.A. Tecchio. 2018. Yield performance of new juice grape varieties grafted onto different rootstocks under tropical conditions. Sci. Hortic. 241:194-200. http://doi.org/10.1016/j.scienta.2018.06.085.

Dry, N. 2007. Grapevine rootstocks: selection and management for South Australian vineyards. Lythrum Press, Adelaide, Australia.

Elaidy, A., A. Abo-Ogiala, and I. Khalf. 2019. Effect of different grape rootstocks on the growth, yield and quality of Superior grape under salt stress. Middle East J. Agric. Res. 8:167-175.

Ferree, D., G. Cahoon, M. Ellis, D. Scurlock, and G. Johns. 1996. Influence of eight rootstocks on the performance of 'White Riesling' and 'Cabernet Franc' over five years. Fruit Var. J. 50: 124-130.

Gao, Z., H. Zhai, X. Zang, H. Zhu, and Y. Du. 2014. Using differential thermal analysis to analyze grape buds cold hardiness of 8 rootstocks and 6 cultivars. Acta Hortic. Sinica 41:17-25. https://doi.org/10.3969/j.issn.0513-353X.2014.01.003.

Hou, P., J. Zhang, and X. Zhang. 2010. Fuzzy comprehensive evaluation for selecting mini watermelon cultivars. J. Sci. Food Agric. 90:938-942. http://doi.org/10.1002/jsfa.3881.

Jin, Z., T. Sun, H. Sun, Q. Yue, and Y. Yao. 2016a. Modifications of 'Summer Black'grape berry quality as affected by the different rootstocks. Sci. Hortic. 210:130-137. http://doi.org/10.1016/j.scienta.2016.07.023.

Jin, Z., H. Sun, T. Sun, Q. Wang, and Y. Yao. 2016b. Modifications of 'Gold Finger'grape berry quality as affected by the different rootstocks. J. Agric. Food Chem. 64:4189-4197. http://doi.org/10.1021/acs.jafc.6b00361.

Jogaiah, S., A.K. Sharma, and P.G. Adsule. 2014. Rootstock influence on the biochemical composition and polyphenol oxidase activity of 'Thompson Seedless' grapes and raisins. Intl. J. Fruit Sci. 14:133-146. http://doi.org/10.1080/15538362.2013.817767.

Keller, M., M. Kummer, and M.C. Vasconcelos. 2001. Soil nitrogen utilisation for growth and gas exchange by grapevines in response to nitrogen supply and rootstock. Aust. J. Grape Wine Res. 7:2-11. http://doi.org/10.1111/j.1755-0238.2001.tb00187.x.

Kodur, S., J. Tisdall, P.R. Clingeleffer, and R.R. Walker. 2013. Regulation of berry quality parameters in 'Shiraz' grapevines through rootstocks (Vitis). Vitis 52: 125-128.

Li, M., Z. Guo, N. Jia, J. Yuan, B. Han, Y. Yin, Y. Sun, C. Liu, and S. Zhao. 2019a. Evaluation of eight rootstocks on the growth and berry quality of 'Marselan'grapevines. Sci. Hortic. 248:58-61. http://doi.org/10.1016/j.scienta.2018.12.050.

Li, M., X. Yan, Z. Guo, N. Jia, J. Yuan, B. Han, Y. Yin, Y. Sun, C. Liu, and S. Zhao. 2019b. Rootstock influence on vegetative growth, yield, and fruit quality of 'Petit Verdot'. Eur. J. Hortic. Sci. 84:343-349. http://doi.org/10.17660/eJHS.2019/84.6.3.

Loureiro, M.D., P. Moreno-Sanz, A. García, O. Fernández, N. Fernández, and B. Suárez. 2016. Influence of rootstock on the performance of the Albarin Negro minority grapevine cultivar. Sci. Hortic. 201:145-152. http://doi.org/10.1016/j.scienta.2016.01.023.

Ozden, M., H. Vardin, M. Simsek, and M. Karaaslan. 2010. Effects of rootstocks and irrigation levels on grape quality of *Vitis vinifera* L. cv. Shiraz. Afr. J. Biotechnol. 9:3801-3807.

Pulko, B., S. Vršič, and J. Valdhuber. 2012. Influence of various rootstocks on the yield and grape composition of Sauvignon blanc. Czech J. Food Sci. 30:467-473. http://doi.org/10.17221/347/2011-CJFS.

Riaz, S., D. Pap, J. Uretsky, V. Laucou, J.-M. Boursiquot, L. Kocsis, and M. Andrew Walker. 2019. Genetic diversity and parentage analysis of grape rootstocks. Theor. Appl. Genet. 132:1847-1860. doi: http://doi.org/10.1007/s00122-019-03320-5.

Romero, P., P. Botía, F.M. del Amor, R. Gil-Muñoz, P. Flores, and J.M. Navarro. 2019. Interactive effects of the rootstock and the deficit irrigation technique on wine composition, nutraceutical potential, aromatic profile, and sensory attributes under semiarid and water limiting conditions. Agric. Water Manage. 225:105733. http://doi.org/10.1016/j.agwat.2019.105733.

Satisha, J., G. Prakash, R. Bhatt, and P. Sampath Kumar. 2007. Physiological mechanisms of water use efficiency in grape rootstocks under drought conditions. Int. J. Agric. Res. 2:159-164. http://doi.org/10.3923/ijar.2007.159.164.

Satisha, J., R. Somkuwar, J. Sharma, A. Upadhyay, and P. Adsule. 2010. Influence of rootstocks on growth yield and fruit composition of Thompson seedless grapes grown in the Pune region of India. S. Afr. J. Enol. Vitic. 31:1-8. http://doi.org/10.21548/31-1-1392.

Shen, B., Y. Li, S. Zhao, W. Ding, N. Hui, and J. Li. 2014. Effect of dark period lighting regulation on cucumber seedlingmorphology and comprehensive evaluation analysis and comprehensive evaluation. Transactions of the Chinese Society of Agric. Engineering 30:201-208. http://doi.org/10.3969/j.issn.1002-6819.2014.22.025.

Smith, B., N. Morales, M.R. Thomas, H. Smith, and P.R. Clingeleffer. 2017. Grapevine rootstocks resistant to the root-knot nematode *Meloidogyne javanica*. Aust. J. Grape Wine Res. 23:125-131. http://doi.org/10.1111/ajgw.12242.

Soylemezoglu, G., K. Demir, A. Inal, and A. Gunes. 2009. Effect of silicon on antioxidant and stomatal response of two grapevine (*Vitis vinifera* L.) rootstocks grown in boron toxic, saline and boron toxic-saline soil. Sci. Hortic. 123:240-246. http://doi.org/10.1016/j.scienta.2009.09.005.

Tecchio, M.A., M.J.R. da Silva, D. Callili, J.L. Hernandes, and M.F. Moura. 2020. Yield of white and red grapes, in terms of quality, from hybrids and *Vitis labrusca* grafted on different rootstocks. Sci. Hortic. 259:108846. http://doi.org/10.1016/j.scienta.2019.108846.

Vijaya, D., V. Joshi, G.R. Reddy, D.A. Kumari, and B.S. Rao. 2019. Effect of rootstock-scion interaction on petiole nutrient content, bud break, and yield of three commercial grape cultivars. Agri. Res. J. 56:84-91. http://doi.org/10.5958/2395-146X.2019.00013.9.

Wang, Z., J. Zhou, X. Xu, A. Perl, S. Chen, and H. Ma. 2017. Adoption of table grape cultivars: An attribute preference study on Chinese grape growers. Sci. Hortic. 216:66-75. http://doi.org/10.1016/j.scienta.2017.01.001.

Whiting, J.R. 2005. Grapevine rootstocks, in Viticulture, Volume 1: Resources. Winetitles Pty Ltd, Ashford, Australia, pp. 167-188.

Wooldridge, J., P. Louw, and W. Conradie. 2010. Effects of rootstock on grapevine performance, petiole and must composition, and overall wine score of Vitis vinifera cv. Chardonnay and Pinot Noir. S. Afr. J. Enol. Vitic. 31:45-48. https://doi.org/10.21548/31-1-1399.

Yang, Y., C. Huang, Q. Gu, X. Qu, and X. Xu. 2015. Evaluation of drought-resistance traits of citrus rootstock seedlings by multiple statistics analysis. Acta Hortic. 1065:379-386. https://doi.org/10.17660/ActaHortic.2015.1065.4.

Yuan, J., M. Li, N. Jia, C. Liu, B. Han, Y. Yin, Y. Sun, Z. Guo, and S. Zhao. 2019. Evaluation of salt stress tolerance in twenty-one grape rootstocks. Acta Agri. Boreali-occidentalis Sinica 28:602-606. http://doi.org/10.7606/j.issn.1004-1389.2019.04.013.

Zhou, J., L. Cao, S. Chen, A. Perl, and H. Ma. 2015. Consumer-assisted selection: the preference for new table grape cultivars in China. Aust. J. Grape Wine Res. 21:351-360. https://doi.org/10.1111/ajgw.12156.