Effect of Application Ratio of Potassium over Nitrogen on Litchi Fruit Yield, Quality, and Storability

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Abstract. Soils of litchi orchards in China are commonly deficient in nitrogen and potassium. The cultivar Feizixiao litchis planted in a typical acidic upland orchard, which is low in nitrogen and potassium, were used as a subject in field experiments with different ratios of potassium to nitrogen (K₂O:N = 0.6, 0.8, 1.0, 1.2, and 1.4). Field experiments were conducted from 2009 to 2012. The effects of K₂O:N ratio on the yield, quality, and storability of litchi were investigated and discussed. Results indicated that with the increase of K₂O:N ratio, fruit yield initially increased and then decreased, and litchi had the highest yield when K₂O:N was 1.2. When K and N fertilizers were applied at the ratio of 1.2, litchi had a better fruit quality with higher vitamin C content, soluble sugar, and soluble solid. With the increase of K₂O:N ratio, healthy fruit rate initially increased and then decreased. This rate reached the maximum value when K₂O:N was 1.2. Meanwhile, fruit-rotting rate, peel-browning index, cell membrane permeability, and peroxidase (POD) activity decreased at first and then increased and reached the minimum value when the K₂O:N ratio was 1.2. Therefore, litchi fruit had the highest yield, better quality, and best storage property when K₂O:N was 1.2. Thus, this ratio is recommended for the main litchi production areas in China.

Litchi chinensis Sonn, a famous subtropical fruit originated in south China and southeast Asia, has been regarded as the rare fruit of China and the choice of fruit in Lingnan. This fruit is planted in tropical and subtropical Asia as well as in South Africa, Australia, the United States (Phunchaisri and Apichartsrangkoon, 2005; Wall, 2006). With a litchi-cultivated area and production accounting for over 80% of the world, China is the largest country producing litchi (Liu et al., 2014; Xu et al., 2010). However, litchi's unit yields are generally low and unstable (Xu et al., 2010). Unreasonable litchi orchard fertilization (Yao et al., 2009), generally low N and K soil contents (Li et al., 2011, 2012), and litchi trees with low K nutrition (Yao et al., 2009) are some of the most significant reasons for these low and unstable unit yields. Furthermore, as a non-climacteric fruit, litchi is harvested in hot and humid summer and can easily undergo pericarp browning, flesh deterioration, and

fruit rotting after harvest (Hu et al., 2005; Jiang and Fu, 2000). Thus, litchi is one of the fruits with the shortest storage duration. Currently, litchi is treated with low temperature and controlled atmosphere storage, medication, packaging improvement, smoldering sulfur, and pickling for longer shelf life (Jiang et al., 2003). Nevertheless, "cold chain" circulation facilities are still deficient in China (Wu et al., 2001). Chemical treatment leaves drug residue, whereas packaging storage can lead to low O₂ and high CO₂ concentrations, which result in accumulation of smelly substances, such as acetaldehyde and ethyl alcohol caused by anaerobic glycolysis (Duan et al., 2004). Therefore, this issue in litchi production should be urgently solved to improve the storability and preservation of fresh litchi fruit.

Research has revealed that mineral element is important to the improvement of fruit storability (Fallihi, 1985, 1988). Litchi sprouts and roots repeatedly in a growth year and consumes a large amount of nutrients in its growth and fruitage period. Potassium and nitrogen are two mineral nutrition elements required most in normal litchi growth and development (Yao et al., 2009). However, Chinese litchi orchards are usually deficient in nitrogen and potassium (Li et al., 2011, 2012). In addition to its significant effect on fruit yield and quality, potassium and

nitrogen nutrition is also essential to fruit storability. Earlier studies showed that appropriate application of potassium can improve the fruit storability of peach (Cummings, 1980), longan (Wei et al., 2008), orange (Lin et al., 2006), kiwifruit (Wang et al., 2006), fig (Huang, 2007), and sweet cherry (Xu et al., 2009). However, few studies have focused on the effect of potassium and nitrogen nutrition on litchi fruit yield, quality, and storability after harvest. Thus, this paper takes 'Feizixiao', which is the leading litchi cultivar in China, as the research object and discusses the effect of different application ratio of potassium over nitrogen on litchi fruit yield, quality, and storability after harvest to find a theoretical foundation for scientific litchi fertilization, and improvement of litchi fruit yield and storability.

Materials and Methods

Plant material, growth conditions

Field experiments were carried out in Shouwang orchard (23.0290° N, 114.5551° E) located in Huidong County, Guangdong Province, from June 2009 to June 2012, during three fruit harvest seasons. The 'Feizixiao' variety of the litchi species was used and planted in 1995 with a spacing of 5 m × 6 m (330 plants per hectare) in the slope terraces. The crown was in good order and complete. The tree vigor, cultivation environment, and all horticultural practices were the same. 'Feizixiao' is the dominant litchi cultivar in China. It has wide environmental adaptation, and the crops grow well in most growing areas. The soil in this orchard was the lateritic red soil type, which is typical in southern China. Soil samples were collected at 0 cm to 60 cm soil depth before the experiment. The soil contained organic matter (8.6 g·kg⁻¹), alkali-hydrolysable N (44.1 mg·kg⁻¹), NH₄⁺-N (2.0 mg·kg⁻¹), and NO₃⁻-N (1.2 mg·kg⁻¹) and contained P (7.9 mg·kg⁻¹), K (73.3 mg·kg⁻¹), Ca (866.4 mg·kg⁻¹), Mg (66.1 mg·kg⁻¹), Zn (0.45 mg·kg⁻¹), B (0.16 mg·kg⁻¹), and Mo (0.08 mg·kg⁻¹). In addition, the soil had a pH value of 4.61 and a loamy clay texture.

Experimental treatments and design

The field experiments were conducted using five treatments, more specifically, five fertilizers with specific K₂O:N ratios. The K₂O:N ratios of 0.6, 0.8, 1.0, 1.2, and 1.4 were set and denoted as K_{0.6}N, K_{0.8}N, K_{1.0}N, K_{1.2}N, and K_{1.4}N. Each treatment was conducted in three replicates with five trees in each plot.

The usage rates of N in litchi were 198, 129, and 165 kg·ha⁻¹ in 2009–10, 2010–11, and 2011–12, respectively. K₂O was applied at rates that were 0.6, 0.8, 1.0, 1.2, and 1.4 times that of N in each growth year. In addition, the same amount of P, Ca, Mg, Zn, B, and Mo was added in all treatments in the same year to prevent nutrient deficiencies other than that of N and K. All fertilizers were divided and applied after fruit harvest, before blossoming, at flower fading, and fruit

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developing stages. Urea, super phosphate, potassium chloride, lime, magnesium sulfate, zinc sulfate, borax, and ammonium molybdate were used in this experiment. In the entire growth period, three circular canals or three holes were ditched by the dripping line. The fertilizer was sprayed into the canals or holes. The soil was covered and then watered.

Data collection and measurement

Yield and quality. Yields were recorded in the experiment, as fruit fresh weight per tree at commercial harvest, so as to calculate yield per hectare. Fresh fruits, consisting of 50 fruits for each plot, were obtained for quality analysis, as well as to examine vitamin C, soluble sugar, organic acid, soluble solid, and pH at each harvest during 2010–12.

Biomass composition of fruit. Five litchi fruits were picked from the south, west, north, and east of a litchi tree crown. A total of 20 fruits were harvested from one tree, and 100 litchi fruits from each plot were picked to obtain the composite sample. The fruit was peeled and divided into peel, pulp, and kernel. The fruit was weighed, and the percentage of the weight of each part of the fruit was calculated.

Natural storage at room temperature. Fruits were picked from each plot with similar size and maturity and without pests and mechanical injury. The fruits were wrapped with fresh-keeping film, and the natural storage experiment was initiated at room temperature ($25 \pm 1^\circ\text{C}$). Samples were taken every 2 d to determine relevant indexes. The specific methods of determination are enumerated and explained below.

Calculation of the healthy fruit rate follows the method suggested by Tian et al. (2006). A total of 40 fruits picked from each area were divided into five grades according to the fruit appearance: grade 1 = bright red pericarp, without browning on epicarp or endocarp; grade 2 = the browning area is less than one-fourth of the fruit surface; grade 3 = the browning area is one-fourth to one-third of the fruit surface; grade 4 = the browning area is one-third to two-thirds of the fruit surface; and grade 5 = the browning area is more than two-thirds of the fruit surface. The healthy fruit rate is computed as follows: healthy fruit rate (%) = (quantity of grade 1 fruits + quantity of grade 2 fruits)/total fruit quantity $\times 100\%$.

A specified number of fruits (40 from each area) were picked for fixed observation. The rotting rate is denoted as the percentage of fruits with mildew, musty pericarp, and liquid flesh from the overall number of the observed fruits. The formula for rotting rate is as follows: rotting rate = quantity of rotten litchis/total litchi quantity $\times 100\%$.

Calculation of the pericarp browning index follows the method suggested by Jiang (2000) with slight modification. A total of 40 fruits were picked from each area and were divided into five grades according to the percentage of the browning area from the total area of the fruit surface. The grading standards are as follows: grade 0 = no pericarp browning;

Table 1. Effect of various K_2O ratios on litchi fruit yield (mean $\pm$ SE, $n = 3$).

Treatment	2010		2011		2012	
	Yield ($\text{t}\cdot\text{ha}^{-1}$)	Yield increase (%)	Yield ($\text{t}\cdot\text{ha}^{-1}$)	Yield increase (%)	Yield ($\text{t}\cdot\text{ha}^{-1}$)	Yield increase (%)
$\text{K}_{0.6}\text{N}$	7.77 ± 1.00 a	—	9.59 ± 0.36 b	—	3.36 ± 0.86 b	—
$\text{K}_{0.8}\text{N}$	9.38 ± 2.52 a	20.7	9.99 ± 0.78 b	4.2	3.95 ± 0.46 b	17.6
$\text{K}_{1.0}\text{N}$	10.80 ± 2.14 a	39.0	10.88 ± 1.78 ab	13.5	4.34 ± 0.93 b	29.2
$\text{K}_{1.2}\text{N}$	9.71 ± 1.21 a	25.0	12.63 ± 1.10 a	31.7	6.03 ± 0.48 a	79.5
$\text{K}_{1.4}\text{N}$	9.60 ± 1.74 a	23.6	11.19 ± 1.96 ab	16.7	4.37 ± 0.07 b	30.1

Treatment means followed by a different letter are significantly different ($P < 0.05$).

grade 1 = browning area $\leq 25\%$ (slight browning); grade 2 = $25\% <$ browning area $\leq 50\%$; grade 3 = $50\% <$ browning area $\leq 75\%$; grade 4 = browning area $> 75\%$. The browning index is calculated as follows: browning index % = $(0 \times \text{N}_0 + 1 \times \text{N}_1 + 2 \times \text{N}_2 + 3 \times \text{N}_3 + 4 \times \text{N}_4) \times 100 / (4 \times \text{NT})$. In the formula, N_0 – N_4 refers to the quantity of fruits in relevant browning grade, and NT corresponds to the overall number of fruits.

The measurement of pericarp cell membrane permeability follows the method suggested by Jiang and Chen (1995) with slight modification. Fifteen litchi fruits picked from each area were processed with a 10-mm puncher to obtain 15 round slices. About 20 mL of distilled water was added and let stood for 20 min. Conductivity was measured with a conductometer. The slices were kept in boiling water for 20 min, and the amount of water evaporated was added. The slices were cooled to ambient temperature, and conductivity was again measured. The ratio between the two measured conductivities is the cell membrane permeability.

The polyphenol oxidase (PPO) activity of the pericarp is determined with phosphate extraction colorimetry. About 1.0 g of fresh pericarp was cut into pieces and placed into a mortar. The pericarp was mixed with an appropriate amount [$1:3.5$ (w/v)] of $0.1 \text{ mol}\cdot\text{L}^{-1}$ phosphate buffer (pH 6.8) and ground into homogenate in ice bath. All homogenates were transferred into a centrifuge tube and centrifuged for 10 min at $6000 \text{ r}\cdot\text{min}^{-1}$ at a low temperature (4°C). The liquid supernatant is the extracting solution of crude enzyme. About 3.5 mL of $0.1 \text{ mol}\cdot\text{L}^{-1}$ phosphate buffer (pH 6.8), 1 mL of $0.2 \text{ mol}\cdot\text{L}^{-1}$ catechol solution, and 0.2–0.5 mL of crude enzyme were added into a 10-mL stoppered test tube. The liquid was mixed to a 30°C water bath for 15 min, and absorbance A was measured at 525 nm. The value of absorbance is the relative activity of PPO.

Peroxidase (POD) activity is determined with *o*-methoxyphenol method. About 1.0 g of fresh pericarp was cut into pieces and placed in a mortar. The fresh pericarp was mixed with 5 mL of tris-HCl buffer (pH 8.5) and ground into homogenate. The homogenate was placed in a centrifuge for 5 min at $4000 \text{ r}\cdot\text{min}^{-1}$ at a low temperature (4°C). The liquid supernatant was poured out for standby application. Two 1-cm cuvettes were used; 1 mL of extracted enzyme solution and 3 mL of reaction mixture were added into one cuvette. The stopwatch was started immediately. Subsequently, $0.2 \text{ mol}\cdot\text{L}^{-1}$ phosphate buffer

(pH 6.0) was added into the other cuvette for contrast. The optical density (OD) at wavelength 470 nm was measured after 5 min of reaction. Enzymatic activity is the change of the OD within 1 min (a change in value of 0.01 of OD at 470 nm within 1 min represents one activity unit).

Statistical analyses

All the data were the means of three replications, and results were represented as mean $\pm$ SE. Analysis of variance with least significant difference was performed using SAS/STAT software (SAS V9, SAS Institute Inc., Cary, NC). Figures in this paper were made using EXCEL 2013.

Results

Fruit yield. As shown in Table 1, with the increase of $\text{K}_2\text{O}:\text{N}$ ratio, fruit yield initially increased and then decreased. The trees treated with $\text{K}_{1.2}\text{N}$ produced the highest fruit yield. Table 1 also illustrates that the $\text{K}_2\text{O}:\text{N}$ ratio affected the fruit yield more obviously as the application time of K and N fertilizers extended. Yield and weight data from 2012 show that the litchi fruit yield and weight per fruit have a positive correlation and were nearly the same with significant level ($r = 0.7869$, $P = 0.0516$). Therefore, improving the $\text{K}_2\text{O}:\text{N}$ ratio can increase the litchi yield as this improvement promotes fruit expansion and single fruit weight. Consequently, the proper application of K and N fertilizer can considerably increase the fruit yield.

Fruit quality. There was no significant difference in vitamin C (Vc) content among treatments with different use ratios of $\text{K}_2\text{O}:\text{N}$ in 2010 and 2011, however, the Vc content increased and then decreased as the $\text{K}_2\text{O}:\text{N}$ ratio elevated in 2012 (Table 2). Fruits obtained after the $\text{K}_{1.2}\text{N}$ treatment contained significantly higher Vc than all the other treatments. The soluble solid content had similar changing trends as the vitamin C for all three harvests. It seemed that the soluble sugar content was not closely related with the $\text{K}_2\text{O}:\text{N}$ ratio for all three harvests. Significant and positive correlation between organic acid content and $\text{K}_2\text{O}:\text{N}$ ratio was observed for 3 years (Fig. 1), which could be contributed to the enhanced metabolism of organic acid, such as malic acid, by increased K nutrition (Lu, 2003). Increased content of organic acid might be beneficial for the production of litchi wine while brewing (Liu et al., 2011). Simultaneously, significant and negative relation was found between sugar:acid ratio

and K₂O:N ratio (Fig. 1). Figure 1 also illustrates that the K₂O:N ratio affected the organic acid content and sugar:acid ratio more obviously as the application time of K and N fertilizers extended. As more organic acid in fruit was generated with increasing K₂O:N ratio, consequently, the fruit pH decreased. The change in sugar:acid ratio in different treatments indicated that the taste of litchi fruit could be affected by the application of K and N fertilizer. Decreased or increased use of ratio of K₂O:N might worsen the fruit taste.

Fruit storability. The postharvest storability of litchi fruit was compared. Tables 3–8 suggested that at the beginning of the experiment, the pericarp cell membrane permeability was different although the processed litchis showed the same healthy fruit rate, rotting rate, and pericarp browning index. A significant difference in the pericarp PPO and POD activity was observed. Both enzymatic activities declined significantly with the increase in the K₂O:N ratio. As the storage duration prolonged, the healthy fruit rate of all the processed fruits declined dramatically, whereas the rotting rate and pericarp browning index rose significantly. On the 4th day, the rotting rate increased rapidly, and the fruits entered the peak stage of senescence and deterioration.

As the storage duration extended, litchi fruits softened and rotted slowly. Tables 3 and 4 suggested that, in an 8-day storage cycle, the healthy fruit rate increased first and then declined with the increase in the K₂O:N ratio. The rate reached the maximum when the K₂O:N ratio was 1.2. The rotting rate changed in an opposite way. In contrast to K_{0.6}N treatment, when the fruits were treated with K_{0.8}N, K_{1.0}N, K_{1.2}N, and K_{1.4}N, the healthy fruit rate increased by 8.7%, 20.0%, 27.5%, and 15.0% on the 4th day, respectively, and the rotting rate declined by 9.1%, 27.3%, 68.2%, and 27.3%, respectively. On the 6th day, the healthy fruit rate of fruits treated with K_{0.8}N, K_{1.0}N, K_{1.2}N, and K_{1.4}N increased by 38.2%, 55.3%, 81.6%, and 0.0%, and the rotting rate declined by 5.0%, 12.0%, 43.0%, and 4.0%, respectively. On the 8th day, all treated fruits became completely rotten. Therefore, K_{1.2}N treatment was significantly effective for reducing the rotting rate of litchi fruit, and the effect was more obvious as the storage time prolongs within 6 d of storage. The appropriate application of potassium–nitrogen fertilizer can inhibit litchi fruit rotting and benefit the healthy fruit rate. The effect was more evident on the 4th to 6th day of storage and reflected good fruit storability.

Tables 5 and 6 suggested that as the K₂O:N ratio increased, the pericarp browning index and cell membrane permeability declined first and increased later and reached the minimum when the K₂O:N ratio was 1.2. In contrast to K_{0.6}N treatment, when the fruits were treated with K_{0.8}N, K_{1.0}N, K_{1.2}N, and K_{1.4}N, the pericarp browning index declined by 2.6%, 7.7%, 56.3%, and –28.2% on the 4th day of storage and declined by 0.0%,

Table 2. Effect of various K₂O ratios on litchi fruit quality (mean ± SE, n = 3).

Yr	Treatment	Vc [mg (100 g) ⁻¹]	Soluble sugar (%)	Soluble solid (%)	pH
2010	K _{0.6} N	40.9 ± 0.6 a	15.8 ± 0.8 a	18.5 ± 0.0 a	—
	K _{0.8} N	41.5 ± 2.0 a	14.8 ± 0.4 a	18.5 ± 0.5 a	—
	K _{1.0} N	42.6 ± 1.2 a	14.8 ± 0.7 a	18.7 ± 0.6 a	—
	K _{1.2} N	42.4 ± 0.2 a	15.2 ± 0.4 a	19.0 ± 0.5 a	—
	K _{1.4} N	42.3 ± 0.0 a	14.8 ± 1.1 a	18.7 ± 0.8 a	—
2011	K _{0.6} N	50.5 ± 7.0 a	15.4 ± 0.7 a	19.0 ± 0.5 a	5.25 ± 0.04 a
	K _{0.8} N	45.4 ± 2.8 a	15.6 ± 0.1 a	18.5 ± 0.5 a	5.20 ± 0.07 a
	K _{1.0} N	47.2 ± 5.6 a	15.4 ± 0.2 a	19.0 ± 0.0 a	5.18 ± 0.16 a
	K _{1.2} N	47.0 ± 1.9 a	15.9 ± 0.4 a	19.2 ± 0.3 a	5.12 ± 0.22 a
	K _{1.4} N	46.2 ± 4.6 a	15.8 ± 0.1 a	19.0 ± 0.0 a	5.18 ± 0.04 a
2012	K _{0.6} N	44.8 ± 0.0 c	14.5 ± 0.4 b	18.3 ± 0.8 a	5.03 ± 0.13 a
	K _{0.8} N	45.7 ± 0.5 b	13.1 ± 0.6 b	18.7 ± 0.6 a	5.01 ± 0.12 a
	K _{1.0} N	46.2 ± 0.0 b	14.4 ± 0.0 ab	19.1 ± 0.9 a	5.08 ± 0.04 a
	K _{1.2} N	47.4 ± 0.3 a	14.7 ± 0.4 a	19.0 ± 0.0 a	4.88 ± 0.13 ab
	K _{1.4} N	42.1 ± 0.3 d	14.4 ± 0.1 b	18.8 ± 0.3 a	4.79 ± 0.05 b

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Fig. 1. Correlation between organic acid content, sugar:acid ratios in litchi fruit with different K₂O:N fertilizer ratios during 2010–12. Significant differences between treatment at $P < 0.05$ and $P < 0.01$ are denoted by (*) and (**), respectively.

Table 3. Effect of various K₂O ratios on healthy fruit rate of litchi fruit (%) (mean ± SE, n = 3).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	100.0 ± 0.0 a	98.3 ± 2.9 a	66.7 ± 2.9 c	31.7 ± 11.3 b	0.0 ± 0.0 b
K _{0.8} N	100.0 ± 0.0 a	100.0 ± 0.0 a	72.5 ± 3.5 bc	43.8 ± 8.8 ab	2.5 ± 0.0 b
K _{1.0} N	100.0 ± 0.0 a	98.3 ± 1.4 a	80.0 ± 2.5 ab	49.2 ± 8.0 ab	3.3 ± 1.4 ab
K _{1.2} N	100.0 ± 0.0 a	98.8 ± 1.8 a	85.0 ± 7.1 a	57.5 ± 10.6 a	11.3 ± 8.8 a
K _{1.4} N	100.0 ± 0.0 a	99.2 ± 1.4 a	76.7 ± 5.2 ab	31.7 ± 9.5 b	3.3 ± 3.8 ab

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Table 4. Effect of various K₂O ratios on rotting rate of litchi fruit (%) (mean ± SE, n = 3).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	0.0 ± 0.0 a	8.3 ± 3.8 a	36.7 ± 9.5 a	83.3 ± 1.4 a	100.0 ± 0.0 a
K _{0.8} N	0.0 ± 0.0 a	8.3 ± 1.4 a	33.3 ± 1.4 a	79.2 ± 6.3 a	100.0 ± 0.0 a
K _{1.0} N	0.0 ± 0.0 a	5.8 ± 1.4 ab	26.7 ± 6.3 a	73.3 ± 6.3 a	99.2 ± 1.4 a
K _{1.2} N	0.0 ± 0.0 a	1.7 ± 1.4 b	11.7 ± 3.8 b	47.5 ± 11.5 b	98.3 ± 1.4 a
K _{1.4} N	0.0 ± 0.0 a	5.0 ± 2.5 ab	26.7 ± 9.5 a	80.0 ± 4.3 a	99.2 ± 1.4 a

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Table 5. Effect of various K₂O ratios on browning index of litchi peel (%) (mean ± SE, n = 3).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	0.0 ± 0.0 a	1.9 ± 0.6 b	8.1 ± 1.7 ab	49.6 ± 1.3 a	87.1 ± 8.5 a
K _{0.8} N	0.0 ± 0.0 a	1.7 ± 0.4 bc	7.9 ± 2.2 ab	49.6 ± 4.4 a	86.3 ± 3.8 a
K _{1.0} N	0.0 ± 0.0 a	1.0 ± 0.4 c	7.5 ± 3.8 ab	43.5 ± 9.5 a	83.3 ± 9.1 a
K _{1.2} N	0.0 ± 0.0 a	0.2 ± 0.4 d	3.6 ± 1.9 b	27.7 ± 5.6 b	62.3 ± 7.7 b
K _{1.4} N	0.0 ± 0.0 a	2.7 ± 0.4 a	10.4 ± 5.7 a	43.1 ± 5.3 a	82.8 ± 6.6 a

Treatment means followed by a different letter are significantly different ($P < 0.05$).

12.2%, 44.1%, and 13.0% on the 6th day of storage, respectively. K_{1.2}N treatment was effective for inhibiting pericarp browning, delaying membrane lipid peroxidation, and

detering growth of pericarp membrane permeability.

As the K₂O:N ratio increased, the POD activity of the pericarp declined first and

increased later and reached the minimum when the K₂O:N ratio was 1.2 (Table 7). In contrast to K_{0.6}N treatment, when the fruits were treated with K_{1.2}N, the pericarp POD activity reduced by 23.7%, 27.3%, 16.4%, 16.7%, and 31.6% on the 0th, 2nd, 4th, 6th, and 8th day of storage, respectively. Table 6 suggested that, within the first 2 d, as the K₂O:N ratio increased, PPO activity of the pericarp declined and reached the minimum when the K₂O:N ratio was 1.4. After the 2nd day, the activity declined first and increased later and reached the minimum when the K₂O:N ratio was 1.2. The fitting of the relationship between the PPO activity and the K₂O:N ratio on the 2nd day reflected that the relationship between the two satisfies the linear equation in one unknown ($y = -1.582x + 5.8389$, $R^2 = 0.8421$, $P = 0.029$) and showed a significant negative correlation. The K_{1.2}N treatment inhibited pericarp browning by significantly reducing the PPO activity and delayed fruit senescence by significantly reducing the POD activity.

Moreover, the K_{1.2}N treatment was the best for fruit storability and prolonged shelf life. In litchi production, potassium–nitrogen fertilizer should be applied to improve fruit storability.

Biomass composition of fruit. Table 9 indicated that under the treatment, pulp percentage showed certain difference in the first year, and the difference became significant in the third year. As the K₂O:N ratio increased, the pulp percentage declined first and then increased and reached the minimum when the K₂O:N ratio was 1.2. The peel percentage changed in an opposite way and reached the maximum when the K₂O:N ratio was 1.2. With the increase in K₂O:N, the edible rate of the fruit declined first and then increased later, and the peel thickness changed in an opposite way. When the K₂O:N ratio was 1.2, the litchi peel thickness increased most significantly.

Discussion

Nutrition is the base of fruit growth and development, yield formation, and quality improvement. Potassium is one of the recognized quality elements. Application of K can accelerate fiber compounding and epidermal tissue development, thicken the cell wall, and improve the mechanical resistance of collenchymas against bacterial parasite. In addition, K can adjust cell membrane permeability, increase turgor pressure, improve membrane

stability and tissue resistance, and prolong the postharvest storage duration and shelf life of fruiters (Huang et al., 2000). According to the report by Koo (1985), as the application amount of potassium increased to the most appropriate range, the incidence of stem-end rot and green mold of sweet orange reduced during storage. According to this research, the rotting rate of litchi fruit declined first and increased later with the increase of the K₂O:N ratio and reached the minimum when the K₂O:N ratio was 1.2. This finding indicated that appropriate application of potassium–nitrogen fertilizer can effectively inhibit the postharvest rotting of litchi fruit. As shown in the study of Cummings (1980), the shelf life of peach prolonged, and fruit browning was effectively inhibited after potassium fertilizer is applied. Pericarp browning, one of the most serious issues in litchi storage, is the primary factor that inhibits the longtime storage of litchi. Pericarp browning also shortens shelf life and reduces commodity value. Earlier studies have shown that litchi pericarp browning was closely related to the PPO and POD activities (Ruenroengklin et al., 2009; Zhang et al., 2005). This research found that as the K₂O:N ratio increased, litchi pericarp browning index and POD activity declined first and increased later and reached the minimum when the K₂O:N ratio was 1.2; the PPO activity declined within 0–2 d with an increase in the K₂O:N ratio and reached the minimum when the K₂O:N ratio was 1.4; after the 2nd day, the PPO activity declined first and increased later and reached the minimum when the K₂O:N ratio was 1.2, indicating that appropriate application of potassium–nitrogen fertilizer can effectively inhibit the postharvest rotting of litchi fruit. This finding also showed that the enzymatic browning effect was least significant when the K₂O:N ratio was 1.2. However, Jiang and Fu (1999) believed that the main cause of browning is the integrity compromise of pericarp cell membrane. This research found that as the K₂O:N ratio increased, the cell membrane permeability declined first and increased later and reached the minimum when the K₂O:N ratio was 1.2. Appropriate application of potassium–nitrogen fertilizer can effectively prevent the pericarp cell membrane systems from being attacked and can improve the integrity of pericarp cell membrane, thus further inhibiting the leakage of composition in cell and fruit rotting.

Litchi ripens at high temperature in the intense heat of summer, and the fruit browns

Table 6. Effect of various K₂O ratios on relative leakage rate of litchi peel (%) (mean ± SE, $n = 3$).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	64.6 ± 7.3 a	79.6 ± 0.0 a	82.0 ± 8.3 a	96.5 ± 2.1 a	85.4 ± 0.4 a
K _{0.8} N	64.1 ± 0.9 a	78.7 ± 4.0 a	79.8 ± 4.5 a	93.9 ± 1.4 a	88.4 ± 0.2 a
K _{1.0} N	63.5 ± 4.3 a	75.1 ± 12.0 a	75.8 ± 8.3 a	88.8 ± 11.9 a	88.5 ± 0.0 a
K _{1.2} N	62.9 ± 5.5 a	72.4 ± 5.1 a	74.4 ± 8.0 a	89.2 ± 0.5 a	84.5 ± 3.2 a
K _{1.4} N	66.9 ± 2.6 a	73.6 ± 4.5 a	75.3 ± 9.1 a	92.0 ± 3.9 a	88.1 ± 3.5 a

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Table 7. Effect of various K₂O ratios on peroxidase (POD) activity of litchi peel (U·mg⁻¹·min⁻¹) (mean ± SE, $n = 3$).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	5.10 ± 0.36 a	4.97 ± 0.02 a	4.76 ± 0.60 a	5.07 ± 0.60 a	4.18 ± 0.21 a
K _{0.8} N	4.81 ± 0.66 ab	4.61 ± 0.38 ab	4.23 ± 0.31 a	4.54 ± 0.07 a	3.55 ± 0.49 ab
K _{1.0} N	4.07 ± 0.72 bc	4.20 ± 0.61 bc	4.07 ± 0.08 a	4.15 ± 0.82 a	3.37 ± 0.63 ab
K _{1.2} N	3.89 ± 0.54 c	3.61 ± 0.11 c	3.98 ± 0.68 a	4.22 ± 0.58 a	2.86 ± 0.06 b
K _{1.4} N	4.10 ± 0.00 bc	3.89 ± 0.29 bc	4.45 ± 0.37 a	4.07 ± 0.82 a	3.64 ± 0.10 ab

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Table 8. Effect of various K₂O ratios on polyphenol oxidase (PPO) activity of litchi peel (absorption value) (mean ± SE, $n = 3$).

Treatment	0 d	2 d	4 d	6 d	8 d
K _{0.6} N	0.61 ± 0.04 a	0.55 ± 0.03 a	0.69 ± 0.02 a	0.41 ± 0.01 b	0.154 ± 0.01 a
K _{0.8} N	0.58 ± 0.10 a	0.53 ± 0.02 a	0.60 ± 0.01 b	0.40 ± 0.01 bc	0.119 ± 0.01 a
K _{1.0} N	0.56 ± 0.05 a	0.53 ± 0.01 a	0.59 ± 0.00 bc	0.40 ± 0.02 bc	0.102 ± 0.01 a
K _{1.2} N	0.51 ± 0.06 ab	0.53 ± 0.01 a	0.53 ± 0.01 d	0.37 ± 0.02 c	0.096 ± 0.06 a
K _{1.4} N	0.39 ± 0.09 b	0.51 ± 0.04 a	0.55 ± 0.01 cd	0.47 ± 0.01 a	0.137 ± 0.04 a

Treatment means followed by a different letter are significantly different ($P < 0.05$).

Table 9. Effect of various K₂O ratios on biomass composition of litchi fruits (mean ± SE, $n = 3$).

Treatment	2010			2011			2012		
	Pulp (%)	Peel (%)	Kernel (%)	Pulp (%)	Peel (%)	Kernel (%)	Pulp (%)	Peel (%)	Kernel (%)
K _{0.6} N	72.9 ± 2.0 a	21.8 ± 1.3 a	5.3 ± 0.2 a	73.8 ± 1.7 a	22.8 ± 1.3 a	3.4 ± 0.4 a	71.8 ± 1.2 a	22.9 ± 0.8 a	5.3 ± 0.4 a
K _{0.8} N	72.4 ± 1.6 a	22.0 ± 0.5 a	5.5 ± 0.5 a	73.7 ± 0.6 a	22.8 ± 0.7 a	3.5 ± 0.1 a	71.6 ± 0.7 a	22.2 ± 2.5 a	6.2 ± 2.4 a
K _{1.0} N	71.1 ± 0.6 a	23.0 ± 1.0 a	5.9 ± 1.0 a	73.7 ± 0.0 a	22.5 ± 0.2 a	3.8 ± 0.3 a	70.6 ± 0.6 ab	22.3 ± 0.8 a	7.1 ± 0.3 a
K _{1.2} N	69.3 ± 2.0 a	24.0 ± 0.4 a	6.6 ± 0.4 a	73.3 ± 0.0 a	23.2 ± 0.0 a	3.5 ± 0.0 a	69.5 ± 0.5 b	24.1 ± 0.2 a	6.4 ± 0.5 a
K _{1.4} N	72.6 ± 2.1 a	21.6 ± 0.8 a	5.8 ± 0.8 a	73.9 ± 0.5 a	22.2 ± 0.6 a	3.9 ± 0.2 a	71.1 ± 1.3 ab	23.0 ± 1.4 a	5.9 ± 0.2 a

Treatment means followed by a different letter are significantly different ($P < 0.05$).

and rots after harvest. Pericarp browning is closely related to the water loss of fruit (Scott et al., 1982), which mainly occurs to the pericarp (Jiang and Fu, 1999). By contrast, deficiency in nitrogen and potassium can lead to the water loss of fruit in storage (Lu et al., 2001). Citrus peel becomes thinner under nitrogen deficiency treatment, whereas application of potassium fertilizer can improve the thickness of the pericarp. Fruit storage duration is closely related to the pericarp thickness, i.e., the smaller the thickness is, the shorter the storage duration will be (Lu et al., 2004). This research showed that as the K₂O:N ratio increased, litchi pericarp thickness increased first and declined later. When the K₂O:N ratio was 1.2, the thickening effect on litchi pericarp was the most significant, and either excessive large or small K₂O:N ratio can both reduce the pericarp thickness of litchi fruit. Therefore, to keep litchi fruit fresh, appropriate amount of potassium–nitrogen fertilizer should be applied to increase the pericarp thickness to facilitate fruit storability and to achieve prolonged shelf life.

Conclusions

The reasonable applying proportion of potassium and nitrogen fertilizer can produce high yield and quality, longtime storable fruits. In our trial, litchi fruit showed the highest yield, better quality, and best postharvest storability with applying ratio of K₂O:N = 1.2 on nitrogen-deficient and low-potassium soil. Therefore, postharvest storability of fruit will be better through plant nutrient management, which is essential supplementary of fruit preservative and fresh-keeping.

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