The Effects of Different Fertilization Methods on the Fruit Quality of 'Zao Hong' Navels

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Abstract
To compare the effects of different fertilization methods on the fruit quality of 'Zao Hong' navel in Zigui County, Yichang City, Hubei Province, a field experiment was conducted in the 'Zao Hong' navel orchard in Guiya Village, Jiuwanxi Town, Zigui County. The experiment had 4 treatments: applying the Aija microbial formula fertilizer (treatment 1), applying Kangpu microbial formula fertilizer (treatment 2), conventional fertilization (treatment 3), and no fertilization (control group). Each treatment had 20 replicates. The research results showed that compared with no fertilization, the fruit weight per single fruit, fruit flesh weight, transverse diameter, longitudinal diameter, and fruit shape index of the conventional fertilization treatment were significantly increased by 69.23%, 77.92%, 56.61%, 21.69%, and 26.39%, respectively. The content of titratable acid was significantly reduced by 12.36%, and the total sugar content was significantly increased by 14.52%. The ratios of solid acid and sugar acid were significantly increased by 15.44% and 30.00%, respectively. The content of Vc was significantly increased by 11.40%. Applying the Aijia microbial formula fertilizer significantly increased the fruit weight per single fruit, fruit flesh weight, transverse diameter, and longitudinal diameter by 80.46%, 99.77%, 43.72%, and 19.78%, respectively. The hardness of the fruit skin was significantly reduced by 7.13%, and the content of titratable acid was significantly decreased by 23.60%, and the total sugar content was significantly increased by 27.42%. The ratios of solid acid and sugar acid were significantly increased by 51.08% and 65.71%, respectively. The protein and Vc contents were significantly increased by 87.77% and 17.51%, respectively. Applying the Kangpu microbial formula fertilizer significantly increased the fruit weight per single fruit, fruit flesh weight, transverse diameter, and longitudinal diameter by 95.07%, 117.87%, 53.05%, and 26.48%, respectively. The content of titratable acid was significantly decreased by 28.09%, and the total sugar content was significantly increased by 32.26%. The ratios of solid acid and sugar acid were significantly increased by 55.33% and 82.86%, respectively. The protein and Vc contents were significantly increased by 56.12% and 23.14%, respectively. Thus, both applying microbial formula fertilizers and conventional fertilizers have significant effects on improving the fruit quality of 'Zao Hong' navel in Zigui. The effect of applying the Kangpu microbial formula fertilizer is the most significant, followed by applying the Aijia microbial formula fertilizer.

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Introduction

Among all the various fruit trees planted across the country, the cultivation area and output of citrus fruits have been increasing year by year. In terms of both cultivation area and output, citrus fruits have surpassed apples and ranked first [1]. Citrus belongs to the *Rutaceae* family and the Citrus genus. It is a perennial evergreen small tree or shrub. Its varieties include oranges, lemons, tangerines, tangerines, limes, grapefruits, and pomelos, and they have spread throughout tropical and subtropical regions around the world [1].

'Zao Hong' navel is a grafting hybrid of 'Robertson' navel and 'National Day 1' Wenzhou navel. It has the peel of an orange and the flesh of an orange. It has a delicate texture, is sweet and sour, has good melting properties, and the follicles are not obvious when it is ripe [2]. Microbial fertilizer is a new type of fertilizer, rich in various microorganisms and nutrients, with advantages such as environmental protection, high efficiency, long-lasting, and safety. It can improve the soil, enrich soil fertility, enhance crop resilience, promote crop growth, increase yield and quality, reduce the use of pesticides and fertilizers, and has broad market prospects and development potential [3-5]. Different microbial fertilizer types and application methods may have significant differences in their effects on the same crop. Therefore, this study selected two different microbial formula fertilizers and farmers' conventional fertilization as experimental treatments. By comparing the effects of different treatments on the quality of 'Zao Hong' navel fruits, it is expected to provide a scientific basis for the application of microbial fertilizer in 'Zao Hong' navels in Zigui.

Table 1: Fertilizers Applied under Different Treatments and Related Indicators

Treatment	Sources of Fertilizers	Main types of Fertilizers	Main Technical Parameters	Treatment Time and Method	Application Rates of Fertilizers
Treatment 1	Harbin Aijia Biotechnology Co., Ltd.	Microbial Agent	Effective viable bacteria count ≥ 100 million per gram, Bacillus amyloliquefaciens	End of June irrigation	2 kg/plant
		Bian'an Organic Fertilizer	Organic matter ≥ 30 %	End of June irrigation	2 kg/plant
		Egar No. 4	Ca+Mg≧100 g/L	Application of foliar spray at the end of August	5 kg/plant（400X）
		Egar No. 5	10:20:20+TE	7. Foliar spraying at the end of September and the beginning of October	5 kg/plant（400X）
Treatment 2	Kangpo (China) Co., Ltd.	Microbial Agent	Effective viable bacteria count ≥ 5.0 billion/g, organic matter ≥ 60%, containing Bacillus subtilis	End of May irrigation	2.5 kg/plant
		Stable compound fertilizer	17:17:17+TE	End of May irrigation	1 kg/plant
		Medium-level element water-soluble fertilizer	Ca+Mg≧100 g/L	Apply in mid-to-late July	0.2 kg/plant
		Bulk element water-soluble fertilizer	12:8:36+TE	Apply in mid-to-late July	0.1 kg/plant
Treatment 3	Yara Trading (Shanghai) Co., Ltd.	High-potassium compound fertilizer	12:6:24+TE	From the end of May to the beginning of June, irrigation was carried out.	1.5 kg/plant
		Yara Calcium Fertilizer Solution	Ca≧150 g/L	Spraying on the leaf surface from the end of May to the beginning of June	2 kg/plant（800X）
	Swiss Syngenta Crop Protection Company Limited	Amino acid water-soluble fertilizer	amino acid content ≧110 g/L	Spraying on leaves from the end of June to the beginning of July	2 kg/plant（500X）
	Stanley Fertilizer Company Limited	potassium dihydrogen phosphate	KH_2PO_4≧99 %	September foliar spraying	2 kg/plant

2. Materials and Methods

2.1. Experimental Materials

2.1.1. Overview of the Experimental Site

The experimental site is located in Guiya Village, Jiuwanxi Town, Zigui County, Yichang City, Hubei Province. The altitude is 436 meters. The tested variety is 'Zao Hong' navel, and the rootstock is Red navel. All the experimental plants were grafted and replanted in March 2020. They are now in the peak fruiting period, and the planting density is 80 plants per acre.

2.1.2. Test Fertilizers

The two microbial fertilizer types are Aijia Microbial Formula Fertilizer (treatment 1) and Kangpu Microbial Formula Fertilizer (treatment 2); conventional fertilization (treatment 3) refers to the fertilizer applied by farmers according to their own fertilization habits; CK is the blank control, without any fertilizer application. The specific application of fertilizers and related indicators are shown in Table 1.

2.2. Experimental Design

This experiment involved 4 treatments, namely applying the Aijia microbial formula fertilizer (Treatment 1), applying the Kangpu microbial formula fertilizer (Treatment 2), conventional fertilization (Treatment 3), and no fertilization (Control). Each treatment consisted of 20 trees. Fertilization was initiated in May 2024. Other fertilizer and water management practices as well as regular agricultural management remained unchanged. Sampling was conducted once on November 29, 2024. Four trees were randomly selected from each treatment, and one fruit was randomly collected from each tree at each of the six directions: east, west, south, north, up, and down.

2.3. Measurement Methods

All fruits were tested for single fruit weight, flesh weight, peel weight, peel hardness, flesh hardness, transverse diameter, and longitudinal diameter, etc. After peeling, 10 mL of juice was extracted to analyze edible rate, titratable acid, total soluble sugar, vitamin C content, and soluble solids content, etc. The single fruit weight and flesh weight were weighed using an electronic analytical balance, the transverse diameter and longitudinal diameter were measured using a vernier caliper, the peel hardness and flesh hardness were detected using a digital fruit hardness tester, the soluble solids

content was determined using a refractometer, the total soluble sugar was detected using the acid hydrolysis copper reduction direct titration method, the titratable acid was determined using the NaOH neutralization titration method [6], and vitamin C was determined using the ultraviolet spectrophotometry method [7].

2.4. Data Analysis

Data processing and analysis were conducted using Excel 2017 software. A comprehensive check using SPSS Statistics 26.0 was performed to conduct variance analysis and significance test of differences ($P < 0.05$).

3. Results and Analysis

3.1. Effects of Different Fertilization Methods on the Fruit Size of 'Zao Hong' navels in Zigui

As shown in Figure 1, treatments 1, 2, and 3 could all increase the single fruit weight and fruit size of 'Zao Hong' navels to varying degrees. Compared with CK, the single fruit weight and flesh weight of treatment 1 were significantly increased by 80.46% and 99.77% respectively, while those of treatment 2 were significantly increased by 95.07% and 117.87% respectively, and those of treatment 3 were significantly increased by 69.23% and 77.92% respectively. The ratios of flesh to skin weight of the fruits in the four treatments were 0.74, 0.75, 0.70, and 0.67 respectively (Table 2). Thus, the fruits treated with microbial formula bacterial fertilizer and conventional fertilizer were larger in size and had thicker flesh, and the effect of using microbial formula bacterial fertilizer was more obvious.

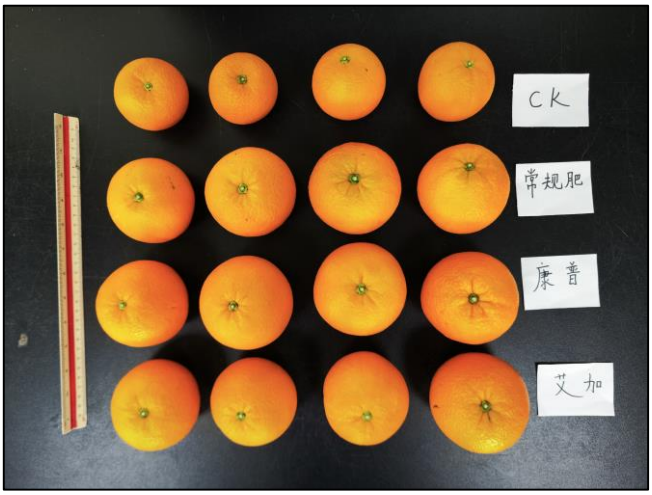

Fig 1: The effects of different fertilization methods on the fruit shape and coloration of 'Zao Hong' navels in Zigui

Table 2: The effects of different fertilization methods on the fruit characteristics of 'Zao Hong' navels

Treatment	Fruit Weight (g)	Pulp Weight (g)	Peel Weight (g)	Fruit Diameter (mm)	Fruit Length (mm)	Fruit Shape Index
Treatment 1	267.46 ± 19.11ab	198.43 ± 11.52ab	18.69 ± 1.28a	66.34 ± 5.12b	77.81 ± 5.33a	0.85 ± 0.07ab
Treatment 2	289.12 ± 18.02a	216.41 ± 12.88a	18.23 ± 1.56a	70.65 ± 4.24a	82.16 ± 6.56a	0.86 ± 0.06ab
Treatment 3	250.82 ± 22.23b	176.73 ± 14.36b	19.39 ± 1.85a	72.29 ± 3.23a	79.05 ± 5.23a	0.91 ± 0.07a
CK	148.21 ± 7.88c	99.33 ± 5.88c	19.21 ± 1.36a	46.16 ± 2.53c	64.96 ± 3.49b	0.72 ± 0.05b

3.2. Effects of Different Fertilization Methods on the Fruit Shape Index of 'Zao Hong' navels in Zigui

As shown in Table 2, compared with CK, the cross-diameter of the fruits in treatments 1 and 2 were significantly increased by 43.72% and 53.05% respectively, the longitudinal diameter was significantly increased by 19.78% and 26.48% respectively, and the fruit shape index was increased by 18.06% and 19.44% respectively; the cross-diameter, longitudinal diameter, and fruit shape index of the fruits in treatment 3 were significantly increased by 56.61%, 21.69%, and 26.39% respectively. Thus, both the use of microbial formula bacterial fertilizer and conventional fertilizer could significantly increase the cross-diameter and longitudinal diameter of the fruits, and change the fruit shape index. Among them, the effect of using conventional fertilizer was more obvious.

3.3. Effects of Different Fertilization Methods on the External Quality of 'Zao Hong' navels in Zigui

Compared with CK, the coloring rate of treatment 1 increased by 6.10%, the hardness of the flesh decreased by 9.95%, and the hardness of the peel significantly decreased by 7.13%. There were no significant differences in coloring rate, peel hardness and flesh hardness among treatments 2 and 3 (Table 3). Thus, the external quality of the fruits treated with the Aijia microbial formula fertilizer was significantly improved.

Table 3: The effects of different fertilization methods on the fruit quality traits of 'Zao Hong' navels

Treatment	Fruit Color Index (%)	Peel Firmness (N)	Flesh Firmness (N)	Soluble Solid (%)	Titratable Acidity (mg/100 mL)	Total Sugar (mg/100 mL)	Solid-to-Acid Ratio	Sugar-Acid Ratio	Protein (%)	Vc content (mg/100 g)
Treatment 1	100.00 ± 0.26a	17.97 ± 1.25b	5.43 ± 0.24a	11.85 ± 1.03a	0.68 ± 0.05c	0.79 ± 0.05a	17.42 ± 1.12a	1.16 ± 0.09a	2.61 ± 0.12a	34.23 ± 2.52a
Treatment 2	97.75 ± 1.23a	20.95 ± 1.31a	5.26 ± 0.32a	11.46 ± 1.01a	0.64 ± 0.03c	0.82 ± 0.05a	17.91 ± 1.08a	1.28 ± 0.04a	2.17 ± 0.15a	35.87 ± 3.91a
Treatment 3	95.25 ± 1.26a	21.93 ± 1.88a	5.81 ± 0.24a	10.38± 0.62a	0.78 ± 0.05b	0.71 ± 0.06a	13.31 ± 0.77b	0.91 ± 0.02b	1.48 ± 0.12b	32.45 ± 2.23b
CK	94.25± 1.61a	19.35 ± 1.21a	6.03 ± 0.41a	10.26± 0.89a	0.89 ± 0.04a	0.62 ± 0.03b	11.53 ± 0.91c	0.70 ± 0.03c	1.39 ± 0.11b	29.13 ± 1.57c

3.4. Effects of Different Fertilization Methods on the Internal Quality of 'Zao Hong' navels in Zigui

Compared with CK, the titratable acid content of fruits in treatments 1, 2 and 3 decreased significantly by 23.60%, 28.09% and 12.36% respectively, the total sugar content increased significantly by 27.42%, 32.26% and 14.52% respectively, and the acid-to-sugar ratio increased significantly by 51.08%, 55.33% and 15.44% respectively, and the sugar-to-acid ratio increased significantly by 65.71%, 82.86% and 30.00% respectively (Table 3). Thus, the internal

quality of the fruits treated with microbial formula fertilizer and conventional fertilizer was significantly improved, and the effect of using microbial formula fertilizer was more obvious.

3.5. Effects of Different Fertilization Methods on Protein and Vc Content of 'Zao Hong' navels in Zigui

Compared with CK, the protein content of fruits in treatments 1 and 2 increased significantly by 87.77% and 56.12% respectively, the Vc content increased significantly by 17.51% and 23.14% respectively, and the Vc content of fruits in treatment 3 increased significantly by 11.40% (Table 3). Thus, the microbial formula fertilizer can significantly increase the protein and Vc content of the fruits.

4. Discussion and Conclusion

Compound fertilizers have the advantages of high nutrient content, adequate nutrition, and the ability to maximize the mutual promotion effect among elements [8]. Studies have shown that applying an appropriate amount of compound fertilizers can promote the growth of citrus trees, increase yield, and improve quality [9]]. Microbial fertilizer is a new type of fertilizer that utilizes the physiological activity and metabolic functions of microorganisms to provide nutrients for crops, improve soil, and prevent diseases and pests [10]. The main components of microbial fertilizer are one or more beneficial microbial strains, such as nitrogen-fixing bacteria, phosphorus-solubilizing bacteria, potassium-solubilizing bacteria, silicon-solubilizing bacteria, humic acid bacteria, etc. They can coexist with the crop roots in the soil and utilize organic matter or inorganic salts in the soil to produce various active substances such as organic acids, plant hormones, antibiotics, etc., promoting the growth and development of crops and increasing crop yield and quality [10]. This is consistent with the research results of this experiment.

This experiment shows that applying Kangpu microbial formula fertilizer has the most significant effect on improving the fruit size, acid-sugar ratio, sugar-acid ratio, protein content, Vc content, and reducing the titratable acid content of 'Zao Hong' orange fruits in Zigui. Applying Aijia microbial formula fertilizer is slightly less effective. Analyzing the reasons, it may be because Kangpu microbial formula fertilizer contains stable compound fertilizer (17:17:17 + TE). Stable compound fertilizer refers to a fertilizer produced during the production process that adds urease inhibitors or nitrification inhibitors, or both inhibitors [11]. Field experiments have been conducted on crops such as rice, corn, and wheat, proving that applying stable compound fertilizer can save time and labor, reduce production costs, increase yield and income, and improve economic benefits [11-14]. Studies by Xu [15] and Kuai [16] show that stable fertilizer combined with microbial fertilizer can significantly increase the yield and quality of lettuce. Xiang [17] also verified that applying stable compound fertilizer and seaweed biological fertilizer can increase the number of fruits per plant, fruit weight per plant, and per plant yield of 'New Holland' orange, and can also increase soluble solids content, reduce fruit skin thickness, improve taste, and enhance quality.

In conclusion, this experiment shows that applying microbial formula fertilizers and conventional fertilizers have significant effects on improving various indicators such as fruit size and quality of 'Zao Hong' orange fruits in Zigui; compared with conventional fertilization, applying microbial formula fertilizers has more significant effects in improving fruit size, acid-sugar ratio, sugar-acid ratio, protein content, Vc content, and reducing titratable acid content; comprehensive comparison shows that applying Kangpu microbial formula fertilizers has the most significant effect, followed by applying Aijia microbial formula fertilizers.

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