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Effects of Different Trellis Systems on Fruit-zone Microclimate, Berry Quality and Anthocyanins of 'Xinyu' Grape (*Vitis vinifera* L.)

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Additional index words: anthocyanin content; berry quality; micro environment; table grape; trellis system

Abstract

In 2021, this study investigated the effects of three different trellis systems on the fruit-zone microclimate, berry quality and anthocyanins of 'Xinyu' grape in Shanshan, Xinjiang, China. The results showed that the light and heat energy of fruit-zone microenvironment were higher for inclined ingle dragon trunk shaping + Horizontal leaf curtain (ISDTS-H) and inclined single dragon trunk shaping + V and Horizontal leaf curtain (ISDTS-VH) than for single dragon trunk shaping + Horizontal leaf curtain (SDTS-H). SDTS-H was more susceptible to low humidity than ISDTS-VH. The canopy area and leaf area index around the fruit were increased and canopy closure was increased with ISDTS-VH compared to SDTS-H. ISDTS-VH increased berry weight, total soluble solids (TSS) and yield. Delphinidin concentration and total delphinidin proportion with SDTS-H were higher than that with ISDTS-VH and SDTS-H, respectively. In general, 'Xinyu' grape grown with the ISDTS-VH trellis system achieved high quality under the local environmental conditions. These results provide a reference for the trellis systems selection and optimization of the 'Xinyu' grape cultivar.

Grapevines are typically supported with trellises, but grape regions choose different training systems that are best suited to them (Tian et al., 2022). The present-day global diversity of grapevine training systems has arisen from differences between grape species and cultivars with respect to growth habit and cropping capacity, as well as from environmental and economic constraints on vineyard management (Wolf et al., 2003). A good training system can optimize canopy structure, which could improve microclimate conditions and affect overall canopy photosynthetic productivity (Liu et al., 2018; Araujo et al., 2008), influence vine performance and berry quality composition under protected cultivation. Vines trained on the SAYM (pergola trellis and closing Y shaped trellis) trellis system had a large leaf area index (LAI) (Yin et al., 2022). It also contributed to total leaf area, the percentage of leaf well-exposed to light, and the percentage of leaves located in the interior of the canopy (Katerji et al., 1994; Reynolds and Heuvel, 2009; Schultz, 1995). Trellis systems can influence berry weight, and fruit soluble solids, and color (Ezzahouani and Williams, 2003; Sanchez-Rodriguez and Spósito, 2019), C_6 volatile compounds and C_9 compounds (Xu et al., 2015). Trellis systems may influence the concentration of monoterpenes, such as specifically geraniol (Ji et al., 2008), as well as berry dry matter (30%) and yield (9-11%) (Sanchez-Rodriguez and Spósito, 2019; Salvi et al., 2021),

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and primary and secondary metabolites, such as soluble solids, acidity, and phenolic profiles of grapes (Azuma et al., 2012). Although training system effects on yield and fruit composition have been extensively evaluated in cool climates (Carbonneau and Huglin, 1982; Reynolds et al., 1995), less work has been done in warm to hot climates, where the mean January (or July) temperature (MJT) is greater than 21°C (Smart et al., 1985). Some studies also indicate that berry weight, length and diameter, and total soluble solids were not significantly different among the trellis systems (Kim et al., 2014). Ezzahouani and Williams (2003) also found that yield per vine was not affected by any of the trellis treatments.

Berry skin color is one of the most important fruit traits selected for with red grape cultivars. It is mainly determined by the quality and composition of anthocyanins (Azuma et al., 2015). There are six main anthocyanins in plants, which are cyanidin, delphinidin, pelargonidin, peonidin, malvidin, and petunidin (Wang et al., 2021). Anthocyanins accumulate in berry skins during ripening, and several agroecological factors, such as cultivar, climate, soil conditions, canopy management, crop level, irrigation, ripening, and temperature have been related to anthocyanin accumulation in red grape skins (Jackson and Lombard., 1993; Esteban et al., 2001).

The 'Xinyu' table grape (*Vitis vinifera* L.) was bred from a cross between the natural hybrid single 'Red Globe' plant E-42-6 (female parent) and 'Rizamat' (male parent) at the Grapes and Melons Research Institute of Xinjiang Uighur Autonomous Region and registered by Xinjiang Uygur Autonomous Region Crop Variety Registration Committee in 2005. Its berries are oval with dark red/violet skin, a slightly crisp texture, and sour-sweet flavor as well as good storage, transportation, and adaptability characteristics (Luo et al., 2007). At present, 'Xinyu' is widely cultivated in Xinjiang, Yunnan, Shaanxi, and other provinces in China. Grapes were previously cultivated on small trellis systems in the Turpan region that provided a good windproof effect while requiring a minimal amount of material. However, these systems were also low to the ground and not amenable to mechanized cultivation and management. There are a multitude of trellis systems for grapevines in different parts of China. Each system has it peculiarities, which may be related to the characteristics of the region, such as the relief, climatic condition, technological level and cultural habit of grape grower (Sander et al., 2019).

This research was conducted in the Turpan region of China, in 2021, and is a typical extremely arid area, with high temperatures and low humidity. During the fruit coloring, the air temperature is at its highest for the year, which can result in poor color or excessively dark coloration. To increase 'Xinyu' production and to optimize fruit quality, it is very important to choose the appropriate trellis system to obtain light interception and photosynthetic radiation. Therefore, a new trellis system is required. To date there are still few studies aimed at the fruit quality and other characteristics of 'Xinyu' grown in a high temperature, low humidity, and strong light environment. The aim of this study was to investigate the effects of three different trellis systems on the fruit-zone microclimate, canopy structure, fruit quality, and anthocyanin concentration of 'Xinyu' grape cultivated in Turpan, Xinjiang, China, in order to provide a reference for the production of high-quality fruit.

Materials and Methods

Experimental site and treatments

The own-rooted 'Xinyu' table grapes (*Vitis vinifera* L.) that had been planted in 2015 were sourced from Yuanyichang (42°91′N, 90°30′E), Shanshan county, Turpan, Xinjiang, China, in 2021.

The experiment consisted of three treatments: (1) single dragon trunk shaping and horizontal leaf curtain (SDTS-H, Figure 1), (2) inclined single dragon trunk shaping and horizontal leaf curtain (ISDTS-H, Figure 2.),

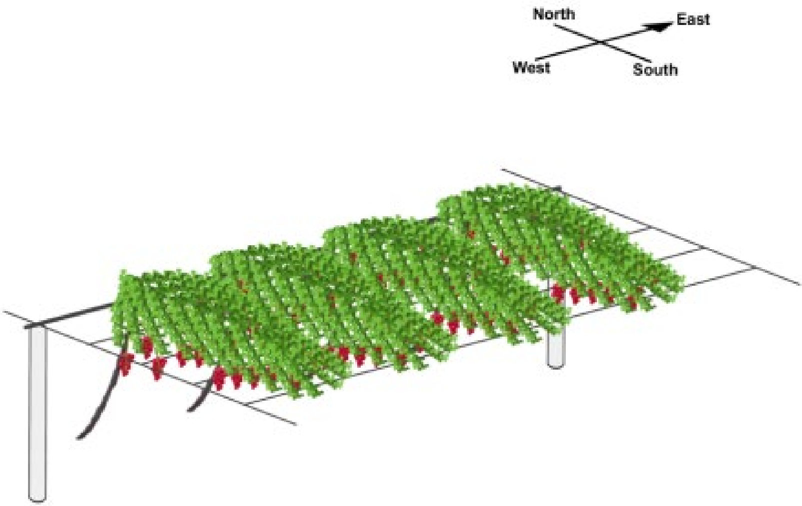

Figure 1. Single dragon trunk shaping + Horizontal leaf curtain, SDTS-H

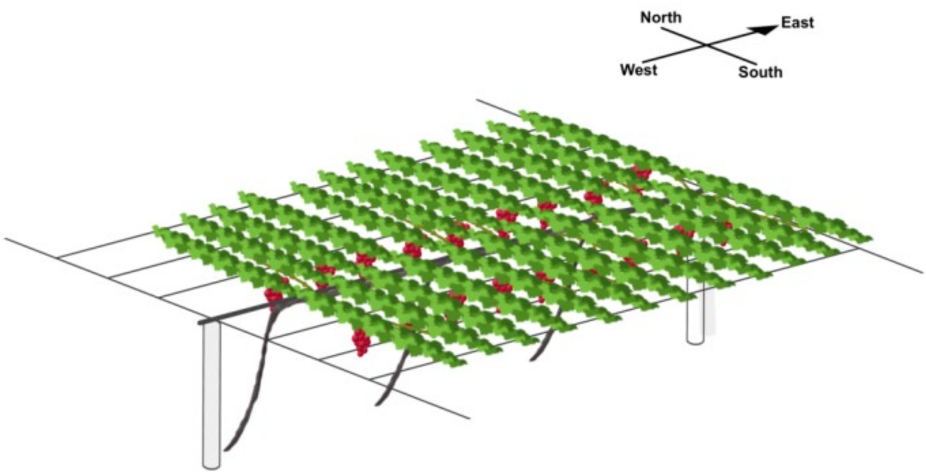

Figure 2. Inclined single dragon trunk shaping + Horizontal leaf curtain, ISDTS-H

(3) inclined single dragon trunk shaping with vertical and horizontal leaf curtains (ISDTS-VH, Figure 3.). Both ISDTS-H and ISDTS-VH vines were oriented in an east–west direction with an angle of 15° to the west/east and were spaced at 2.0 m×3.5 m, the SDTS-H vines were spaced at 1.2 m×4.0 m and trunk was north-south. ISDTS-H and ISDTS-VH treatments were applied to 42 grapevine experimental units, and SDTS-H treatment applied to 62 grapevine experimental units, each unit area was about 300 m^2, and the treatments were replicated three times in a completely randomized design. Four grapevines at each end of the experiment plot were excluded to minimize the border effect.

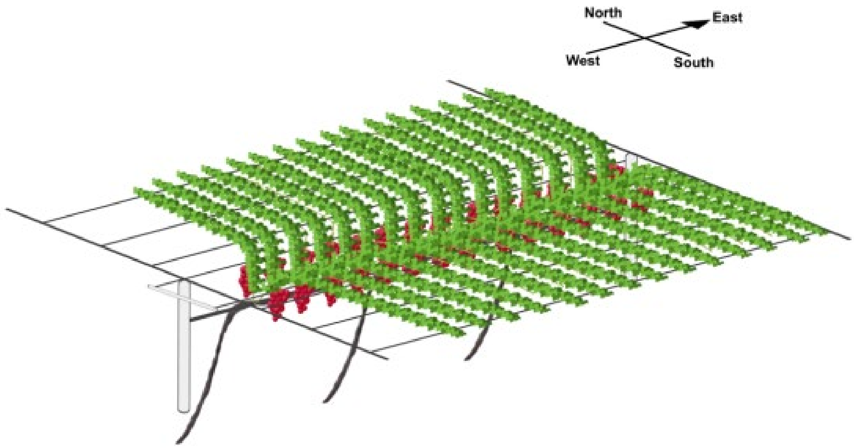

Figure 3. Inclined single dragon trunk shaping + V and Horizontal leaf curtain, ISDTS-VH

The vineyard was irrigated with a micro-spray irrigation system. The total amount of irrigation water was about 15,000 $m^3 \cdot ha^{-1}$ for each year. Organic fertilizer (sheep manure, 30 $m^3 \cdot ha^{-1}$), diammonium phosphate (DAP, 900 $kg \cdot ha^{-1}$), carbamide (300 $kg \cdot ha^{-1}$), compound fertilizer (15% N : 1.4% P : 6.55% K, 600 $kg \cdot ha^{-1}$) and potassium sulphate (300 $kg \cdot ha^{-1}$) were applied each year. Pest and disease management followed the standard procedure used in the production yard.

Fruit-zone microclimate monitoring

To measure the fruit-zone microclimate, a temperature-humidity recorder (EL-USB-2, Lascar, United Kingdom) was hung in the fruit zone during the fruit coloration period to monitor the fruit-zone temperature and humidity. One sensor was applied to each experimental unit; there were 9 sensors. Values were recorded at 30-min intervals throughout each day from the early stage of veraison (5 June) to the fruit ripening stage (20 August).

Grape sample collection and measurement

Leaf curtain structure, branch growth, and leaves area index

The length, width, and thickness of the leaf curtain were measured using a tape measure, seven days after secondary tips were trimmed in early July. A plant canopy analyzer (LAI-2200C, LI-COR Biosciences, Lincoln, NE, USA) was used to measure leaf area index (LAI) for each replicate from 12 randomly selected sites in each plot.

Berry quality and yield

For each replicate, 1500 g of berries were collected and immediately transported to the laboratory to measure fruit quality.

A subsample of 30 berries per replicate was weighted on an electronic balance (AL214, Sartorius, Germany), and berry longitudinal diameter and transverse diameter were measured using Vernier calipers (DL3944, Deli Group Co. LTD, China). Berry shape index was calculated as longitudinal diameter (mm)/transverse diameter (mm).

A portable refractometer (PAL-1, Atago, Tokyo, Japan) was used to determine the total soluble solids (TSS, °Brix). Titratable acid concentration (TA) was determined by titration with 0.05 $mol \cdot L^{-1}$ NaOH to an endpoint of pH 8.2, and was expressed as tartaric acid equivalents. Vitamin C (VC) concentration was determined according to food safety national standard Determination of total acid in foods (GB 12456-2021, 2021), total anthocyanins concentrations were determined utilizing the pH differential method (Stojanovic and Silva, 2007). Each measurement was repeated 3 times. When the berry was mature, clusters were picked and weighed to calculate the yield of each plot.

Color measurement

Berry color was determined around the equatorial belt of each berry for 20 berries per treatment. A chroma meter (CR-400, Atago, Tokyo, Japan) was used to measure L^*, a^*, and b^* values. The values of a^* and b^* were used to calculate the chroma axis C^* with the equation $C^*=[(a^*)^2 + (b^*)^2]^{0.5}$. The hue angle ($h°$) was calculated with the equation $h°=\text{tang}^{-1}(b^*/a^*)$. These values were used to calculate the color index for red grape (CIRG) with the equation CIRG=(180−h°)/(L*+C*) (Carreño et al., 1995), green-yellow (CIRG <2), pink (2<CIRG<4), red (4<CIRG<5), dark red (5<CIRG<6), blue-black (CIRG>6) (Carreño et al., 1996).

Detection of anthocyanin compounds in peel

Chemicals and reagents. High-performance liquid chromatography-grade methanol (MeOH) was purchased from Merck (Darmstadt, Germany). MilliQ water (Millipore, Bedford, MA, USA) was used in all experiments. All of the standards were purchased from isoReag (Shanghai, China). Formic acid was purchased from Sigma-Aldrich (St. Louis, MO, USA). Hydrochloric acid was obtained from Xinyang Chemical Reagent (Xinyang, China). Stock solutions of standards were prepared at a concentration of 1 mg/ml in 50% MeOH and stored at -20°C. Working solutions were prepared by diluting the stock solutions with 50% MeOH before use.

Sample preparation and extraction. Samples were freeze-dried, ground into powder (30 Hz, 1.5 min), and stored at -80°C until use. The powder (50 mg) was extracted with 0.5 ml methanol/water/hydrochloric acid (500:500:1, v/v/v) and the extract was vortexed for 5 min, ultrasonicated for 5 min, and centrifuged at 12,000×*g* and 4°C for 3 min. The residue was re-extracted by repeating the above steps under the same conditions. The supernatant was collected and passed through a membrane filter (0.22 µm; ANPEL Laboratory Technologies, Shanghai, China) before liquid chromatography–tandem mass spectrometry (LC–MS/MS) analysis.

Ultrahigh-performance liquid chromatography (UPLC). Sample extracts were analyzed using a UPLC-electrospray ionization (ESI)–MS/MS system (ExionLC™ and Triple Quad 6500; AB Sciex, Framingham, MA, USA). The analytical conditions were as follows, ACQUITY BEH C18 (1.7 µm, 2.1×100 mm) (Waters, Milford, MA, USA); solvent system, water (0.1% formic acid):methanol (0.1% formic acid); gradient program, 95:5 v/v at 0 min, 50:50 v/v at 6 min, 5:95 v/v at 12 min, hold for 2 min, 95:5 v/v at 14 min, hold for 2 min; flow rate, 0.35 ml/min; temperature, 40°C; and injection volume, 2 µL.

ESI–MS/MS conditions. Linear ion trap and triple quadrupole scans were acquired on a triple quadrupole linear ion trap mass spectrometer (QTRAP6500+ LC–MS/MS system) equipped with an ESI turbo ion spray interface, operating in positive ion mode and controlled with Analyst v1.6.3 software (AB Sciex). The ESI source operation parameters were as follows: ion source, ESI+; source temperature, 550°C; ion spray voltage, 5500 V; and curtain gas, 35 psi. Anthocyanins were detected using scheduled multiple reaction monitoring (MRM). Analyst v1.6.3 software (AB Sciex) was used for data acquisition, and Multiquant v3.0.3 software (AB Sciex) was used to quantify metabolites. MS parameters including the declustering potential (DP) and collision energy (CE) for individual MRM transitions were used with further DP and CE optimization. A specific set of MRM transitions were monitored for each period according to the metabolites eluted within this period.

Data analysis

Excel 2007 software (Microsoft, Redmond, WA, USA) and SPSS v20.0 (IBM, Armonk, NY, USA) were used for statistical analyses. Statistically significant differences (P<0.05) between groups were evaluated by 1-way analysis of variance and Duncan's multiple range test for multiple comparisons. Figure 1 was produced with photoshop (CC2019, Adobe, America). Figure 2 was plotted using OriginLab OriPro 2021 (MicroLalab, USA).

Results

Fruit-zone microclimate

The minimum and mean temperatures were higher for ISDTS-H and ISDTS-VH than those for SDTS-H. Means of the minimum temperature and mean temperature were higher for ISDTS-H and ISDTS-VH than for SDTS-H, with differences of 2.77°C and 2.72°C, and 2.29°C and 2.24°C, respectively (Figure 4).

The maximum and mean humidities were higher for SDTS-H than for ISDTS-H and ISDTS-VH, and ISDTS-VH was slighter higher than ISDTS-H. Compared with SDTS-H, the maximum humidity and the minimum humidity for ISDTS-H and ISDTS-VH were decreased (Figure 5).

Leaf curtain structure

Canopy thickness was lower for ISDTS-VH and ISDTS-H than for SDTS-H. Canopy length was significantly longer for SDTS-H than for the other systems, whereas SDTS-H and ISDTS-VH were not different. Canopy width was highest for ISDTS-VH and progressively lower for ISDTS-H and SDTS-H. Canopy height was the highest for ISDTS-H, followed by ISDTS-VH, SDTS-H, with sig-

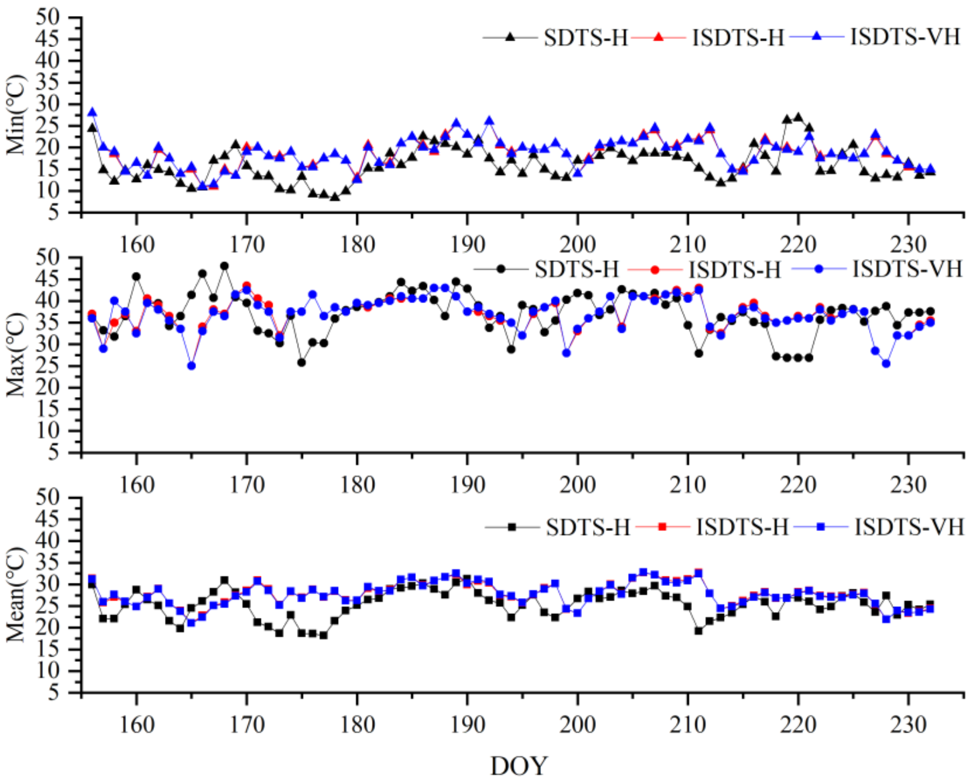

Figure 4. Daily average minimum, maximum and mean temperatures within the canopies of 'Xinyu' grape vines trained to three systems.

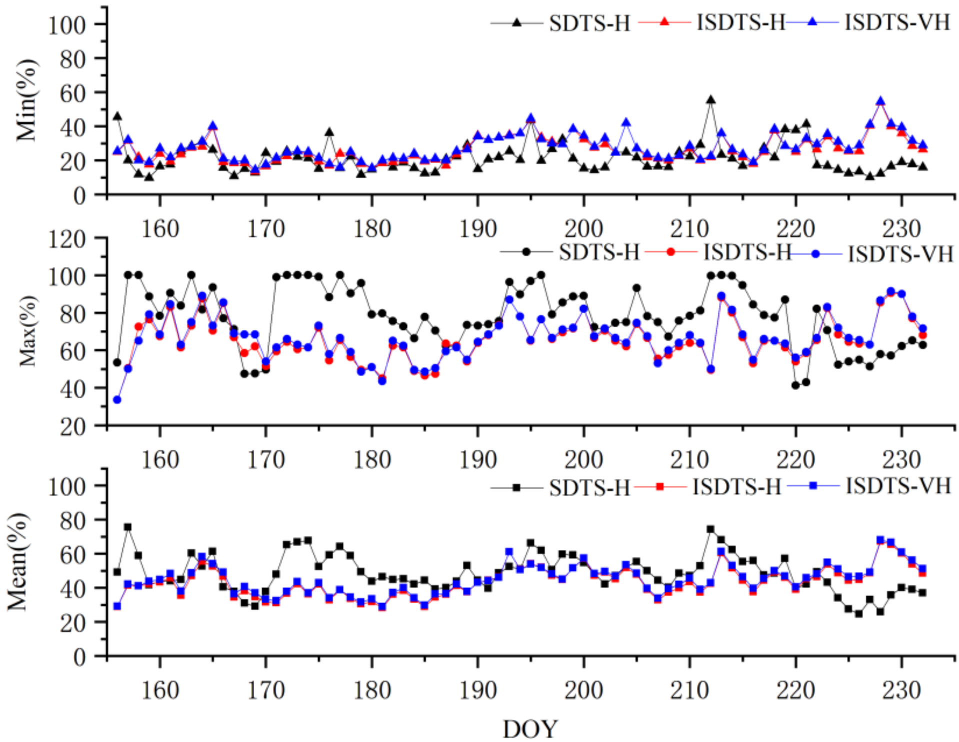

Figure 5. Daily average minimum, maximum and mean relative humidity measured within the canopies of 'Xinyu' grape vines trained to three systems.

nificant differences among the three groups. For leaf area index (LAI), SDTS-H was the highest (5.84), followed by ISDTS-VH (5.25) and ISDTS-H (4.80), and differences among the trellis systems were significant (Table 1).

Berry quality

Berry weight, berry longitudinal diameter, and fruit shape index were significantly higher for ISDTS-VH than ISDTS-H and SDTS-H, but the latter two treatments were not significantly different. Berry transverse diameter was not affected by trellis system (Table 2).

Total soluble solids and TSS/TA were significantly higher for ISDTS-VH and ISDTS-H than for SDTS-H, and titratable acid (TA) concentration was significantly lower for ISDTS-H and ISDTS-VH than for SDTS-H. Vitamin C concentration was highest for ISDTS-VH, followed by ISDTS-H, and SDTS-H. Total anthocyanins concentration was highest for ISDTS-H, followed by ISDTS-VH, and SDTS-H. Number of clusters per ha and yield were significantly highest for SDTS-H, followed by ISDTS-VH and ISDTS-H. Berries on ISDTS-H ripened earliest (15 July), and fruit on SDTS-H ripened latest (10 August).

Fruit color

Compared to SDTS-H, values of *L**, *a**, *b**, and *C** were significantly lower for ISDTS-VH and ISDTS-H (Table 3). CIRG for SDTS-H was significantly lower than for ISDTS-VH and ISDTS-H.

Table 1. Leaf curtain structure characteristics of 'Xinyu' grape vines trained to three different trellis systems.

Canopy characteristic	SDTS-H	ISDTS-H	ISDTS-VH
Thickness (cm)	51.67±6.24 [a]	28.17±2.03 [c]	36.75±2.37 [b]
Length (m)	4.06±0.13 [a]	2.13±0.06 [b]	2.11±0.07 [b]
Width (m)	1.13±0.04 [c]	3.10±0.07 [b]	3.45±0.02 [a]
Area (m^2)	4.59±0.15 [c]	6.60±0.12 [b]	7.28±0.08 [a]
Height (m)	1.48±0.08 [c]	1.91±0.01 [a]	1.70±0.12 [b]
Leaf area index	5.84±0.32 [a]	4.80±0.16 [c]	5.25±0.19 [b]

[z] Values are means ± standard deviations of three replicates. Values within rows followed by common letters do not differ at the 5% level of significance, by Duncan's multiple range test.

Table 2. Berry characters of 'Xinyu' grapes harvest from vines trained to three different trellis systems.

Berry charqcteristic	SDTS-H	ISDTS-H	ISDTS-VH
Berry weight (g)	10.57± 0.67 [b z]	10.04±0.31 [b]	12.99± 0.26 [a]
Longitudinal diameter (mm)	29.54± 1.43 [b]	28.79±1.25 [b]	32.81±1.34 [a]
Transverse diameter (mm)	25.06±1.00 [a]	24.36± 1.32 [a]	25.07± 0.81 [a]
Fruit shape index	1.18± 0.07 [b]	1.19±0.07 [b]	1.31±0.06 [a]
Total soluble solids (%)	13.33±0.95 [c]	19.20±0.90 [a]	17.71±0.51 [b]
Titratable acid ($mg \cdot g^{-1}$)	7.03±0.24 [a]	5.82±0.18 [c]	6.31± 0.22 [b]
TSS/TA	19.84±0.57 [c]	33.27±0.87 [a]	28.73±0.46 [b]
Vitamin C ($mg \cdot kg^{-1}$)	366.75± 4.89 [c]	411.23±3.71 [b]	455.72±4.58 [a]
Total anthocyanins ($\mu g \cdot g^{-1}$)	521.00± 8.51 [c]	811.84±16.74 [a]	627.88±31.01 [b]
Actual no. clusters/ ha	24762.45±1611.3 [a]	18150.90±1325.4 [c]	20724.60±1429.3 [b]
Yield ($t \cdot ha^{-1}$)	29.10±3.37 [a]	15.63±1.14 [c]	24.30±1.84 [b]
Ripen date	10 August	15 July	22 July

[z] Values are means ± standard deviation of three replicates. Values within rows followed by common letters do not differ at the 5% level of significance, by Duncan's multiple range test.

Table 3. Berry color of 'Xinyu' grape berry harvested from vines trained to three different trellis systems.

Color values	SDTS-H	ISDTS-H	ISDTS-VH
*L**	33.27±4.98 [a z]	25.10±2.32 [b]	23.85±1.82 [b]
*a**	8.92±2.51 [a]	4.13±1.36 [c]	5.28±0.57 [b]
*b**	1.45±0.68 [a]	-4.05±0.51 [b]	-3.62±0.78 [b]
*C**	9.59±1.94 [a]	5.84±1.19 [b]	6.43±0.79 [b]
CIRG	4.09±1.11 [c]	7.45±0.29 [a]	6.89± 0.15 [b]

[z] Values are means ± standard deviation of three replicates. Values within rows followed by common letters do not differ at the 5% level of significance, by Duncan's multiple range test.

Table 4. Anthocyanin compounds in skins of 'Xinyu' grapes harvested from vines of three trellis systems.

Anthocyanin compound	SDTS-H	ISDTS-H	ISDTS-VH
Delphinidins ($\mu g \cdot g^{-1}$)	135.02±2.20 [c z]	315.99±6.51 [a]	193.80±23.77 [b]
Petunidins ($\mu g \cdot g^{-1}$)	55.37±0.90 [b]	92.98±1.92 [a]	64.18±7.87 [b]
Malvidins ($\mu g \cdot g^{-1}$)	190.72±3.11 [b]	239.18±4.93 [a]	205.572±25.22 [b]
Cyanidins ($\mu g \cdot g^{-1}$)	2.27±0.37 [b]	28.87±0.60 [a]	28.21±3.46 [a]
Peonidins ($\mu g \cdot g^{-1}$)	115.35±1.88 [b]	131.38±2.71 [a]	133.44±6.37 [a]
Pelargonidins ($\mu g \cdot g^{-1}$)	1.87±0.03 [c]	3.45±0.07 [a]	2.68±0.32 [b]
Total cyanidins proportion (%)	26.49±1.12 [a]	19.63±0.98 [b]	25.75±1.13 [a]
Total delphinidins proportion (%)	73.26±0.95 [b]	80.37±0.98 [a]	74.25±1.13 [b]

[z] Values are means ± standard deviation of three replicates. Values within rows followed by common letters do not differ at the 5% level of significance, by Duncan's multiple range test.

Anthocyanin compounds in berry skin

High total and peel anthocyanin concentrations are the main reason for the deep coloration of 'Xinyu' grapes, which is also enhanced by increased total delphinidin concentration. Delphinidin, petunidin, malvidin, cyanidin, and pelargonidin concentrations in berry skin were highest for ISDTS-H and lowest for SDTS-H, but concentrations for ISDTS-H and ISDTS-VH were not always significantly different (Table 4). Pelargonidin concentrations were lowest for SDTS-H. The proportion of total cyanidins was lowest and the proportion of total delphinidins was highest for ISDTS-H.

Methylation was the predominant modification observed for anthocyanins. Berries from SDTS-H generally had lowest concentrations of methylated and non-methylated anthocyanins, and nonmethylated anthocy-

Table 5. Concentration and relative proportion of anthocyanins in 'Xinyu' grape skins harvested from vines of three trellis systems.

Anthocyanin modification	Anthocyanin content (μg·g^{-1})			Anthocyanin proportion (%)		
	SDTS-H	ISDTS-H	ISDTS-VH	SDTS-H	ISDTS-H	ISDTS-VH
Acetylated	5.30±0.1 [c z]	22.07±0.56 [a]	8.27±1.24 [b]	1.06±0.06 [c]	2.72±0.15 [a]	1.32±0.08 [b]
Coumaroylatedd	5.35±0.1 [b]	10.37±0.26 [a]	6.26±0.94 [b]	1.03±0.01 [b]	1.27±0.03 [a]	1.00±0.08 [b]
Coffeelation	0.01±0.0 [c]	0.03±0.00 [a]	0.02±0.00 [b]	0.02±0.00 [b]	0.04±0.00 [a]	0.03±0.00 [b]
Non-acylated	510.1±10.2 [b]	779.3±19.7 [a]	613.3±92.1 [b]	97.9±01.1 [a]	96.0±0.1 [b]	97.7±0.2 [a]
Methylated	361.43±7.2 [b]	465.09±11.0 [a]	463.54±12.2 [a]	69.37±1.2 [a]	56.12±17 [b]	67.45±3.6 [a]
Non-methylated	159.56±3.1 [c]	348.30±8.79 [a]	224.68±33.8 [b]	30.79±1.3 [b]	42.44±1.4 [a]	32.55±3.6 [b]

[z] Values are means ± standard deviation of three replicates. Values within rows and response variable followed by common letters do not differ at the 5% level of significance, by Duncan's multiple range test

anin concentrations were highest for ISDTS-HH (Table 5). The proportion of methylated anthocyanins was significantly lower for ISDTS-H than for SDTS-H and ISDTS-VH, but the proportion of nonmethylated anthocyanins was relatively high, with no difference between SDTS-H and ISDTS-VH. Acetylated and coumaroylated anthocyanins were dominant in berry skin whereas coffeelation and acylation were detected at low levels. The proportion and concentration of acylated anthocyanins were significantly higher for ISDTS-H than for SDTS-H and ISDTS-VH.

Discussion

Effect of trellis system on grape vine structure

Training/Trellis system and canopy management are integral components of vineyard management because of their impact on the microclimate within the canopy (Tsolova et al., 2007). The leaf curtain of grape vines is influenced by the trellis system and new shoot management, and training systems influence total leaf area (Wang et al., 2019). In this study we found that the trellis system impacted the canopy thickness, length, width, and area. Plant spacing and management of new shoots with SDTS-H enhanced apical dominance producing a thicker leaf curtain and higher leaf area index (Pan et al., 2017). Shi et al. (2015) observed that V-shape leaf curtain also had obvious apical dominance, producing a thicker leaf curtain and greater the leaf area index, the results in this experiment were consistent with the previous observations.

Effect of trellis system on fruit quality

Previous studies showed that in cooler climates, yield components, berry weight, berry diameter, total soluble solids, and titratable acidity did not differ among trellis systems (Olson et al., 2021), and berry total anthocyanin concentrations at harvest were not greatly affected by training system (Wolf et al., 2003). In this study, TSS and solid/acid of 'Xinyu' grape were significantly higher when grown under ISDTS trellis systems compared to that under the SDTS system. For dry cultivation, ISDTS may promote the degradation of fruit sugars and organic acids, and berries within the relatively open clusters may experience greater temperature differences between day and night. Unlike the relatively closed SDTS-H system, the ISDTS system may not be conducive for accumulation of sugars and for anthocyanins. The increase in photosynthetic area with ISDTS-VH promoted the accumulation of more nutrients compared with a pergola trellis, while reduction of bearing part of V-shaped trellis protected the fruit from damage caused by hot and dry wind, high temperature, and strong light, resulting in a higher horizontal curtain and larger berries despite a smaller leaf area index (LAI). Although sugar and anthocyanins accumulate, organic acids degrade quickly in overexposed grape berry, the relatively small leaf-to-fruit ratio does not favor berry development, leading to a small berry mass.

Effect of trellis system on anthocyanin accumulation

Color is an important characteristic for evaluating grape quality. It is mainly determined by concentrations of different anthocyanins (Castellarin et al. 2006). In general, a higher total anthocyanin concentration in the peel yield a darker fruit. Berry skin with a high proportion of cyanidins are generally light red or red, whereas those with a high proportion of delphinidins are purple- or blue-black (Jaakola et al. 2002; Azuma et al. 2015). Additionally, a higher proportion of modified anthocyanins was associated with darker fruit color (Gomez et al. 2009). Environmental factors such as light and temperature can affect the anthocyanin composition and level in fruit by altering gene expression (Mazza et al. 1995). The anthocyanin concentration of 'Xinyu' grape skins was significantly higher with ISDTS trellis systems than with the SDTS system, and the anthocyanin was significantly higher for grapes from the ISDTS-H treatment than for those from ISDTS-VH. The number of hours above 35°C was highest for ISDTS-H and lowest for SDTS-H, and the anthocyanin concentration was consistent with the time above 35°C. Mori et al. (2005) also showed that high temperature reduced anthocyanin accumulation in the skin. However, the elevated temperature was beneficial for the increased proportion of malvidin-based anthocyanins (Lu et al. 2022). In this study we also found that malvidin concentration was higher for ISDTS-H than for ISDTS-VH and SDTS-H.

Additionally, the high proportion of total delphinidins may have make berry skin overcoloring which can also occur with high levels of methylated and acylated anthocyanins. Lu et al. (2022) showed that elevated temperature might be the cause of higher proportions of methylated anthocyanins and acylated anthocyanins. Tarara et al. (2008) showed that grape berries might shunt more of the available anthocyanin toward acylation in response to temperature stress, with the potential advantage to the plant of color stability within the vacuole because of the stability of the acylated compounds. In this study, we found that the proportion of acetylated was higher for ISDTS-H than for ISDTS-VH and SDTS-H, however, the proportion of methylated was lower for ISDTS-H than for ISDTS-VH and SDTS-H, but this study was not exactly the same as previous studies. By altering the leaf curtain structure, the different trellis systems further influenced fruit nutrient supply and microclimate, resulting in differences in fruit coloring, although the contribution of other factors such as light intensity and quality that affect anthocyanin synthesis requires further study.

Conclusions

There were significant differences in the fruit quality and characteristics of 'Xinyu' grape trained to three different trellis systems. Canopy thickness, LAI, and yield were highest for SDTS-H and lowest for ISDTS-H. The ISDTS-VH system had the highest berry mass and fruit quality.

The six anthocyanins, including delphinidin, petunidin, malvidin, cyanidin, peonidin and pelargonidin, were detected in the 'Xinyu' berry skin, and delphinidin was dominant. ISDTS-H and ISDTS-VH could increase the proportion of acetylated anthocyanin and decrease the proportion of methylated anthocyanin. Taken together, cultivation of 'Xinyu' grape with the ISDTS-VH trellis system in the arid area of northwest China can achieve relatively high yields and high berry quality.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Credit authorship contribution statement

Shijian Bai: Formal analysis, Investigation, Data curation, Writing-original draft, Writing-review& editing, Project administration, Funding acquisition. **Jinge Hu**: Investigation, Data curation, Soft, Visualization, Supervision, Writing-review & editing.

Ming Zheng: Writing-review& editing. **Jiuyun Wu**: Investigation. **Junshe Cai**: Investigation. **Guang Chen**: Field management. **Ronghua Zhao**: Field management. **Jiangfei Meng**: Writing-review& editing.

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References

Araujo, W.J., Dias, P.C., Moraes, G.A.B.K., Celin, E.F., Cunha, R.L., Barros, R.S. and DaMatta, F.M. 2008. Limitations to photosynthesis in coffee leaves from different canopy positions. Plant Physiol Biochem. 46(10):884-890. https://doi: 10.1016/j.plaphy.2008.05.005

Azuma, A., Ban, Y., Sato, A., Kono, A., Shiraishi, M., Yakushiji, H. and Kobayashi, S. 2015. MYB diplotypes at the color locus affect the ratios of tri/di-hydroxylated and methylated/non-methylated anthocyanins in grapes berry skin. Tree Genet Genomes, 11-33. https://doi: 10.1007/s11295-015-0855-0

Azuma, A., Yakushiji, H., Koshita, Y. and Kobatashi, S. 2012. Flavonoid biosynthesis-related genes in grape skin are differentially regulated by temperature and light conditions. Planta. 234(4):1067-1080. https://doi: 10.1007/s00425-012-1650-x

Carbonneau, A. and Huglin, P. 1982. Adaptation of training systems to French region. In: 'University of California, Davis, Grape and Wine centennial Symposium' Ed. A.D. Webb (University of California: Berkley, CA) pp.376-385.

Carreño, J., Martínez, A., Almela, L., and Fernández-López, J.A. 1995. Proposal of an index for the objective evaluation of the color of red table grapes. Food Res Int. 28:373-377.

Carreño, J., Martínez, A., Almela, L., and Fernández-López, J.A. 1996. Measuring the color of table grapes. Color Res Appl. 21:50-54.

Castellarin, S.D., Di Gaspero, G., Marconi, R., Nonis, A., Peterlunger, E., Paillard, S., Adam-Blondon, A.F., and Testolin, R. 2006. Color variation in red grapevines (*Vitis vinifera* L.): Genomic organisation, expression of flavonoid 3′-hydroxylase, flavonoid 3′,5′-hydroxylase genes and related metabolite profiling of red cyanidin-/blue delphinidin-based anthocyanins in berry skin. BMC Genomics. 7(1):12. https://doi: 10.1186/147-2164-7-12

Colova, C., Bordallo, P., Parker, L., Walters, T. and Leong, S. 2007. Evaluation of yield, fruit quality and photosynthesis of two training-trellis system and canopy management practices for Carlos and noble muscadine grapes in Florida. OENO-One. 41(1):43-49. https://doi.org/10.20870/oeno-one.2007.41.1.856

Esteban, M.A., Villanueva, M.J., and Lissarrague, J.R. 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv Tempranillo (Vitis Vinifera L) grape berries during ripening. J Sci Food and Agr. 81:409-420. https://doi10.1002/1097-0010(200103)81:4<409::aid-jsfa830>3.0.co;2-h

Ezzahouani, A. and Williams, L.E. 2003. Trellising, fruit thinning and defoliation have only small effects on the performance of 'Ruby Seedless' grape in Motocco. J Hortic Sci Biotech. 78(1):79-83. http://dx.doi.org/10.1080/14620316.2003.11511591

Gomez, C., Terrier, N., Torregrosa, L., Vialet, S., Fournier-Level, A., Verries, C., Souquet, J.M., Mazauric, J.P., Klein, M. and Cheynier, V. 2009. Grapevine MATE-type proteins act as vacuolar H+-dependent acylated anthocyanin transporters. Plant Physiol. 150(1):402–415. https://doi:10.1104/99.109135624

Guidelines for the conduct of tests for distinctness, uniformity and stability-grapevine (*Vitis* L.) (UPOV:TG/50/9., Guidelines for the conduct of tests for distinctness, uniformity and stability-Grapevine, NEQ). NY/T 2563-2014.

Jackson, D.I. and Lombard, P.B. 1993. Environmental and management practices affecting grape composition and wine quality. A review. Am J Enol Viticult. 44:409-430.

Jaakola, L., Maatta, K., Pirttila, A. M., Torronen, R., Karenlampi, S. and Hohtola, A. 2002. Expression of genes involved in anthocyanin biosynthesis in relation to anthocyanin, proanthocyanidin, and flavonol levels during bilberry fruit development. Plant Physiol. 130(2):729–739. https://doi:10.1104/pp.006857

Ji, T. and Dami, I.E. 2008. Characterization of free flavor compounds in Traminette grape and their relationship to vineyard training system and location. J Food Sci. 73(4):262–267. https://doi:101111/j.1750-3841.2008.00736.x

Katerji, N., Daudet, F.A., Carbonneau, A. and Ollat, N. 1994. Study at the whole plant level of photosynthesis and transpiration of the vine: Comparison of traditional and lyre training systems. Vitis. 33:197-203.

Kim, S.J., Park, S.J., Jung, S.M., Noh, J.H., Hur, Y.Y., Nam, J.C. and Park, K.S. 2014. Growth and fruit characteristics of 'Cheongsoo' grape in different trellis systems. Korean J Hortic Sci. 3(4):427-433. http://dx.doi.org/10.7235/hort.2014.13144

Liu, Z., Cheng, K.X., Qin, Z.Q., Wu, T., Li, X.M., Tu, J.F., Yang, F.C., Zhu, H.Y. and Yang, L. 2018. Selection and validation of suitable reference genes for qRT-PCR analysis in pear leaf tissues under distinct training systems. PLOS ONE. 13(8):e0202472. http://doi.org/10.1371/journal.pone.0202472

Luo, Q.W., Sun, F., Cai, J.S., Geng, X.L. and Rebiguli. 2007. A new grape cultivar 'Xinyu'. Acta Hortic Sinica. 34(3):797. (in Chinese)

Lu, H.C., Wang, Y., Cheng, C.F., Chen, W., Li, S.D., He, F., Duan, C.Q. and Wang, J. 2022. Distal leaf removal made balanced source-sink vines, delayed ripening, and increased falvonol composition in Cabernet Sauvignon grapes and wine in the semiarid Xinjing. Food Chem. 366:130582. https://doi:10.1016/j.foodchem.2021.130582

Mazza, G. and Francis, F.J. 1995. Anthocyanins in grapes and grape products. Crit Rev Food Sci. 35(4):341–371. http://dx.doi.org/10.1080/10408399509527704

Mori, K., Sugaya, S. and Gemma, H. 2005. Decreased anthocyanin biosynthesis in grape berries grown under elevated night temperature condition. Sci Hortic-amsterdam.105:319-330. https://doi:10.1016/j.scienta.2005.01.032

National Health Commission of the People Republic of China,State Administration of Market Supervision and Administration. Food safety nationalstandardDeterminationoftotalacidinfoods:GB12456-2021 [S]. Beijing: China Standards Press, 2021.

Olson, B.K., Brooke, M., Wang, Z.Y., Svyantek, A., Stenger, J. and Hatterman-Valenti, H. 2021. 'Frontenac' grape response to canopy management in North Dakota. Horticulturae 7(9):288. https://doi.org/10.3390/horticulturae7090288

Pan, M.Q., Zhang, F.C., Zhong, H.X., Han, S.A., Zhou, X.M., Zhang, W. and Wu, X.Y. 2017. Evaluation of high photosynthetic efficiency and facilitation in grape 'single cordon along the ditch obliquely' in Northern China. J Fruit Sci. 34(9):1134–1143. (In Chinese). https://doi:10.13925/j.cnki.gsxb.20160156

Reynolds, A.G. and Heuvel, J.E.V. 2009. Influence of grapevine training systems on vine growth and fruit composition: A review. Am J Enol Viticult. 60:251-268. https://doi:10.1109ICEMI.2009.5274122

Reynolds, A.G., Wardle, D.A. and Naylr, A.P. 1995. Impact of training system and vine spacing on vine performance and berry composition of Chancellor. Am J Enol Viticult. 46:88-97. https://doi:10.1007/BF00221141

Salvi, L., Eleonora Cataldo, E., Sbraci, S., Paoli, F., Fucile, M., Nistor, E. and Mattii, G.B. 2021. Modeling carbon balance and sugar content of Vitis vinifera under two different trellis systems. Plants. 10(8):1675. https://doi:10.3390/plants10081675

Sanchez-Rodriguez, L.A. and Spósito, M.B. 2019. Influence of the trellis/training system on the physiology and production of *Vitis labrusca* cv. Niagara Rosada in Brazil. Sci Hortic-amsterdam, 261:109043. https://doi:10.1016/j.scienta.2019.109043

Sander, G.F., Macedo, T.A., Silva, P.S.D., Welter, J.F., Posser, A.J., Rufato, L. and Kretzschmar, A.A. 2019. Effect of different training systems to catch greater light interception in apple cultivar Maxi Gala in temperate climate. Aus J Crop Sci. 13(04):574-577. https://doi:10.21475/ajcs.19.13.04.p1542

Schultz, H.R. 1995. Grape canopy structure, light microclimate and photosynthesis. I. A two dimensional model of the spatial distribution of surface area densities and leaf ages in two canopy systems. Vitis. 34:211–215.

Shi, X.B., Liu, F.Z., Cheng, C.G., Wang, X.D., Wang, B.L., Zheng, X.C. and Wang, H.B. 2015. Effects of canopy shapes of grape on canopy microenvironment, leaf and fruit quality in greenhouse. Chinese J Appl Ecol. 26(12):3730–3736. (in Chinese)

Smart, R.E., Robinson, J.B., Due, G.R. and Brien, C.J. 1985. Canopy microclimate modification for the cultivar Shiraz I.. Definition of canopy microclimate. Vitis. 24,17-31.

Stojanovic, J. and Silva, J.L. 2007. Influence of osmotic concentration, continuous high frequency ultrasound and dehydration on antioxidants, colour and chemical properties of rabbiteye blueberried. Food Chem. 101(3):898-906. https://doi:10.1016/j.foodchem.2006.02.044

Tarara, J.M., Lee, J., Spayd, S.E. and Scagel, C.F. 2008. Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. Am J Enol Viticult. 59(3):235-247. https://doi:10.1018/002074500290025617

Tian, M.B., Liu, Y., Lu, H.C., Hu, L., Wang, Y., Cheng, C.F., Chen, W., Li, S.D., He, F., Duan, C.Q. and Wang, J. 2022. Cluster spatial positions varied the phenolics profiles of 'Cabernet Sauvignon' grapes and wines under a fan training system with multiple trunks. Food Chem. 387:132930. https://doi:10.1016/j.foodchem.2022.132930

Wang, R., Ren, C., Dong, S., Chen, C., Xian, B., Wu, Q., Wang, J., Pei, J. and Chen, J. 2021. Integrated metabolomics and transcriptome analysis of flavonoid biosynthesis in safflower (*Carthamus tinctorius* L.) with different colors. Front Plant Sci. 12:712038. https://doi:10.3389/fpls.2021.712038

Wang, X.Y., Zhang, G.J., Sun, L., Zhao, Y., Yan, A.L., Wang, H.L., Ren, J.C. and Xu, H.Y. 2019. Effects of two trellis systems on viticultural characteristics and fruit quality of three table grape cultivars. Sci Agricultura Si

About the Cover:

Velvet apple (*Diospyros blancoi*) is a tropical fruit related to persimmon and native to the Philippines and Taiwan. It is not grown commercially but may be sold in local farmer's markets. Trees are propagated by seed or cuttings. The deciduous trees can be 20 m tall. Seedling trees vary greatly in tree size and shape, and fruits vary in shape, color, taste, and hairiness. The skin is not eaten because it is tough and bitter. Some fruits have large seeds and others are seedless. The fruit is less popular than many other tropical fruits because it lacks sweetness and is fairly dry. Trees flower in late winter and fruits ripen in June to September. Trees produce dark colored wood that is very dense, and the wood is used for flooring, doors and windows in house construction as well as for carving and furniture.