Effects of time and height of shading on yield and quality of pineapple

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Abstract. Effects of time and height of shading on the sunburn rate, yield and quality of pineapples were investigated in order to provide a theoretical basis for high-quality pineapple production. Golden pineapple was used as the material, and three shading times (30 d, 45 d, and 60 d after flower-fading), and the heights of 0 cm, 20 cm, and 40 cm (the distance from the top of the plant) were set. Golden pineapple’s internal and external fruit qualities were measured. The results showed that the incidence of sunburn of pineapple fruits increased with the delay of the shading time, and no differences were found among three heights at 30 d after flower fading. When pineapple plants were shaded at 30 d after flower fading and at height of 0 cm, pineapple fruits showed good external qualities, including larger fruit size, less fruit eyes, less fruit shape index, larger fruit hardness, higher edible rate and good internal qualities, including higher soluble solid content, higher soluble sugar content and lower total acidity. Shading at 30 d after flower fading and at height of 0 cm was suggested in pineapple production.

1. Introduction

Pineapple (Ananas comosus (L.) Merr) is the third largest tropical fruit in the world, and the seventh largest fruit in the world. It is native to tropical rainforest areas such as Brazil, Argentina, and Paraguay in South America and is now distributed about 60 countries and regions. The main production areas are concentrated in Thailand, the Philippines, China, Brazil, India, Nigeria, and the United States. China is one of the world’s largest pineapple producing countries. China’s pineapple production areas are mainly distributed in Hainan, Guangdong, Guangxi, Yunnan, Fujian and other provinces (regions). Golden pineapple (MD-2) was bred by Del Monte in the United States. It is an excellent fresh pineapple variety, so it became the leading variety in the international fresh pineapple trade. Because of its beautiful shape, easy-peeled fruit eyes and golden flesh, strong flavor, and sweet and sour taste, it was favored by consumers in high-end consumer market [1].

With the reform of China’s agricultural supply side, the area of pineapple plantation reached 81946 ha in 2018, with an output of 2 million tons, and the area of new varieties has been increasing[2]. The pineapple industry has become one of pillar industries in the tropical regions of southern China[3-5].
In China’s pineapple planting areas, especially in Yunnan’s high altitude and low latitude regions, strong sunlight in summer and autumn often leads to fruit sunburn with severe sunburn rate of up to 50%, and even death of the entire plant [6]. The strong sunlight in summer and autumn has become one of the main influencing factors restricting the development of the pineapple industry. The shading net is one of the main measures to prevent the hazard of strong sunlight in production, and has achieved good results in the application of sunburn prevention and control in different fruit trees. Wan et al. [7] believed that shading net had better effect on sunburn prevention of grape than no shading. The results of Zhao et al. [8] indicated that shading nets had best effect on sunburn prevention of Murcott Citrus than mulching of tree base, sprinkler Irrigation, fruit bagging, paper paste on fruit, spraying borax and potassium dihydrogen phosphate and spraying gibberellins. Chen et al. [9] applied shading nets on citrus in Nanjing County, which had better anti-sunburn effect, and believed that shading net for citrus was a practical and effective measure to prevent sunburn. In practical pineapple production, some farmers use shading net to prevent sunburn. However, the effects of time and height of shading net on pineapple yield and quality are rarely reported. The purpose of this study is to analyze the effect of time and height of shading net on the sunburn rate, yield and quality of pineapples in order to provide theoretical basis for high-quality pineapple cultivation.

2. Materials and methods

2.1 Materials

Golden pineapple seedlings were introduced from the South Tropical Crops Research Institute, Chinese Academy of Tropical Agricultural Sciences, with average plant height of 55 cm-60 cm and plant weight of 450 g-500 g. Blue shading net (70% light transmittance) is produced by Shandong Linyi Lumeng Shading Net Factory.

2.2 Trial design and field planting

This experiment was conducted at Modern Tropical Agricultural Scientific Research and Teaching Base of Yunnan Agricultural University (Pu’er City, Yunnan Province) from 2018 to 2019. Organic fertilizer (800 kg), calcium, magnesium and phosphorus (80 kg), and 10 kg of compound fertilizer (10 kg) per 666.67 m² were used as base fertilizer. Seedlings were transplanted in May 2018, the flowering forcing was conducted on April 12, 2019, and the floral emergence period was in late May, 2019. The flowering fading period was in late June, 2019, and the harvest period is in mid-October, 2019.

The experiment is conducted using completely random design. There were three shading times (30 d, 45 d, 60 d after flowering fading), and three shading height from the top of the plant (0 cm, 20 cm, 40 cm). A total of nine treatments were formed: 60d after flowering fading + 0 cm, 60 d after flowering fading + 20 cm, 60 d after flowering fading + 40 cm, 45 d after flowering fading + 0 cm, 45 d after flowering fading + 20 cm, 45 d after flowering fading + 40 cm, 30 d after flowering fading + 0 cm, 30 d after flowering fading + 20 cm, 30 d after flowering fading + 40 cm. The shading net was not released until harvest. Each treatment was consisted of 3 plots with an area of 30 m² and about 100 plants per plot.

2.3 Measurement items

When harvesting, the sunburn fruit was counted (Damage part of the fruit is white, yellow or black).

The sunburn rate (%) = Number of diseased fruits / Total number of fruits surveyed × 100.

Ten fruits were randomly collected from each treatment. After harvest, pineapple yield, external qualities (Fruit longitude diameter, fruit transverse diameter, average fruit weight, fruit eye number, fruit hardness and edible rate) and internal quality (soluble solid content, soluble sugar content, vitamin C content and total acidity content) were measured.

Edible rate (%) = W1 / W × 100, where W was the weight of no-crown bud fruit and W1 was the weight of the pulp. The content of soluble solids was measured with a handheld refractometer (ATAGO, Japan), and the content of soluble sugar was measured using anthrone colorimetric method.
The content of vitamin C was determined by the 2, 6-dichloroindophenol method. The total acidity content was measured by acid-base neutralization titration method.

2.4 Statistical analysis
The statistics of experimental data was conducted using Excel 2007 and was analyzed using Duncan’s new complex range method by software DPS v9.50.

3. Results and analysis

3.1 Effect of different treatments on the sunburn rate of pineapple fruits
It can be seen from Fig. 1 that the incidence of sunburn of pineapple fruits increased with the delay of the shading time. Shading at 30 d after flower fading had best effect on prevention of sunburn, second at 45 d after flowering fading and third at 60 d after flowering fading. At 30 d after flowering fading, the sunburn rate showed lowest value of 4.51% at shading height of 40 cm and there was no significant difference on the sunburn rate of pineapple fruits treated among three different shading heights.

![Fig.1 Effects of shading time and height on sunburn rate of pineapple fruits](image)

3.2 Effects of different treatments on external quality of pineapple fruits
It can be seen from Table 1 that shading time and height had no significant effects on fruit width. At 40 d after flower fading and at shading height of 40 cm, average fruit weight was significantly higher than other treatments, up to 1246.85 g. At 40d after flower fading and at shading height of 40 cm, fruit longitudinal diameter was highest, up to 14.53 cm. Except that treatment at 60 d after flower fading and height of 40 am and that treatment at 45 d after flower fading and height of 0 cm, there was no significant difference on fruit longitudinal diameter at other treatments. At 30 d after flower fading and at shading height of 0 cm, fruit transverse diameter was highest, up to 12.23 cm. There was no significant

| Days after flower fading (d) | Height (cm) | Average fruit weight (g) | Fruit longitude diameter (cm) | Fruit transverse diameter (cm) | Fruit eye numbers | Fruit shape index | Fruit hardness (kg/cm²) | Edible rate (%) |
|-----------------------------|-------------|--------------------------|-------------------------------|-------------------------------|-------------------|-------------------|----------------------------|----------------|
| 60                          | 0           | 651.87±28.09b            | 11.70±0.7ab                   | 10.63±0.38a                   | 53.00±7.81a       | 1.10±0.06ab       | 5.63±3.45a               | 69.52±6.89a     |
| 40                          | 20          | 705.55±23.12b            | 13.27±1.14a                   | 11.30±0.52a                   | 56.67±8.08a       | 1.17±0.07ab       | 4.80±0.75ab               | 64.49±2.83ab    |
| 45                          | 40          | 524.65±42.86b            | 10.77±1.5b                    | 9.97±0.59a                    | 40.33±10.21a      | 1.08±0.09ab       | 4.07±0.35ab               | 59.77±3.33ab    |
| 40                          | 0           | 667.28±301.56b           | 11.20±1.71b                   | 10.97±1.84a                   | 45.33±6.11b       | 1.02±0.02ab       | 3.70±0.44ab               | 65.44±4.26ab    |
| 45                          | 20          | 711.90±27.03b            | 12.90±0.32ab                  | 11.37±0.64a                   | 60.33±14.29ab     | 1.14±0.02ab       | 2.85±0.04ab               | 66.31±2.17ab    |
| 30                          | 40          | 1246.85±320.18a          | 14.53±1.38a                   | 12.10±0.80a                   | 75.00±8.54a       | 1.20±0.05a        | 3.33±0.95ab               | 69.30±3.24ab    |
| 30                          | 0           | 699.12±132.33b           | 11.83±0.85a                   | 12.23±2.62a                   | 48.33±6.66a       | 1.01±0.28ab       | 3.80±0.70ab               | 64.94±7.33ab    |
| 40                          | 20          | 533.51±123.81b           | 10.35±0.82a                   | 10.67±0.60a                   | 44.67±3.06a       | 0.97±0.09b        | 4.93±0.23ab               | 67.70±1.98ab    |
| 40                          | 40          | 719.93±113.04b           | 12.10±0.95a                   | 11.27±0.40a                   | 42.33±8.14a       | 1.07±0.05ab       | 2.83±0.68ab               | 65.40±4.25ab    |
difference on fruit longitudinal diameter at nine treatments. At 60 d after flower fading and shading height of 40 cm, fruit eye number was lowest, only 40.33. At 60 d and 30 d after flower fading, no significant difference was found on fruit eye number. At 30 d after flower fading and shading height of 20 cm, fruit shape index was lowest, only 0.97. Except that treatment at 45 d after flower fading and height of 40 cm, there was no significant difference on fruit shape index. At 60 d after flower fading and shading height of 0 cm, fruit hardness was highest, up to 5.63 kg/cm². Except that treatment at 45 d after flower fading and height of 20 cm and treatment at 30 d after fading and height of 40 cm, there was no significant difference on fruit hardness. At 60 d after flower fading and shading height of 0 cm, edible rate was highest, up to 69.52%. Except that treatment at 60 d after flower fading and height of 40 cm, there was no significant difference on edible rate. When pineapple were shaded at 30 d after flower fading and at height of 0 cm and 20 cm, pineapple fruit showed larger fruit size, better fruit shape index, lower fruit eye number, higher fruit hardness and higher edible rate.

3.3 Effects of different treatments on internal qualities of pineapple fruits

It can be seen from Fig. 2 that at 30 d after flower fading and height of 40 cm, soluble solid content was highest, up to 12.19% while soluble solid content was lowest, only 9.22% at 60 d after flower fading and height of 20 cm. There was no significant difference on soluble solid content among nine treatments.

![Fig. 2 Effects of shade time and height on soluble solid content in pineapple fruits](image)

It can be seen from Fig. 3 that at 45 d after flower fading and height of 40 cm, soluble sugar content was highest, up to 14.71%. Except that treatment at 45 d after flower fading and height of 20 cm and treatment at 30 d after flower fading and height of 40 cm, no significant difference on soluble sugar content was found among other treatments.

![Fig. 3 Effects of shading time and height on soluble sugar content in pineapple fruits](image)

It can be seen from Fig. 4 that Vc content at 60 d after fading and height of 20 cm and 40 cm was significantly higher than that at other treatments.
It can be seen from Fig. 5 that total acidity at 30 d after flower fading and height of 0 cm was significantly lower than that at other treatments. There was no significant difference on total acidity among three treatments at 30 d after flower fading and height of 0 cm, at 45 d after flower fading and height of 0 cm, and at 60 d after flower fading and height of 20 cm.

4. Discussion and conclusion

The occurrence of sunburn is a complicated process. It is closely related to climate, variety, fruit development period, tree vigor, fruit growing position, and soil condition. High temperature of fruit surface excessively is the eventual cause of sunburn. By adopting measures such as planting resistant varieties, cultivating reasonable tree types, fertilizer and water management, ground cover, intercropping, and fruit bagging, the environmental temperature of fruits can be effectively reduced [10-11]. Different space sizes caused by different shading heights could affect the temperature and humidity of the space environment. Hu et al. [12] measured the effect of shading nets (40% light transmittance) on the temperature and humidity of tea canopy at heights of 2 m and 2.5 m, and the results showed that average daytime temperature was higher when shading net was at a height of 2.5 m higher than at a height of 2 m by 0.1-0.2°C. Shading time and shading period had different impacts on the environment and crops [13-15]. In our study, the incidence of sunburn increased with the delay of shading time. The effect of sunburn prevention at 30 d after flowering fading was better than that of the other two times. It was shown that early shading could reduce sunburn. The sunburn prevention and control effect at a height of 20 cm was better than other treatments. It could be explained that low height of shading net could reduce air flow under shading net while high height of shading net could increase hot air from outside environment.

Shading could reduce the energy source of photosynthesis, cause the decrease of net photosynthetic rate and net carbon assimilation rate and lead to a decrease in dry weight and a reduction in yield. However, under strong light and high temperature stress, most crops show a clear "lunch break" phenomenon. Therefore, moderate shading at sunny noon in summer may improve photosynthesis and increase yield by improving the micro-meteorological environment of crop growth [16]. Fruit is one of the main organs of horticultural crops as harvested products. Average fruit weight, size, hardness and edible rate are the main indicators of external qualities of fruits. The results of this study indicated that
at the same shading height, the shading time had a small effect on average fruit weight, fruit size, and fruit shape index of the pineapple. It is generally considered that the treatment at 30 d after flowering fading and height of 0 cm and 20 cm could result in better external qualities of pineapple fruit. Xue et al. [17] believed that the length of shading time had a small effect on average fruit weight of tomato, but had a large effect on green vegetables. The yield of shaded plots was lower than the control, which should be related to the different harvesting organs of plants. The harvest of tomatoes and pineapples come from reproductive organs while vegetables are from vegetative organs.

Light can obviously change the growth environment of crops; affect the tissue structure of plants, and then affect a series of physiological processes such as photosynthesis, nutrient absorption and redistribution in plants, and ultimately affect crop quality formation. Bartholomew et al. [18] thought that the titratable acid of pineapple ‘Smooth Cayene’ fluctuated greatly under the influence of light while the soluble solids fluctuated little. This study believed that the shading height and time had no effect on the soluble solids content and had significant effect on total acidity of pineapple fruits. Our study had similar result with the study of Bartholomew et al. [18]. In our study, Vc content at 60 d after flower fading were higher than other treats. It is clear that enough sunlight could improve Vc content of fruit.

In conclusion, early shading could decrease sunburn rate. The treatment was set at 30 d after flower fading and at height of 0 cm, better pineapple fruits could be produced, showing good external qualities such as larger fruit size, less fruit eyes, less fruit shape index, larger fruit hardness, higher edible rate and good internal qualities, including higher soluble solid content, higher soluble sugar content and lower total acidity.

Recommendation
1. The work described has not been submitted elsewhere for publication, in whole or in part, and all the authors listed have approved the manuscript.
2. The shading net is one of the main measures to protect fruit from sunburn. There were little theoretical studies on sunburn of pineapple fruit. The results of our study indicated that there were significant effects of time and height of shading on yield and quality of pineapple. Shading at 30 d after flower fading and at height of 0 cm had better effect of sunburn prevention and high quality fruit. It could provide theoretical basis for shading against sunburn in pineapple production.

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