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Effects of Changes of Mineral Element Concentration in Fruit Development of Prunus Salicina Lindl. on Fruit Splitting

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Abstract: We want to clarify the demand for mineral elements during the development of Prunus salicina Lindl. fruits and the effects of changes of mineral element concentrations on fruit splitting, thus contributing to the scientific fertilization and avoidance of fruit splitting after fruit set. The changes of mineral elements in leaves and fruits and the fruit splitting rate were recorded every 7-10 days from 45 days after anthesis. At maturity, the differences in the mineral element concentration between normal fruits and cracked fruits were compared. The results indicate that the concentration of N and Fe in leaves showed a lasting downtrend while that of P, K, Ca and Mg presented a fluctuating uptrend, among which Zn had the highest fluctuation degree. In fruits, the concentration of N, P, Ca, Mg and Zn dropped first and then stabilized. It was worth noting that the inflection points all appeared at 85 days after anthesis (when fruit splitting was observed); During the fruit development of Prunus salicina Lindl., N, K and Ca and Zn fertilizers should be supplemented to meet the huge demand of elements by leaves and fruits and re-duce fruit splitting.

1. Introduction

Native in Yunnan and distributed in southwest provinces in China, Prunus salicina Lindl. has low soil fertility requirements and strong tolerance to barren soil, and trees are manageable and easily grow into flower buds [1-2]. Hence, *P. salicina* has become an ideal tree species worthy of promotion in poverty stricken areas, and its planting has gradually become a pillar industry in many impoverished mountainous areas. However, fruit splitting often occurs after rain as maturity approaches, which severely affects the appearance, quality and yield of *P. salicina* fruits, thus reducing its commodity value, weakening its market competitiveness and restricting its development.

Mineral elements are not only basic to the growth, yield and quality of fruit trees, but also a vital cause for fruit splitting. Therefore, investigating the dynamic changes of mineral elements in leaves and fruits is important for clarifying the demand for mineral elements during fruit development of *P. salicina*, and determining the effects of changes of mineral elements on fruit splitting, to develop fertilizer recommendations to prevent fruit splitting of *P. salicina* after fruit set. At present, the relationship between mineral elements and fruit splitting has been widely studied in pomegranate [3-5], Mango [6], lemon [7], navel orange [8], jujube [9], apricot [10], tomato [11], etc., but the correlation between dynamic changes of mineral elements and fruit splitting in the fruit development of *P. salicina* has rarely been researched. In this study, the changes of mineral elements in leaves and fruits and the fruit splitting rate of *P. salicina* were recorded every 7-10 days from the 45th day after anthesis. This study was conducted to compare the differences in mineral element concentrations between normal fruits and splitting fruits, and to evaluate correlations between mineral elements in leaves and fruits and the fruit splitting rate for *P. salicina* fruits.

2. Materials and Methods

Materials. Six-year-old *P. salicina* from Xiangdanghao Agriculture Co., Ltd., Tongluo Village, Xiangshui Town, Wanzhou District, Chongqing, was chosen for the test. Fruits matured in the first half of July with serious fruit splitting. The rootstock was Amygdalus persica L. Batsch, and the row spacing of plants was 2.5 m×4.0 m. The orchard was well managed. and the trees were robust. The test was carried out in the humid zone of subtropical monsoon, with four distinct seasons, abundant sunshine and rainfall as well as a long frost-free period. The annual average temperature was 17.7℃, the annual average cumulative sunshine duration was 1484.4 h, and the annual average rainfall was 1243 mm. The soil layer was thick and composed of red loam, whose basic physical and chemical properties were: pH = 5.41, alkali-hydrolyzable N = 81.20 mg/kg, available P = 50.60 mg/kg, available K = 63.10 mg/kg, exchangeable Ca = 3.54 g/kg, exchangeable Mg = 214.27 mg/kg, available Zn = 2.09 mg/kg, available iron = 47.50 mg/kg, available Mn = 42.20 mg/kg, available Cu = 1.31 mg/kg and available B = 0.29 mg/kg.

Test methods: Uniform robust *P. salicina* trees were selected. With every 10 trees as a plot, leaves and fruits were sampled from the 45th day after anthesis once every 7-10 days (repeated for 3 times). At least 100 leaves and 30 fruits were collected from each plot. At the same time, fruit splitting rate was recorded on the 119th day after anthesis (when fruits were at the full maturity stage). The samples collected each time were stored in ice boxes for the measurement of relevant indexes. As maturity approached, 30 split fruits and 30 normal fruits were randomly selected for the measurement of relevant indexes in the laboratory.

Measurement methods: The leaf and fruit samples were rinsed with tap water, distilled water and deionized water successively, wiped with clean gauze for water removal on the surface, dried in a dryer at 105 ℃ for 15 min, and then placed in another dryer at 60 ℃ for drying to constant weight. After that, the leaf and fruit samples were cooled, crushed in a grinder, screened in a 40-mesh sieve and stored in sealed dryers. In accordance with the method specified in the third article of Soil Agrochemical Analysis of Bao Sh. D. [12], the concentration of total nitrogen was determined by the Kjeldahl method after the sulfuric acid-hydrogen peroxide digestion, and the concentration of elements was determined by ICP-AES after the nitric acid digestion.

Data processing and analysis. Microsoft Excel 2010 was used for the processing of test data, and related charts were drawn. SPSS18.0 was adopted for statistical analysis.

3. Results

Table 1 displays the concentration of mineral elements in leaves and fruits of *P. salicina* in the whole growth period. The concentration of Ca (41,116.19 mg/kg) in leaves was much higher than that of other elements, followed by K (29,196 mg/ka), whereas Mn (13.34 mg/kg) in leaves was the lowest. For fruit, the concentration of N (2,099.94 mg/kg) was highest, followed by K but significantly much higher than that of other elements. P ranked third, but concentration did not largely differ from that of other elements. Like in leaves, the average concentration of Mn (0.86 mg/kg) in fruits was the lowest.

Table 1: Differences in mineral elements in leaves and fruits of *P. salicina* in the whole growth period

Element (mg/kg)	Concentration in leaves	Concentration in fruits
N	23889.67c	2099.94a
P	3410.91e	236.72b
K	29196.43b	1980.52a
Ca	41116.19a	154.45b
Mg	7434.07d	94.91b
Fe	216.87e	4.49b
Zn	49.81e	4.22b
B	42.01e	3.36b
Cu	84.12e	7.24b
Mn	13.34e	0.86b

Note: Different letters in the Column "Concentration in leaves" and "Concentration in fruits" indicate significant differences in the concentration of elements between leaves and fruits (P<0.05).

As presented in Figure 1, during the fruit development of *P. salicina*, the concentration of N in both leaves and fruits declined during the season, but it declined from 29.92 g/kg to about 8 g/kg in leaves and from 3.76 g/kg to 2.7 g/kg in fruits at 45-119 days after anthesis. In the period of fruit splitting (at 85-119 DAA), the concentration of N slightly increased in leaves but slightly decreased in fruits. In particular, in the period with a high incidence rate of fruit splitting (at 106-119 days after anthesis), the concentration of N in leaves and fruits remained stable.

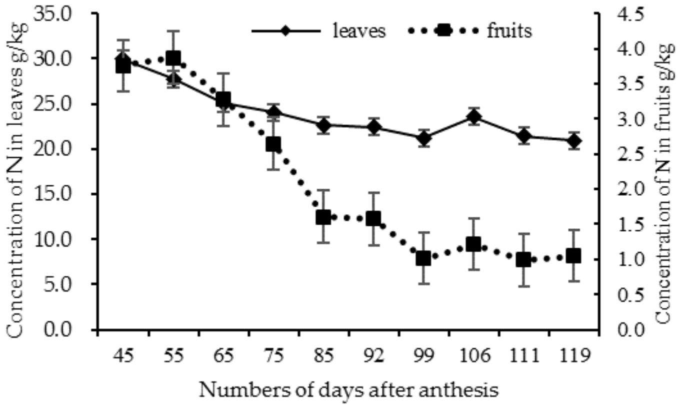


Figure 1: Changes of concentration of N in leaves and fruits during the fruit development of P. salicina

Leaf P levels declined slightly from 45 to 75 days, then increased gradually for the remainder of the season (Fig. 2). From 45 to 55 days, fruit P declined, then increased and stabilized for three weeks before declining and remained stable after 85 days. When fruit splitting frequently occurred (at 99-119 days after anthesis), leaf P declined first and then rose sharply, and it reached 4.18 g/kg at the maturity stage with the most serious fruit splitting. On the contrary, the concentration of P in fruits presented a fluctuating downtrend, and it declined from 0.51 g/kg to 0.25 g/kg at 45-55 DAA, showing the most significant downtrend. Moreover, it rose slightly at 55-65 days, declined sharply again at 65-85 days, remained stable at 85-119 days after anthesis (in the period of fruit splitting) and reached 0.15 g/kg when fruits became mature.

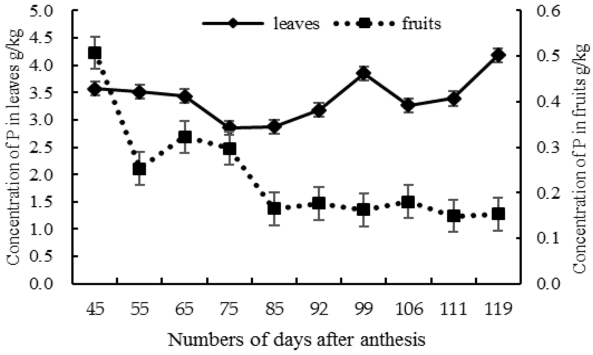


Figure 2: Changes of concentration of P in leaves and fruits during the fruit development of P. salicina

Leaf and fruit K levels fluctuated in opposite directions during the season (Fig. 3). Leaf K levels initially increased, then declined slightly before increasing just before harvest. Fruit K levels declined for about three weeks before rapidly increasing for three weeks, then declined rapidly at 92 days after anthesis and remained stable until harvest.

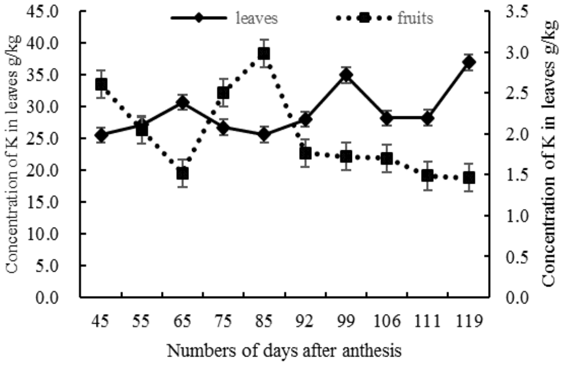
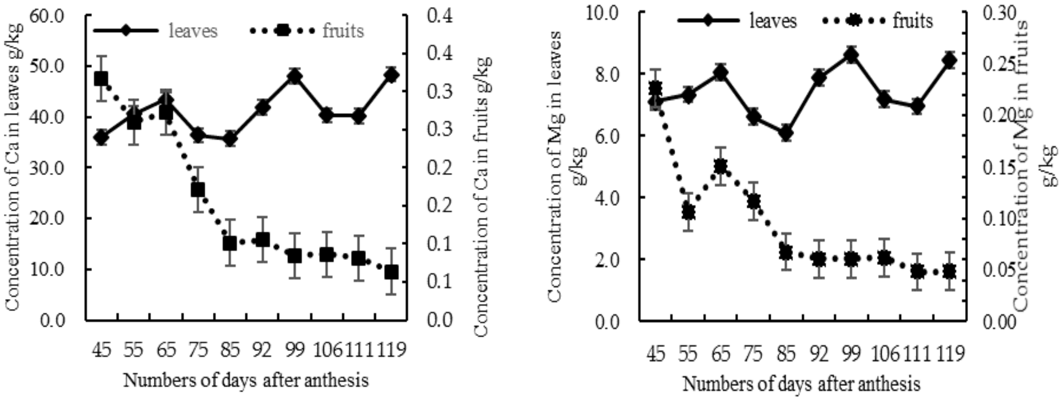


Figure 3: Changes of concentration of K in leaves and fruits during the fruit development of P. salicina



(**a**) (**b**)

Figure 4: Changes of concentration of Ca and Mg in leaves and fruits during fruit development of P. salicina (a) Changes of concentration of Ca; (b) Changes of concentration of Mg.

Seasonal trends for leaf and fruit Ca and Mg concentrations were similar (Fig. 4). Leaf concentrations generally increased three times during the season, at 45-65, 85-99 and 111-119 DAA. Fruit concentrations declined initially, then rose slightly at 55-65 DAA before declining until 85

DAA and stabilizing until harvest

Leaf Fe concentrations declined rapidly until 75 DAA, then stabilized, whereas Fruit Fe levels were variable during the season (Fig. 5).

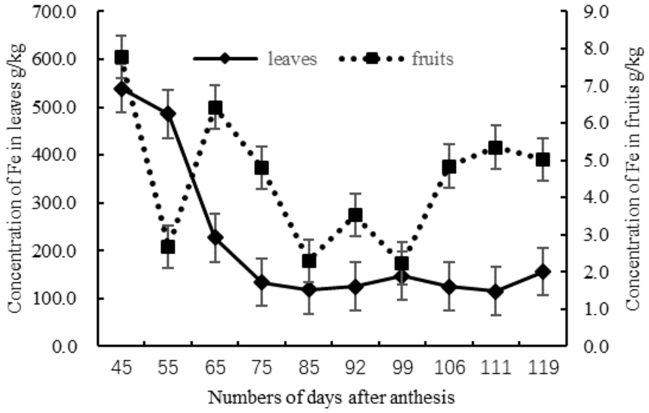


Figure 5: Changes of concentration of Fe in leaves and fruits during the fruit development of P. salicina

Leaf Zn levels generally declined during the season, but values were inconsistent (Fig. 6).

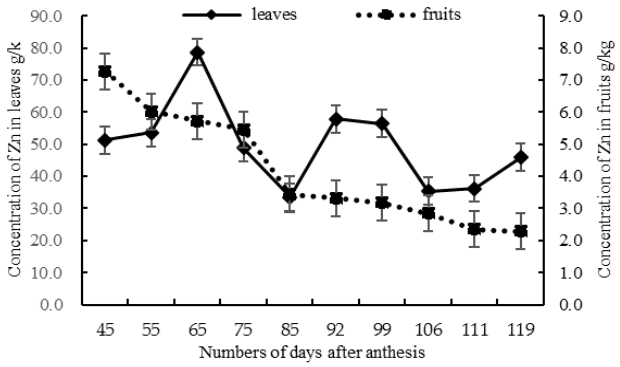
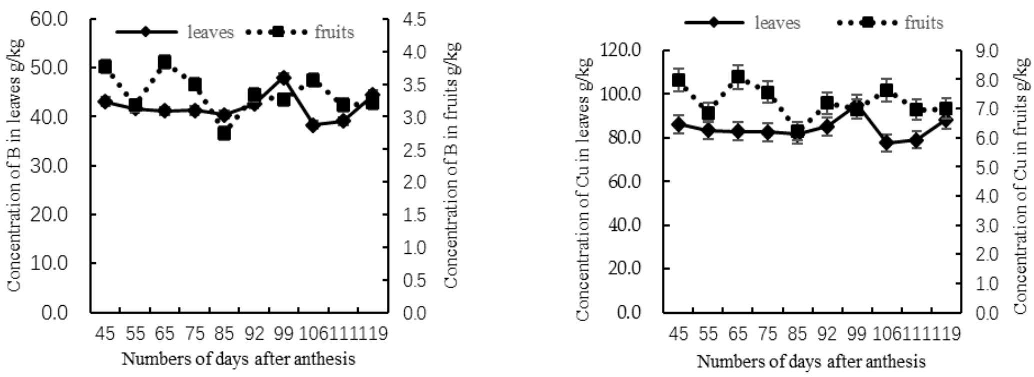


Figure 6: Changes of concentration of Zn in leaves and fruits during the fruit development of P. salicina

Fruit Fe concentrations generally declined nearly linearly during the season. Leaf and fruit B and Cu concentrations changed little during the season (Fig. 7).



(**a**) (**b**)

Figure 7: Changes of concentration of B and Cu during the fruit development of P. salicina: (a) Changes of concentration of B; (b) Changes of concentration of Cu.

Fruit and leaf Mn concentrations declined until about 85 DAA before stabilizing (Fig. 8).

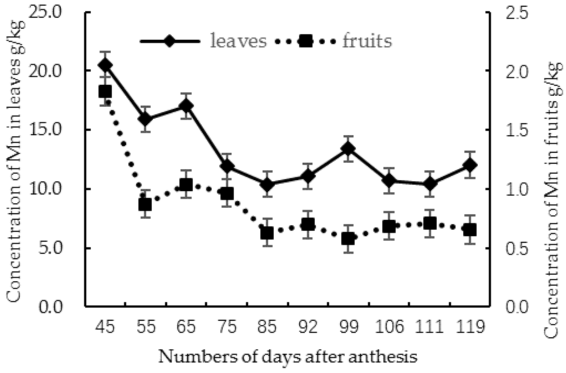


Figure 8: Changes of concentration of Mn in leaves and fruits during the fruit development of P. salicina

Elemental concentrations for normal and split fruits are shown in Table 2. Concentrations of K, Ca and Zn for normal fruits were significantly higher than for split fruits, and concentrations of N, P, Mg, Fe, B and Mn were similar for normal and split fruits.

Table 2: The differences in the mineral element concentration between normal and splitting fruits of Prunus salicina Lindl

Element (mg/kg)	Concentration in leaves	Concentration in fruits
N (g/kg)	1.067a	0.919a
P (g/kg)	0.150a	0.138a
K (g/kg)	1.447a	1.195b
Ca (g/kg)	0.065a	0.045b
Mg (g/kg)	0.051a	0.046a
Fe (mg/kg)	4.772a	3.775a
Zn (mg/kg)	2.241a	0.722b
B (mg/kg)	3.196a	2.841a
Cu (mg/kg)	6.981a	5.046a
Mn (mg/kg)	0.686a	0.638a

Note: Different letters indicate significant differences ($P<0.05$).

This research team has previously studied cracking rate of *P. salicina* fruit [13], and the resulting correlation is shown in Table 3-4. Fruit splitting was negatively correlated with fruit Ca and Zn concentrations. Fruit splitting was not linearly related to fruit concentrations of Ca, Zn or any leaf elemental concentrations However, the leaf P concentration was negatively related to fruit Ca concentration and fruit N and Ca were correlated. the concentration of Ca in fruits, and the concentration of N and Mg showed a remarkable positive correlation with that of Ca in fruits. Furthermore, significant positive correlations were observed between the concentration of Fe and that of Mg and between the concentration of Ca and that of Zn.

Leaf P concentrations were positively correlated with leaf concentrations of K, Ca, Mg and Fe, leaf concentrations of K were correlated with the concentration of Ca, Fe and Mg, and the leaf Ca was correlated with Mg, Fe and Mn. Leaf Mn was correlated with leaf K, Ca, Mg, Fe, B, and Cu. Additionally, a strongly significant positive correlation was also found between the concentration of Cu and Mn in fruits.

Table 3: The analysis of the correlations among the concentration of mineral elements and those of mineral elements in leaves with the fruit splitting rate

The correlation	Dehiscent fruit rate	N in leaves	P in leaves	K in leaves	Ca in leaves	Mg in leaves	Fe in leaves	Zn in leaves	B in leaves	Cu in leaves	Mn in leaves
Dehiscent fruit rate	1										
N in leaves	-0.49	1									
P in leaves	0.71	-0.77	1								
K in leaves	0.59	-0.75	0.98**	1							
Ca in leaves	0.48	-0.71	0.95**	0.96**	1						
Mg in leaves	0.32	-0.59	0.84*	0.87*	0.97**	1					
Fe in leaves	0.50	-0.61	0.91*	0.96**	0.91*	0.84*	1				
Zn in leaves	-0.19	-0.39	0.42	0.49	0.67	0.81	0.51	1			
B in leaves	-0.01	-0.67	0.66	0.78	0.81	0.81	0.80	0.79	1		
Cu in leaves	-0.03	-0.66	0.65	0.77	0.80	0.80	0.79	0.79	0.99**	1	
Mn in leaves	0.07	-0.61	0.75	0.85*	0.88*	0.87*	0.84*	0.71	0.95**	0.95**	1

Note: * represents significant correlation, ** represents extremely significant correlation

Table 4: The analysis of the correlations among the concentration of mineral elements and those of mineral elements in fruits with the fruit splitting rate

The correlation	Dehiscent fruit rate	N in fruits	P in fruits	K in fruits	Ca in fruits	Mg in fruits	Fe in fruits	Zn in fruits	B in fruits	Cu in fruits	Mn in fruits
Dehiscent fruit rate	1										
N in leaves	-0.62	1									
P in leaves	-0.57	0.5	1								
K in leaves	-0.59	0.73	0.22	1							
Ca in leaves	-0.87*	0.84*	0.62	0.61	1						
Mg in leaves	-0.74	0.72	0.73	0.76	0.87*	1					
Fe in leaves	0.77	-0.48	-0.26	-0.67	-0.58	-0.77	1				
Zn in leaves	-0.81*	0.77	0.54	0.71	0.87*	0.93*	-0.87*	1			
B in leaves	0.19	-0.37	0.44	-0.76	-0.22	-0.21	0.48	-0.35	1		
Cu in leaves	0.22	-0.35	0.45	0.75	-0.22	-0.22	0.54	-0.38	0.96**	1	
Mn in leaves	0.26	0.12	0.12	-0.34	0.08	-0.38	0.76	-0.24	0.35	0.42	1

Note: * represents significant correlation, ** represents extremely significant correlation

4. Discussion

In this study, the concentration of Ca and K was the highest in leaves while that of N and K was the highest in fruits, indicating high demand for Ca and K in leaves and for N and K in fruits in the growing period of *P. salicina*, Therefore, Ca, N and K fertilizers should be supplemented after fruit set, so as to meet the demand for elements in leaves and fruits, which is consistent with the results for Hongyu mango [14] and winter jujube [15]. In this study, leaf concentrations of N and Fe declined whereas concentrations of P, K, Ca and Mg increased in a fluctuating manner, and Zn fluctuated most. For fruits, concentrations of N, P, Ca, Mg and Zn declined first and then stabilized. It was worth noting that the inflection points all appeared at 85 days after anthesis when fruit splitting appeared. At this time, the concentration of K reached the peak but then dramatically declined, and the concentration of Fe fluctuated.

Ca salts can be formed when, Ca, a structural component of the cell wall, is combined with pectic substances, which enhances the elasticity of protoplasm, weakens the permeability of plasma membrane, and strengthens the pressure resistance and extensibility of cells, so as to enhance the splitting resistance of pericarp [16-18]. As shown in previous research on pomegranate [19], sweet cherry [20-21], ziziphus jujube [22], Jincheng orange [23], etc., a large amount of Ca can relieve fruit splitting. This study revealed that the concentration of Ca in normal fruits was significantly higher than that in splitting fruits, and that there was a significant negative correlation between the concentration of Ca in fruits and the fruit splitting rate, namely, and the lower the concentration of Ca in fruits, the higher the fruit splitting rate. However, there was no significant correlation between the concentration of Ca in leaves and the fruit splitting rate, which may be due to the poor mobility of Ca in plants. Therefore, it is speculated that to apply Ca fertilizer to the roots, instead of leaves, can more effectively increase the concentration of Ca in fruits and reduce fruit splitting.

In addition, the concentration of Zn in normal fruits was also evidently higher than that in splitting fruits. The analysis of the correlation between the fruit splitting rate and mineral elements also demonstrated that there was a significant negative correlation between the concentration of Zn and the fruit splitting rate, and the lower the former, the higher the latter. The reason may lie in that Zn is the regulator of cell wall related enzymes, preventing cell wall loosening. Li J. et al [24] found that the application of Zn can increase the resistance of pericarp and reduce the fruit splitting rate. Ding Ch. X. [25] discovered that the application of Zn (NO3)2 can reduce the occurrence of fruit pitting of Hongjiang orange.

The further analysis of the correlation among mineral elements demonstrated that there was a significant negative correlation between the concentration of P in leaves and that of Ca in fruits, and significant positive correlations were observed between the concentration of N and Mg and that of Ca in fruits and between the concentration of Fe and Mg and that of Zn in fruits. Hence, during the fruit development of *P. salicina*, Ca and Zn fertilizers that can reduce the fruit splitting rate should be applied in combination with N, Mg and Fe fertilizers that can facilitate the absorption of Ca and Zn fertilizers. At the same time, the amount of P fertilizer should be controlled to prevent the antagonism to Ca fertilizer.

5. Conclusion

In actual production, during the fruit development period of *P. salicina*, N, K, Ca and Zn fertilizers should be applied to meet the huge demand for elements in leaves and fruits and reduce the occurrence of fruit splitting. Meanwhile, N, Mg and Fe fertilizers that can promote the absorption of Ca and Zn fertilizers and P fertilizer that suppresses the absorption of Ca should also be applied. Moreover, this study proves that Zn, in addition to Ca and P that are generally acknowledged, is closely related to the fruit splitting of *P. salicina*. However, this relationship has been rarely studied, so the specific mechanism and whether it exists in other fruit trees still require further research.

Acknowledgements

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