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Comprehensive Mineral Nutrition Analysis of Watermelon Grafted onto Two Different Rootstocks

HUANG Yuan, ZHAO Liqiang, KONG Qiusheng, CHENG Fei, NIU Mengliang, XIE Junjun, Muhammad Azher Nawaz, and BIE Zhilong *

College of Horticulture and Forestry Sciences, Huazhong Agricultural University, Key Laboratory of Horticultural Plant Biology, Ministry of Education, Wuhan 430070, China

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Abstract

Grafting is a widely used practice in fruit-bearing vegetables. However, why grafting affects plant growth, fruit yield, and quality, especially from the aspect of mineral nutrition, remains unclear. In this study, watermelon cultivar 'Zaojia 8424' was grafted onto bottle gourd 'Jingxinzhen 1' (*Lagenaria siceraria*) and pumpkin 'Qingyanzhen 1' (*Cucurbita maxima* × *C. moschata*). Non-grafted plants were used as the control. Results show that rootstock grafting significantly increases plant growth and single fruit weight of watermelon. Watermelon grafted onto rootstocks, especially pumpkin, exhibits significantly higher root volume, root surface area, and number of root tips and forks in comparison with non-grafted plants. Fruit flesh, rind firmness, and rind thickness were enhanced by grafting. However, fruit soluble solids and taste significantly decreased in plants grafted onto pumpkin. The total uptake (mg · plant^{-1}) and concentration (mg · g^{-1} DW) of N, K, Ca, Fe, Mg, and Mn in root, stem, leaf, fruit rind, and flesh were generally higher in grafted plants compared to non-grafted ones, especially for N of pumpkin rootstock-grafted plants. The total uptake of nutrients of plants grafted onto bottle gourd and pumpkin was increased by 30.41% and 49.14% at fruit development stage and by 21.33% and 47.46% at fruit maturation stage, respectively, compared with non-grafted plants. We concluded that watermelon grafting onto suitable rootstocks can increase the uptake of mineral nutrition, especially for N in the pumpkin rootstock grafted plants, thereby affecting plant growth, fruit yield, and quality.

Keywords: watermelon; grafting; rootstock; mineral element; fruit quality; nitrogen

1. Introduction

Watermelon is widely cultivated across the world. China is the leading producer of watermelon worldwide. Owing to the limited availability of arable land and high market demand, watermelon plants are continuously cultivated under unfavorable conditions in certain regions in China. Successive cropping can increase the incidence of soil-borne diseases (like *Fusarium* wilt) and unfavorable conditions, including low temperature, salinity, and low light intensity and quality, which widely affect plant growth and development of watermelon (Davis et al., 2008). Grafting of susceptible watermelon cultivars onto resistant rootstocks is used to control soil-borne disease (Yetisir et al., 2003; Miguel et al., 2004; Thies et al., 2010). Moreover, grafting can increase watermelon tolerance to low temperature (Liu et al., 2004a), salinity (Colla et al., 2006), flooding (Yetisir et al., 2006), and alkalinity (Colla et al., 2010), as well as enhance the uptake and utilization of nitrogen (Pulgar et al., 2000; Colla et al., 2011), phosphorus (Zhang et al., 2012), and potassium (Huang et al., 2013). Therefore, grafting is widely used as a tool for biotic and abiotic stress tolerance in the world.

Bottle gourd (*L. siceraria*) and pumpkin (*Cucurbita maxima* × *C. moschata*) are often used as rootstocks for watermelon (Davis et al., 2008). Plant growth, single fruit weight, and fruit quality are affected by rootstocks. Yetisir and Sari (2004) tested the effect of 11 rootstocks on watermelon. All grafted plants produced more biomass than non-grafted plants. In general, interspecific hybrid pumpkin rootstocks are more vigorous in comparison with bottle gourd rootstocks (Davis et al., 2008). 'Shintoza' rootstock (*C. maxima* × *C. moschata*) grafting

* Corresponding author. Tel.: +86 27 87286908.
E-mail address: biezhilong@hotmail.com

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increased watermelon single fruit weight and yield (Miguel et al., 2004). On the other hand, several researchers reported that interspecific pumpkin grafting decreases taste, total soluble solids (TSS), and sugar content of watermelon fruits (Ioannou et al., 2002; Liu et al., 2004b, 2006). However, significant adverse effect on fruit quality is generally not observed in watermelon fruits grafted onto bottle gourd (Salam et al., 2002; Turhan et al., 2012).

Rootstock is responsible for the uptake of mineral nutrients in grafted plants, and various rootstocks may result in different concentration of nutrients reaching the stems, leaves, and fruits of grafted plants in comparison with non-grafted plants. Effects of rootstock on uptake and utilization of certain mineral nutrients in watermelon plant have been reported in previous studies, and efficiency of nutrient uptake and utilization is often related to rootstock and scion combinations (Rivero et al., 2004; Colla et al., 2011; Huang et al., 2013; Yetisir et al., 2013). Plant nutrition may vary at different growth stages. In addition, as plant growth, fruit yield, fruit quality, and mineral nutrition were measured separately in previous studies, no comprehensive data are available on the relationship between mineral nutrition and plant growth, fruit yield, and quality of grafted watermelon. Therefore, this work aims to investigate how rootstock grafting induces changes in plant growth, fruit yield, and quality of watermelon by changing uptake of mineral nutrients at different stages, with widely used pumpkin and bottle gourd cultivars as rootstocks.

2. Materials and methods

2.1. Materials and growth conditions

The experiment was conducted under a plastic greenhouse during March to July 2012 at the National Center of Vegetable Improvement in Huazhong Agricultural University, Central China. ‘Zaojia 8424’ [*Citrullus lanatus* (Thunb.) Matsum. and Nakai, Xinjiang Academy of Agricultural Sciences, China] was grafted onto two rootstocks: ‘Jingxinzhen 1’ (*L. siceraria* Standl., Beijing Vegetable Research Center, China) and ‘Qingyanzhen 1’ [(*C. maxima* × *C. moschata*), Qingdao Academy of Agricultural Sciences, China], using the procedure of ‘insertion grafting’ as described by Lee (1994). Non-grafted ‘Zaojia 8424’ plants were used as control. ‘Zaojia 8424’ was selected as the representative watermelon hybrid that is commercially cultivated in China.

When the third true leaf of grafted or non-grafted plants emerged, plants were transplanted into plastic pots containing 10 L of substrate (peat:vermiculite:perlite = 1:1:1, volume ratio), with each pot containing one watermelon seedling. Pots were arranged at 150 cm row spacing and spaced 50 cm apart. Three treatments are as follows: non-grafted ‘Zaojia 8424’ (Z), ‘Zaojia 8424’ grafted onto ‘Jingxinzhen 1’ (Z/J), ‘Zaojia 8424’ grafted onto ‘Qingyanzhen 1’ (Z/Q). The treatments were replicated three times and arranged in a randomized complete block design. Each replicate consisted of 18 plants. Plants were trained vertically, only the main stem was propped out with rope during growth, and one fruit was allowed to develop on each plant. Insects, diseases, and weeds were controlled by standard practices for watermelon. During cultivation in the plastic greenhouse, day temperature ranged between 16 °C and 36 °C (mean temperature, 28 °C), night temperature was maintained above 14 °C, and day relative humidity was 30% to 93% (mean relative humidity, 64%).

The plants were irrigated with full strength Hoagland nutrient solutions (Hoagland and Arnon, 1950). The nutrient solution was pumped from tanks through a drip-irrigation system, with two emitters per plant, at the flow rate of $2\ L \cdot h^{-1}$. The amount of irrigation solution applied for each plant was 0 to 3 L per day, depending on plant growth stage and environmental conditions.

2.2. Plant growth measurement

Three plants from each treatment were harvested at the vine growth stage (26 days after planting), fruit development stage (14 days after pollination), and fruit maturation stage (31 days after pollination), separately. The plant was cut into roots, stem, leaf, fruit rind, and fruit flesh (fruit maturation stage). Then, roots, stem, leaf, fruit rind, fruit flesh were placed in an oven at 105 °C for 15 min, followed by 70 °C for 3 days to measure dry weight. Root morphology analysis was performed by harvesting roots at the fruit development stage (14 days after pollination), rinsed and put in a transparent tray with distilled water, separated from each other by hand, and placed on the Imagery Scan Screen (Epson Expression 11000XL, Regent Instruments, Canada). The volume, surface area, and the number of tips and forks of roots were measured by image analysis using the WinRHIZO 2003a software (Regent Instruments Inc., Quebec, Canada).

2.3. Determination of single fruit weight

Fully mature fruits were harvested on July 5 (31 days after pollination). Single fruit weight is the mean of three randomly selected fruits harvested at fruit maturating stage per replicate. After the determination of single fruit weight, fruits were used to determine fruit quality (rind and flesh firmness, rind thickness, soluble solid content, and taste).

2.4. Determination of rind and flesh firmness and rind thickness

Rind and flesh firmness were measured by using a penetrometer (GY-4, Zhejiang Top Instrument Co., Ltd., Zhejiang, China) equipped with a 7.9 mm puncture probe. Three fruits are included for each replicate, and each fruit was measured three times. Rind firmness was recorded as the maximum resistance force that is used to penetrate around the heart of each fruit in cross section to a depth of 10 mm. Firmness of the edge flesh was measured after removal of the rind. Rind thickness was measured using a digital vernier caliper.

2.5. Determination of total soluble solids (TSS) content and taste

Nine fruits for each treatment, with 3 fruits for each replicate, were used. TSS was determined by squeezing the juice of the replicate fruit flesh onto a digital refractometer (Atago Co., Ltd, Tokyo, Japan), and the results were expressed as °Brix. The taste was determined by a panel of 15 tasters, following a 1–5 scale (where 1 = very bad, 2 = bad, 3 = medium, 4 = good, 5 = very good).

2.6. Measurement of mineral nutrition

The dried powders of roots, stem, leaf, fruit rind, and flesh were digested in a mixture of H_2SO_4–H_2O_2 (volume ratio 5:1).