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Quality Differences and Comprehensive Evaluation of Green and Ripe Fruits of *Citrus reticulata* Blanco var. Gonggan, "Shatang" Mandarin Fruit (*Citrus reticulata* Blanco cv.) and "Orah" (*Citrus reticulata* Blanco)

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Abstract [**Objectives**] To comparatively evaluate the quality differences between green (before color turning) and ripe (fully mature) fruits of three *Citrus reticulata* cultivars: Gonggan, "Shatang" mandarin, and Orah. [**Methods**] Fruit quality was systematically assessed across three dimensions: External morphology, internal flavor attributes, and nutritional-functional components. Two external appearance indices and three internal quality indicators were determined. [**Results**] Gonggan and Orah fruits exhibited significantly larger size than those of the "Shatang" mandarin. During the transition from green to ripe stages, the total soluble solids content of Gonggan and Orah was slightly higher than that of "Shatang" mandarin fruit. In green fruits, Orah exhibited the highest titratable acidity (TA), while "Shatang" mandarin had the highest TA content in ripe fruits. Regarding nutritional composition, Gonggan had the highest ascorbic acid content in green fruits, while Orah demonstrated the highest ascorbic acid content at full maturity. [**Conclusions**] the quality changes of the three varieties not only conform to the general rules of citrus fruit ripening but also exhibit significant variety specificity. Differentiated industrial strategies can be formulated based on the quality characteristics of different varieties.

Key words Gonggan, "Shatang" mandarin fruit, Orah, Green fruit, Ripe fruit

0 Introduction

Citrus (*Citrus reticulata* Blanco) belongs to the genus *Citrus* within the family Rutaceae and represents one of the most widely cultivated fruit crops globally, particularly in China. Its fruits are rich in nutrients, with low protein and fat contents, but high levels of dietary fiber, vitamins, carotenoids, flavonoids, limonin, and other active components, thus possessing good economic value and health benefits[1].

Gonggan (*Citrus reticulata* Blanco var. Gonggan, GG), primarily cultivated in the Lingnan region, is historically renowned as "Emperor Citrus" due to its status as a tribute fruit during the Northern Song Dynasty. This variety is rich in dietary fiber, polyphenols, pectin, and other nutrients, with various physiological activities such as antioxidant, anti-inflammatory, lipid-lowering, and hypoglycemic effects. Both the peel and pulp possess significant edible and medicinal values[2].

"Shatang" mandarin fruit (*Citrus reticulata* Blanco cv., STJ) is a major citrus cultivar in Guangdong Province, with a maturity period from November to early January of the following year. It is characterized by thin and crisp peel, juicy and sweet pulp, and is rich in citric acid, glucose, and vitamin C. It has the functions of invigorating the spleen, enriching blood, clearing the intestines, and moistening the lungs, and is widely consumed as a fresh fruit in China[3].

Orah mandarin (*Citrus reticulata* Blanco, WG) is a late-maturing hybrid cultivar distinguished by its bright coloration, delicate texture, juicy pulp, and pronounced aroma. It also demonstrates strong commercial potential due to its high yield and good storage potential. It is rich in vitamins, carotenoids, amino acids, flavonoids, coumarins, limonin, and other active components, and possesses multiple physiological functions such as cosmetic, antioxidant, and cardiovascular potency[4].

Recently, the growth rate in the economic benefit of the citrus industry has slowed down, and improving fruit quality has become a key approach to promoting industrial development. Fruit quality is a direct indicator of commercial value and is strongly influenced by genetic and varietal characteristics. Therefore, systematic comparative evaluation of fruit quality across cultivars is essential for guiding breeding programs, optimizing cultivation practices, and improving planting structures.

In quality evaluation, indicators such as total soluble solids (TSS) and titratable acid (TA) content are often used to characterize the internal quality of fruits. In addition, the types, contents, and ratios of sugars and acids also exert important effects on fruit flavor. Among them, sugars and acids are the core evaluation factors determining the flavor characteristics of citrus fruits.

1 Materials and methods

1.1 Experimental materials Gonggan fruits were collected from Deqing County, Zhaoqing City, Guangdong Province. "Shatang" mandarin fruits were also obtained from Deqing County, while Orah fruits were sampled from the core production area of

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Wuming, Guangxi. Green fruit samples were defined as healthy fruits at the pre-color turning stage, while ripe fruit samples were defined as fruits at commercial maturity. For each cultivar, 11 uniformly sized fruits free of diseases and insect pests were randomly selected at both developmental stages for subsequent analysis.

1.2 Determination of quality indicators

1.2.1 Single fruit weight. Single fruit weight was measured using an electronic balance (0.01 g).

1.2.2 Fruit shape index. The longitudinal and transverse diameters of fruits were measured with a vernier caliper.

Fruit shape index (ratio of length to width) = Longitudinal diameter/Transverse diameter.

1.2.3 Total soluble solids and titratable acid. Juice was extracted from each fruit, and the TSS content was measured using a handheld refractometer. After opening the instrument, the prism surface was wiped with clean paper. Several drops of distilled water were placed on the measuring prism of the refractometer to attain zero calibration. Subsequently, several drops of the squeezed juice were placed on the measuring prism of the digital refractometer to determine the TSS content. The average value of three replicate measurements was recorded as the TSS content of the fruit.

The tested juice was diluted 10-fold with purified water, and one drop was taken for measurement of TA content using an ATAGO PAL-BX/ACID 1 refractometer.

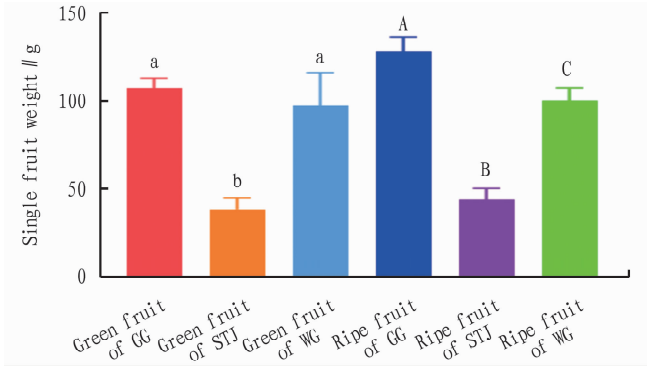
1.2.4 Ascorbic acid content. Ascorbic acid content was determined using a standard curve method. Standard solutions of ascorbic acid were prepared to generate a calibration. For each sample, 1.0 mL of extract was analyzed following the same procedure as the standards, and the ascorbic acid concentration was calculated based on the calibration curve.

1.3 Data analysis All data were analyzed using the Statistical Package for the Social Sciences software. Differences among groups were assessed using Duncan's multiple range test at a significance level of $P \leqslant 0.05$. GraphPad Prism software (version 9) was used for graphical visualization. Principal component analysis was employed for comprehensive quality evaluation.

2 Results and analysis

2.1 Morphological characteristics of green and ripe fruits

From the green to ripe stages, all three cultivars exhibited a significant increase in single fruit weight, longitudinal diameter, and transverse diameter (Figs. 1 – 2). Among them, Gonggan exhibited the greatest increase in single fruit weight, with an increase of 19.6%, while "Shatang" mandarin and Orah recorded an increase of 15.8% and 3%, respectively. The fruit shape index, defined as the ratio of longitudinal to transverse diameter, was less than 1 for both green and ripe fruits across all cultivars. As illustrated in Fig. 2, significant differences in fruit shape index were observed among the three cultivars during the transition from growth to ripening stages, reflecting cultivar-specific morphological development patterns.



NOTE Different letters indicate significant differences at $P < 0.05$. The same below.

Fig. 1 Determination of single fruit weight of green and ripe fruits of 'Gonggan', 'Shatang' mandarin, and 'Orah'

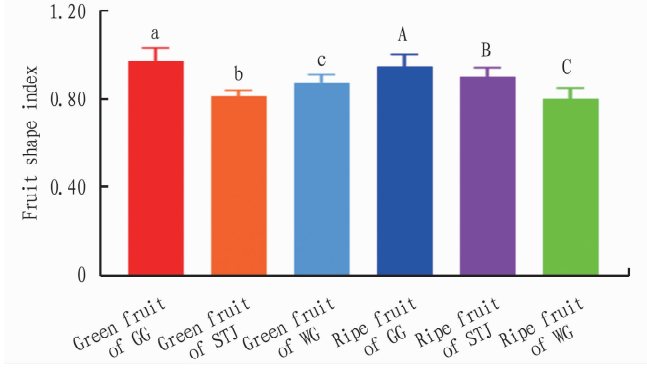


Fig. 2 Determination of fruit shape index of green and ripe fruits of 'Gonggan', 'Shatang' mandarin, and 'Orah'

2.2 Changes in TSS of green and ripe fruits TSS, which is a key indicator of sweetness and maturity, increased consistently from green to ripe stage in all three varieties (Fig. 3). At the green stage, Gonggan exhibited the highest TSS content (up to 11%), significantly exceeding that of the other varieties. At the ripe stage, TSS values converged, with no significant difference observed between "Shatang" mandarin fruit and Orah, although Orah exhibited the highest TSS content, reaching up to 12%.

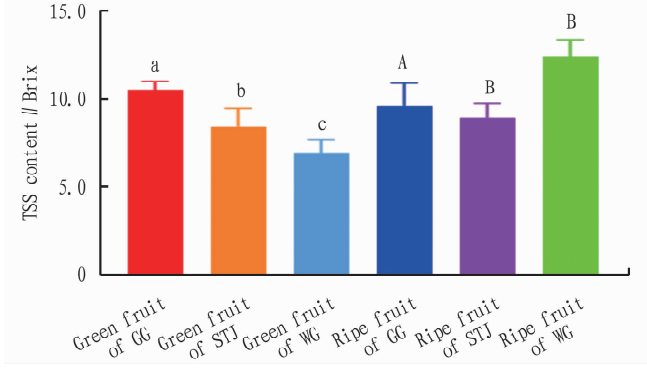


Fig. 3 Determination of soluble solids content of green and ripe fruits of 'Gonggan', 'Shatang' mandarin, and 'Orah'

2.3 TA content of green and ripe fruits TA, which reflects fruit sourness, exhibited distinct varietal trends during ripening.

TA content decreased in Gonggan and Orah, but demonstrated a slight increase in "Shatang" mandarin fruit (Fig. 4). While no significant difference was observed between Gonggan and "Shatang" mandarin fruit at the green stage and between Gonggan and Orah at the ripe stage, these contrasting patterns suggest differential acid metabolism among varieties.

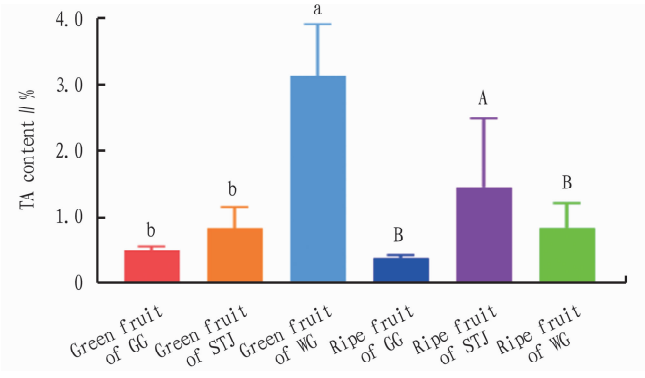


Fig. 4 Determination of titratable acid content of green and ripe fruits of 'Gonggan', 'Shatang' mandarin, and 'Orah'

2.4 Determination of ascorbic acid in green and ripe fruits

Ascorbic acid (vitamin C), an important antioxidant and nutritional indicator, demonstrated decreasing trends in Gonggan and Orah during fruit maturation, whereas "Shatang" mandarin fruit exhibited a slight increase. At the green stage, no significant difference was observed between Gonggan and Orah. Similarly, no significant intervarietal differences were found at the ripe stage (Fig. 5).

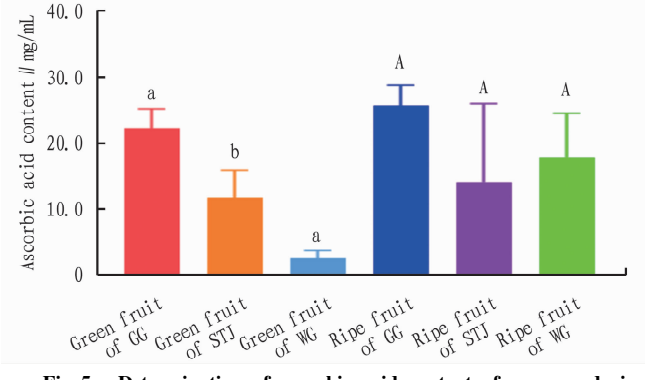


Fig. 5 Determination of ascorbic acid content of green and ripe fruits of 'Gonggan', 'Shatang' mandarin, and 'Orah'

3 Discussion and conclusions

Citrus is one of the most important fruits in China, and the diversity of its germplasm resources, as well as the characteristics of fruit quality, have long attracted much attention. This study systematically evaluated the morphological, flavor, and nutritional characteristics of three citrus varieties across two developmental stages. Morphologically, the larger fruit size observed in Gonggan and Orah compared to "Shatang" mandarin fruit is consistent with their genetic background and commercial classification. In terms of internal quality, sugar and acid components are the main substances that constitute citrus flavor. Additionally, TSS and TA content can reflect fruit sweetness and sourness to some extent. The study observed that the TSS content of Gonggan and Orah was slightly higher than that of "Shatang" mandarin as maturity progressed. Among green fruits, Orah had the highest TA content, while "Shatang" mandarin fruit had the highest TA content among the ripe fruits. The content of ascorbic acid is closely related to the nutritional value of fruits and is one of the most important antioxidants in citrus fruits. The experimental results demonstrated that among green fruits, Gonggan had the highest ascorbic acid content, while Orah had the highest ascorbic acid content among the ripe fruits. In summary, the quality changes of the three varieties not only conform to the general rules of citrus fruit ripening but also exhibit significant variety specificity. Differentiated industrial strategies can be formulated based on the quality characteristics of different varieties.

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