



Changes of sugar distribution in different tissues of satsuma mandarine

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ABSTRACT

The present study analyzed the changes of total sugar, fructose, glucose, and sucrose contents in leaves, roots, and fruits of *Citrus unshiu* cv Guoqing No. 1 grafted on *Poncirus trifoliata* in fruit enlargement period (August) and fruit mature period (October). The results showed an increase of glucose, sucrose, and total sugar from enlargement period to mature period. Total sugar content ranked as the trend of fruit pulp > fruit peel > root > distal leaf > proximal leaf. Significantly higher sucrose content was ranked as the trend of fruit pulp > fruit peel > proximal leaf > distal leaf > root in August and fruit pulp > fruit peel > root > proximal leaf > distal leaf in October. Significantly higher fructose content was rated as the trend of fruit pulp ≈ fruit peel > distal leaf > root ≈ proximal leaf in fruit enlargement period and fruit pulp > fruit peel ≥ distal leaf > proximal leaf > root in fruit mature period. Significantly higher glucose content was ranked as the trend of fruit pulp > root > fruit peel > proximal leaf ≈ distal leaf in fruit enlargement period and fruit pulp ≥ root > fruit peel > proximal leaf > distal leaf in fruit mature period. It concludes that roots recorded relatively lower sugar content than other four tissues, and sugars could transfer from proximal leaf into fruit, which is the center of energy requirement, especially fruit pulp.

1. INTRODUCTION

Citrus is one of the important fruit trees, whose production is the largest in China among the world. Citrus industry in China also faces many shortcomings, including low yields and poor fruit quality, resulting in a low competition in the international market. Citrus is characterized by fragrant flowers and edible juicy fruit [1].

Fruit quality includes two aspects of external quality and interior quality. External quality consists of fruit shape, size, pericarp smoothness, colour, lustre and peel puffing. Interior quality including edible rate, sugar-acid ratio, flavor, juice sacs, sugar content, and squeeze rate [2]. Meanwhile, flavor quality depends largely on sour and sweet, and the composition, content and proportion of sugar and organic acid are closely related to the fruit flavor quality. Soluble sugar of citrus includes sucrose, glucose and fructose [3]. Sugar

accumulation in fruit citrus had an important influence on flavor formation. These sugars might be originated from the allocation of other tissues. Hence, analyzing sugar changes in different tissues in citrus will illumine the strategy of sugar allocation and fruit flavor quality. The purpose of this study is to assess the changes of sucrose, glucose, and fructose contents in fruit, leaves and roots in fruit enlargement and mature period in citrus tree grown in the field.

2. MATERIALS AND METHODS

2.1. Plant material

In August (fruit enlargement period) and October (fruit mature period) 2015, we collected the roots, proximal leaves surrounding fruits, distal leaves surrounding fruits, fruit peel, and fruit pulp from a Citrus Orchard of Yangtze University, Jingzhou, China (30°36'N, and 112°14'E), where 28-yr-old *Citrus unshiu* grafted on *Poncirus trifoliata* was planted. The collected samples were oven-dried at 75°C for 72 h and sieved by 1-mm mesh.

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2.2. Experimental design

The experiment consisted of five treatments (root, proximal leaf surrounding fruits, distal leaf surrounding fruits, fruit peel, and fruit pulp) for each five replicates in a completely random arrangement. Roots, leaves, and fruits were selected from four directions of a satsuma mandarin tree and mixed as a replicate. There were five 28-yr-old satsuma mandarin (*Citrus unshiu* grafted on *Poncirus trifoliata*) trees used here. The growth vigor of satsuma mandarin trees is middle and was randomly selected between the lines in this orchard.

2.3. Determinations of sugars

The dry samples of roots, proximal leaves surrounding fruits, distal leaves surrounding fruits, fruit peels, and fruit pulps were incubated with 80% alcohol for 40 min at 80°C, and the contents of sucrose, glucose and fructose were colorimetrically determined by the procedure outlined by Wu et al. [4]. Total sugar was the sum of sucrose, fructose, and glucose.

2.4. Statistical analysis

The data (means \pm SD, $n=5$) were analyzed by the ANOVA of SAS (8.1), and the significant differences between the treatments were compared with the Duncan's Multiple Range Test at 0.05 level.

3. RESULTS

3.1. Sucrose content

As shown in Table 1, the content of sucrose was generally higher in October (fruit mature period) than in August

(fruit enlargement period) in each tissue. In fruit enlargement period, significantly higher sucrose content was rated as the trend of fruit pulp > fruit peel > proximal leaf > distal leaf > root. In fruit mature period, significantly higher sucrose content was ranked as the trend of fruit pulp > fruit peel \geq distal leaf > root > proximal leaf.

3.2. Fructose content

In fruit enlargement period (August), significantly higher fructose content was rated as the trend of fruit pulp \approx fruit peel > distal leaf > root \approx proximal leaf (Table 2). In fruit mature period (October), significantly higher fructose content was ranked as fruit pulp > fruit peel \geq distal leaf > proximal leaf > root in a decrease trend.

3.3. Glucose content

The content of glucose was increased from August to October. In fruit enlargement period (August), significantly higher glucose content was ranked as the trend of fruit pulp > root > fruit peel > proximal leaf \approx distal leaf (Table 3). In fruit mature period (October), significantly higher glucose content was rated as the trend of fruit pulp \geq root > fruit peel > proximal leaf > distal leaf.

3.4. Total sugar content

Total sugar content was increased from fruit enlargement period (August) to fruit mature period (October) (Table 4). In fruit enlargement period and mature period, significantly higher sucrose content was rated as the trend of fruit pulp > fruit peel > root > distal leaf > proximal leaf (Table 4).

Table 1: Change of sucrose content (mg/g DW) in different tissues of satsuma mandarin.

Month	Fruit peel	Fruit pulp	Proximal leaf	Distal leaf	Root
August	25.23 \pm 1.25b	79.20 \pm 3.96a	21.96 \pm 1.10c	15.33 \pm 0.67d	10.94 \pm 1.02e
October	52.60 \pm 2.90b	115.11 \pm 9.03a	36.04 \pm 1.80d	49.86 \pm 3.78b	37.65 \pm 2.22c

Different letters in the same row mean a significant difference among the tissues ($p<0.05$). The same below.

Table 2: Change of fructose content (mg/g DW) in different tissues of satsuma mandarin.

Month	Fruit peel	Fruit pulp	Proximal leaf	Distal leaf	Root
August	45.33 \pm 3.06a	46.56 \pm 2.27a	23.45 \pm 0.63c	28.58 \pm 0.80b	25.43 \pm 0.35c
October	34.09 \pm 1.51b	69.09 \pm 1.10a	25.97 \pm 1.63d	29.52 \pm 1.02c	15.28 \pm 0.85e

Table 3: Change of glucose content (mg/g DW) in different tissues of satsuma mandarin.

Month	Fruit peel	Fruit pulp	Proximal leaf	Distal leaf	Root
August	79.62 \pm 0.56c	117.11 \pm 2.30a	52.14 \pm 4.32d	48.81 \pm 3.21d	104.39 \pm 3.85b
October	94.13 \pm 3.24b	159.28 \pm 8.90a	63.28 \pm 5.01c	58.08 \pm 2.12d	123.11 \pm 9.79a

Table 4: Change of total sugar content (mg/g DW) in different tissues of satsuma mandarin.

Month	Fruit peel	Fruit pulp	Proximal leaf	Distal leaf	Root
August	150.18 \pm 9.51b	242.87 \pm 5.64a	97.55 \pm 4.18e	112.72 \pm 4.42d	142.10 \pm 6.22c
October	180.82 \pm 5.29b	343.48 \pm 8.30a	125.29 \pm 5.27e	137.46 \pm 3.80d	175.52 \pm 8.83c

4. DISCUSSION

This study showed that total sugar, glucose, and sucrose content increased with the fruitful development of the Mandarin satsuma, suggesting that in fruit mature period, citrus tissues would accumulate more total sugar, glucose, and sucrose content for fruit flavor and tissue storage. The accumulation of photosynthates would increase rapidly from enlargement period to mature period [5]. Plant sugar is originated from leaf photosynthesis [6]. In fruit enlargement period, glucose and sucrose content was significantly higher in proximal leaf than in distal leaf. However, in fruit mature period, glucose and sucrose content was higher in distal leaf than in proximal leaf, suggesting that proximal leaf might transfer more sucrose and glucose into fruits according to the principle of proximity.

On the other hand, in fruit, fruit pulp showed significantly higher total sugar, glucose, and sucrose content than fruit peel, suggesting that more sugar was accumulated in fruit pulp for fruit flavor and sweetness. It is well known that the hexose (including glucose and fructose) accumulation had given priority to fruit pulp [7]. The result is in agreement with previous reports in Okitsu satsuma fruit.

It is known that in fruit development, fruit is the center of energy requirement in whole plant, and many photosynthates would allocate into the needful center, namely, fruit. At the same time, roots would be in a disadvantaged place. Hence, in this study, in the five tissues, roots generally showed relatively lower hexose content than other four tissues. In sucrose, glucose, and fructose, roots exhibited a relatively higher glucose than sucrose and fructose. It is documented that root sucrose was cleaved into glucose and fructose by sucrose-cleaved enzymes [8,9]. Therefore, we guess that roots induced phloem-loaded sucrose cleaved more glucose, but not fructose, for root storage.

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