

‘琯溪蜜柚’园土壤和树体的硼素营养与果实粒化关系分析

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摘要:【目的】研究福建省平和县‘琯溪蜜柚’园土壤和树体的硼素营养状况及其与果实粒化的关系。【方法】采集平和县314个蜜柚园土壤、叶片和果实样品,进行硼素营养和果实品质的测定。【结果】蜜柚园土壤有效硼含量(w ,后同)范围为0.05~4.61 mg·kg⁻¹,平均值为0.77 mg·kg⁻¹,土壤有效硼低量(<0.5 mg·kg⁻¹)、适宜(0.5~1 mg·kg⁻¹)和高量(>1 mg·kg⁻¹)的比例分别为43.57%、33.54%和22.89%,0~60 cm土层土壤有效硼含量随土层深度的增加而降低,呈现明显的表聚特征。蜜柚叶片硼含量范围为9.61~252.02 mg·kg⁻¹,平均值为72.47 mg·kg⁻¹,叶片硼含量属于低量(<15 mg·kg⁻¹)、适宜(15~50 mg·kg⁻¹)和高量(>50 mg·kg⁻¹)的比例分别为0.32%、24.84%和74.84%。叶片硼高量的比例显著高于土壤有效硼高量的比例,说明含硼叶面肥的过量施用是造成叶片硼含量高的主要原因。蜜柚果实硼含量范围为1.13~57.50 mg·kg⁻¹,平均值为14.07 mg·kg⁻¹,果实硼含量8~16 mg·kg⁻¹和高于16 mg·kg⁻¹样品汁胞严重粒化(粒化率>40%)的比例分别较硼含量低于8 mg·kg⁻¹的样品提高了31.87%和31.89%。相关分析表明,果实硼含量与果实Ca/B比值呈极显著负相关($y=304.81x^{-0.63}$, $r=0.77^{**}$),果实汁胞严重粒化(粒化率>40%)的比例随Ca/B比值的提高而降低。【结论】平和县蜜柚园土壤和叶片均存在硼过量的问题,硼过量可能会增加蜜柚果实汁胞粒化的风险,施用含钙肥料、提高果实Ca/B比值,可缓解果实汁胞粒化的程度。平和县蜜柚生产应限制含硼叶面肥的过量使用,增加含钙肥料的施用。

关键词:蜜柚园;土壤有效硼;叶片硼;果实硼;果实粒化

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Analysis of boron nutrition status in soils and trees and its relationship with fruit granulation in ‘Guanximiyu’ pomelo

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Abstract:【Objective】Honey pomelo of ‘Guanximiyu’ (*Citrus grandis*) is one of the important citrus varieties in China, and the largest production and export region is in Pinghe County (24°02'~24°35'N, 116°53'~117°31'E), Fujian Province, which is known as “the hometown of honey pomelo”. At present, the annual yield of honey pomelo is about 120×10⁴ t and the planting area was more than 5×10⁴ hm². But, there are some problems caused by excessive application of chemical fertilizers and unreasonable nutrient ratio of fertilization in honey pomelo orchards, which results in the quality reduction. The serious problem of juice sac granulation, which reduces the edible quality and commercial value of honey pomelo, is an urgent problem to be solved. Boron (B) is an essential nutrient element for plants and

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plays important physiological and biochemical roles in the flowering and fruit development of citrus. In pomelo production, farmers often unreasonably apply and/or overuse B fertilizer. However boron is a micro-element, whose critical ranges in soils and plants are very narrow between deficiency and excess. Excessive B can cause toxicity to plants. In order to provide a theoretical and practical basis for rational application of B containing fertilizers, the B status in soils, leaves and fruits of honey pomelo in orchards in Pinghe County and its relationship with fruit quality were investigated.【Methods】Relative paired samples of soils, leaves and fruits were collected from 314 10-15 year old pomelo orchards in 10 main production towns including Wenfeng, Qiling, Luxi, Jiufeng, Nansheng, Guoqiang, Banzai, Shange, Xiazhai and Xiaoxi in Pinghe County, Fujian Province. Representative samples of each orchard were collected from five individual trees and soil. In order to show the B status of different soil depths, a total of 144 soil samples at depths of 0-20 cm, 20-40 cm, and 40-60 cm were collected from 48 orchards with age above 15 years. All the soil samples were taken 10 cm inward from the canopy drip line for avoiding fertilization ditch. Soil available boron was extracted with boiling water and determined with curcumin colorimetry. The total boron content in leaves and fruits was determined by curcumin colorimetry after drying and ashing. The total content of calcium (Ca) in fruit was determined by atomic absorption spectrometry. Four to five fruit were taken from each orchard for the determination of fruit granulation rate.【Results】In the sampled pomelo orchards, the soil available B content ranged from 0.05 to 4.61 mg·kg⁻¹, with an average value of 0.77 mg·kg⁻¹. Based on the classification, the percentage of low (<0.5 mg·kg⁻¹), adequate (0.5-1 mg·kg⁻¹) and high (>1 mg·kg⁻¹) was 43.57%, 33.54% and 22.89%, respectively. The content of available B in soils of different town was quite different, with a coefficient of variation of 88.31%. The percentage of soils with low level of available B in Wenfeng and Guoqiang town was 68.75% and 65.38%, respectively, while that in Qiling and Jiufeng town was 64.71% and 35.00%, respectively. Additionally, the content of available B in different soil layers decreased with soil depth, reflecting an obvious surface accumulation characteristic. The available B contents in 0-20 cm, 20-40 cm and 40-60 cm soil layers were 0.59, 0.40 and 0.33 mg·kg⁻¹, respectively. It was significantly higher in 0-20 cm soil layer than in 20-40 cm and 40-60 cm soil layers, but there was no significance between 20-40 cm and 40-60 cm layers. Besides, the total B content in leaf ranged from 9.61 to 252.02 mg·kg⁻¹, with an average value of 72.47 mg·kg⁻¹. The percentage of low (<15 mg·kg⁻¹), adequate (15-50 mg·kg⁻¹) and high (>50 mg·kg⁻¹) was 0.32%, 24.84% and 74.84%, respectively. The proportion of pomelo orchards with high leaf B reached 94.12% and 80% in Luxi and Jiufeng town, respectively. The proportion of orchards with high leaf B was significantly higher than the percentage of orchards with high available soil B, indicating excessive use of B fertilizer as foliar spray. The total B content of fruit (or pulp) ranged from 1.13 to 57.50 mg·kg⁻¹ with an average of 14.07 mg·kg⁻¹. Compared with fruit samples with low level B content (<8 mg·kg⁻¹), the incidence of severe juice sac granulation in samples with middle (8-16 mg·kg⁻¹) and high (>16 mg·kg⁻¹) B level increased by 31.87% and 31.89%, respectively. Correlation analysis showed that a significant negative correlation between fruit B content and fruit Ca/B ratio ($y = 304.81x^{-0.63}$, $r = 0.77^{**}$). Our results also showed that the proportion of severe juice sac granulation (granulation rate > 40%) decreased with the increase in Ca/B ratio.【Conclusion】Taken together, the risk of juice sac granulation increases as fruit B content increases in orchards in Pinghe County. The incidence of juice sac granulation can be reduced through increasing fruit Ca/B ratio by applying calcium fertilizer. For sustainable production of honey pomelo in Pinghe County, the excessive use of B containing fertilizer as foliar spray should be avoided while calcium containing fertilizer application should be increased.

Key words: Pomelo orchard; Soil available boron; Leaves boron; Fruit boron; Fruit granulation rate

硼是高等植物生长必需的微量元素,以往关于植物硼素营养的研究主要集中在硼的土壤化学行为^[1-2]、缺硼对植物生理代谢的影响^[3-4]、硼肥的肥料效应^[5-7]以及矿区硼污染的植物毒害作用^[8]和修复^[9]等方面。近年来,由于含硼肥料的不合理施用,柑橘生产上硼富集的现象凸显,唐玉琴等^[10]研究表明江西省安远县和寻乌县甜橙叶片硼含量达100~200 mg·kg⁻¹的比例分别为10.20%和42.42%,而浙江省衢州市椪柑叶片硼高量(>100 mg·kg⁻¹)比例为31.37%,江西省南丰县蜜桔叶片硼高量(>60 mg·kg⁻¹)比例达42.06%^[11]。已有研究表明,高硼会导致柑橘光合作用速率降低^[12]、膜脂过氧化加剧^[13-14]、养分吸收受阻^[15],严重抑制柑橘的生长并导致产量和品质下降。

福建省平和县是‘琯溪蜜柚’的主产区,种植面积和产量分别达 4.33×10^4 hm²和 120×10^4 t,其种植面积、产量和出口量均居全国首位。经过30多年大规模发展,平和县蜜柚生产中长期过量施肥导致的土壤酸化、土壤养分积累和养分不均衡的问题,已严重影响蜜柚的产量和品质^[16-17],然而有关蜜柚土壤和树体硼营养的研究较少。另外,上世纪90年代以来,研究者从品种^[18]、营养调控^[19]、激素代谢^[20-21]等方面开展蜜柚果实粒化机理和控制措施的研究。然而仍没有完全有效的解决方法,果实粒化依然是影响蜜柚生产和品质的最主要因素。谢志南等^[19]研究表明,蜜柚果实汁胞粒化与矿质养分含量有明显关系,果实粒化的蜜柚叶片硼含量明显提高而钙含量明显降低。Awasthi等^[22]发现,叶片和果实钙含量低的甜橙果实粒化指数显著高于正常果实,而施钙缓解猕猴桃^[23]和小麦^[24]硼毒害的研究也被报道。笔者通过对平和县10个蜜柚主产乡镇314个果园的土壤、叶片和果实样品的分析测试,研究果园土壤、叶片和果实的硼营养状况,探究硼、钙营养与果实粒化的关系,旨在为蜜柚合理施用硼肥和果实汁胞粒化的矫治提供依据。

1 材料和方法

1.1 样品采集

1.1.1 土壤样品 土壤、叶片和果实样品在福建省平和县的10个‘琯溪蜜柚’主产乡镇:文峰镇、崎岭乡、芦溪镇、九峰镇、南胜镇、国强乡、坂仔镇、山格镇、霞寨镇和小溪镇分别选取具有代表性的蜜柚园

16个、17个、17个、20个、22个、26个、39个、48个、54个和55个,共计314个蜜柚园进行土壤、叶片和果实样品的采集,采样方法依据《亚热带果树营养诊断样品采集技术规范(DB35/T742-2007)》^[25]。每片果园选取长势一致、有代表性的5株蜜柚作为采样株,采集土壤、叶片和果实样品,做到土壤、叶片、果实样品的一一对应。

1.1.2 土壤剖面样品 土壤剖面样品在福建省平和县的10个蜜柚主产乡镇中共选取48个树龄在15年以上的蜜柚园,每个果园选取长势一致和具代表性的5株蜜柚作为采样株^[26],在树冠滴水线内侧10 cm处(避开施肥沟)分别采集0~20 cm、20~40 cm、40~60 cm深度的土壤样品3个,每株采集对称方向的2个点,将5株所取的土壤样品分层后均匀混合为3个独立样品,合计采集蜜柚园土壤剖面样品144个。

1.2 样品的制备与测定

土壤样品经自然风干,“四分法”分样,挑拣杂物,研磨过1 mm(20目)和0.149 mm(100目)筛,装袋备用。新鲜蜜柚叶片先用稀盐酸溶液洗涤,再用自来水和去离子水洗净,擦干后将样品放在105 °C烘箱内杀青30 min,然后改用65 °C烘至恒重。取出在干燥器中冷却后,磨细过0.5 mm筛,备用。

土壤有效硼含量采用沸水浸提,叶片和果实硼含量用干灰化处理后用姜黄素比色法测定;钙含量采用原子吸收法测定果实钙含量。果实粒化率测定参照Li等^[17]和黄日升等^[27]的方法,以囊瓣中粒化汁胞的长度>10%囊瓣长度作为判断囊瓣粒化的标准,粒化率为粒化囊瓣数占果实总囊瓣数的比率。每个果园采集4~5粒果,以4~5粒果的平均值作为果园蜜柚的粒化率。依据庄伊美等^[28]的分级标准:土壤有效硼含量的分级为低量(<0.5 mg·kg⁻¹)、适量(0.5~1 mg·kg⁻¹)和高量(>1 mg·kg⁻¹),叶片硼含量的分级为低量(<15 mg·kg⁻¹)、适量(15~50 mg·kg⁻¹)和高量(>50 mg·kg⁻¹)。

1.3 数据处理

采用Microsoft Office Excel 2010进行数据统计和作图,SPSS 19.0对数据进行方差和显著性分析。

2 结果与分析

2.1 蜜柚园土壤硼含量

蜜柚园土壤有效硼含量范围为0.05~4.61 mg·kg⁻¹,平均值为0.77 mg·kg⁻¹(表1),土壤有效硼低量(<0.5

表1 平和县蜜柚园土壤有效硼含量状况

Table 1 Soil avail-B content in pomelo orchards in Pinghe county

乡镇 County	数值范围 Data range/ (mg·kg ⁻¹)	平均值 Average/ (mg·kg ⁻¹)	标准差 Standard deviation	变异系数 Coefficient of variation/%	土壤有效硼含量分级比例 Classification based on soil avail-B content/%		
					低量 Low	适量 Adequate	高量 High
文峰镇 Wenfeng	0.12~1.84	0.49	0.42	85.71	68.75	25.00	6.25
崎岭乡 Qiling	0.29~4.47	1.48	1.17	79.05	11.76	23.53	64.71
芦溪镇 Luxi	0.11~2.58	0.85	0.67	78.82	41.18	29.41	29.41
九峰镇 Jiufeng	0.28~2.20	0.96	0.51	53.13	15.00	50.00	35.00
南胜镇 Nansheng	0.22~3.73	0.81	0.80	98.77	40.91	36.36	22.73
国强乡 Guoqiang	0.11~1.23	0.53	0.30	56.6	65.38	26.92	7.70
坂仔镇 Banzai	0.15~1.58	0.54	0.34	62.96	59.52	28.57	11.91
山格镇 Shange	0.13~2.43	0.60	0.48	80.00	51.02	32.65	16.33
霞寨镇 Xiazhai	0.05~3.23	0.85	0.70	82.35	38.89	27.78	33.33
小溪镇 Xiaoxi	0.15~4.61	0.86	0.82	95.35	33.93	46.43	19.64
平均值 Average	0.05~4.61	0.77	0.68	88.31	43.57	33.54	22.89

$\text{mg} \cdot \text{kg}^{-1}$ 、适量($0.5\sim 1 \text{ mg} \cdot \text{kg}^{-1}$)和高量($>1 \text{ mg} \cdot \text{kg}^{-1}$)样品比例分别为43.57%、33.54%和22.89%，表明平和蜜柚园土壤有效硼存在缺乏和高量并存的现象。

不同乡镇蜜柚园的土壤有效硼含量差异较大，变异系数(CV)达88.31%。各乡镇蜜柚园土壤有效硼平均含量由低到高排列的顺序是：文峰镇($0.49 \text{ mg} \cdot \text{kg}^{-1}$)<国强乡($0.53 \text{ mg} \cdot \text{kg}^{-1}$)<坂仔镇($0.54 \text{ mg} \cdot \text{kg}^{-1}$)<山格镇($0.60 \text{ mg} \cdot \text{kg}^{-1}$)<南胜镇($0.81 \text{ mg} \cdot \text{kg}^{-1}$)<芦溪镇、霞寨镇($0.85 \text{ mg} \cdot \text{kg}^{-1}$)<小溪镇($0.86 \text{ mg} \cdot \text{kg}^{-1}$)<九峰镇($0.96 \text{ mg} \cdot \text{kg}^{-1}$)<崎岭乡($1.48 \text{ mg} \cdot \text{kg}^{-1}$)，其中土壤有效硼较为缺乏的文峰镇和国强乡，其土壤有效硼低量($<0.5 \text{ mg} \cdot \text{kg}^{-1}$)的比例分别为68.75%和65.38%；而土壤有效硼含量高的是崎岭

乡和九峰镇，其土壤有效硼高量($>1 \text{ mg} \cdot \text{kg}^{-1}$)的比例分别为64.71%和35.00%。

不同土层土壤有效硼含量随土层深度的增加而降低， $0\sim 20 \text{ cm}$ 、 $20\sim 40 \text{ cm}$ 和 $40\sim 60 \text{ cm}$ 土层有效硼含量的平均值分别为 $0.59 \text{ mg} \cdot \text{kg}^{-1}$ 、 $0.40 \text{ mg} \cdot \text{kg}^{-1}$ 和 $0.33 \text{ mg} \cdot \text{kg}^{-1}$ ， $20\sim 40 \text{ cm}$ 和 $40\sim 60 \text{ cm}$ 土层有效硼含量较 $0\sim 20 \text{ cm}$ 土层分别下降32.20%和44.07%，差异达到显著或极显著水平(图1-a)。不同土层有效硼含量分级的比例间存在明显的不同(图1-b)，土壤有效硼高量($>1 \text{ mg} \cdot \text{kg}^{-1}$)和适量($0.5\sim 1 \text{ mg} \cdot \text{kg}^{-1}$)的比例随土层加深而呈现降低趋势，低量($<0.5 \text{ mg} \cdot \text{kg}^{-1}$)的比例则相反，表明土壤有效硼呈表层富集的特征。

2.2 蜜柚叶片硼含量

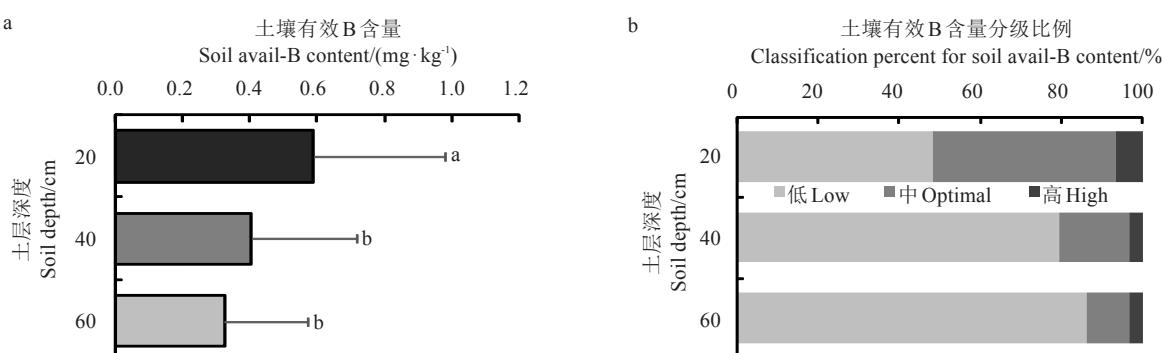


图1 土层深度对蜜柚园土壤有效硼含量

Fig. 1 Soil avail-B content in different soil depths in pomelo orchards

蜜柚叶片硼含量范围为 $9.61\sim 252.02 \text{ mg} \cdot \text{kg}^{-1}$ ，平均值为 $72.47 \text{ mg} \cdot \text{kg}^{-1}$ ，叶片硼含量为低量($<15 \text{ mg} \cdot \text{kg}^{-1}$)、适量($15\sim 50 \text{ mg} \cdot \text{kg}^{-1}$)和高量($>50 \text{ mg} \cdot \text{kg}^{-1}$)的比例分别为0.32%、24.84%和74.84%(表2)，表明平和蜜柚叶片存在硼过量的问题。不

同乡镇蜜柚叶片硼含量存在差异，变异系数(CV)达44.93%，叶片硼平均含量以崎岭乡和九峰镇最高，分别为 $85.96 \text{ mg} \cdot \text{kg}^{-1}$ 和 $83.74 \text{ mg} \cdot \text{kg}^{-1}$ 。除山格镇有2.08%的叶片样品硼低量外，其他乡镇均未出现低量的样品，芦溪镇和九峰镇叶片硼高量的比例分别

表2 平和县蜜柚叶片硼含量

Table 2 Leaf B content in samples from pomelo orchards in Pinghe County

乡镇 County	数值范围 Date range/ (mg·kg ⁻¹)	平均值 Average/ (mg·kg ⁻¹)	标准差 Standard deviation	变异系数 Coefficient of variation/%	叶片硼含量分级比例 Classification percent for leaf B content/%		
					低量 Low	适量 Adequate	高量 High
文峰镇 Wenfeng	28.2~103.4	55.41	21.57	38.92	0	43.75	56.25
崎岭乡 Qiling	32.0~161.0	85.96	37.15	43.22	0	23.53	76.47
芦溪镇 Luxi	38.0~165.4	80.07	27.45	34.28	0	5.88	94.12
九峰镇 Jiufeng	23.2~161.8	83.74	34.26	40.91	0	20.00	80.00
南胜镇 Nansheng	26.2~136.6	69.38	26.21	37.78	0	18.18	81.82
国强乡 Guoqiang	31.0~123.6	63.74	22.03	34.56	0	23.08	76.92
坂仔镇 Banzai	18.0~154.4	72.06	35.97	49.92	0	28.21	71.79
山格镇 Shange	9.6~191.6	69.93	32.51	46.49	2.08	25.00	72.92
霞寨镇 Xiazhai	16.4~252.0	79.43	38.9	48.98	0	22.22	77.78
小溪镇 Xiaoxi	26.4~163.0	67.85	28.96	42.68	0	30.91	69.09
平均值 Average	9.61~252.02	72.47	32.56	44.93	0.32	24.84	74.84

高达94.12%和80.00%。蜜柚叶片硼高量的比例明显高于土壤有效硼高量的比例,表明含硼叶面肥的不合理施用是造成叶片硼含量高的原因。

2.3 蜜柚果实硼含量

蜜柚果实硼含量范围为1.13~57.50 mg·kg⁻¹,平均值为14.07 mg·kg⁻¹(表3),不同乡镇果实硼含量存在较大差异,变异系数(CV)达47.80%,文峰镇和九峰镇的果实硼含量平均值较高,分别为16.26 mg·kg⁻¹和15.57 mg·kg⁻¹,而芦溪镇(13.11 mg·kg⁻¹)和崎岭乡(13.36 mg·kg⁻¹)的果实硼含量较低。

蜜柚果实硼含量受叶片硼含量的影响(表4),叶片硼低量(<15 mg·kg⁻¹)样品的果实硼含量均<16 mg·kg⁻¹,叶片硼适量(15~50 mg·kg⁻¹)和高量(>

表3 平和县蜜柚园果实硼含量

Table 3 Fruit B content in pomelo orchards in Pinghe county

乡镇 County	数值范围 Date range/ (mg·kg ⁻¹)	平均值 Average/ (mg·kg ⁻¹)	标准差 Standard deviation	变异系数 Coefficient of variation/%
文峰镇 Wenfeng	9.55~24.70	16.26	4.19	25.74
崎岭乡 Qiling	5.87~22.40	13.36	3.75	28.11
芦溪镇 Luxi	9.14~17.80	13.11	2.75	20.95
九峰镇 Jiufeng	10.00~31.50	15.57	4.92	31.59
南胜镇 Nansheng	7.19~29.80	13.45	5.19	38.62
国强乡 Guoqiang	6.54~33.20	13.78	5.24	38.02
坂仔镇 Banzai	1.69~49.40	13.49	7.40	54.84
山格镇 Shange	5.27~57.50	14.72	9.18	62.34
霞寨镇 Xiazhai	7.22~31.00	13.98	4.50	32.16
小溪镇 Xiaoxi	1.13~56.40	13.67	8.82	64.50
平均值 Average	1.13~57.50	14.07	6.73	47.80

表4 叶片硼含量对蜜柚果实硼含量的影响

Table 4 Effects of leaf B content on fruit B content in pomelo

w(叶片硼) Leaf B content/ (mg·kg ⁻¹)	果实硼含量 Fruit B content			果实硼含量分级比例 Classification percent for fruit B content/%		
	平均值 Average/(mg·kg ⁻¹)	标准差 Standard deviation	变异系数 Coefficient of variation/%	<8 mg·kg ⁻¹	8~16 mg·kg ⁻¹	>16 mg·kg ⁻¹
<15	13.35	0.07	0.53	0.00	100.00	0.00
15~50	13.26	5.31	40.06	2.74	63.91	34.25
>50	14.41	7.18	49.82	3.70	53.71	42.59

50 mg·kg⁻¹)样品的果实硼含量>16 mg·kg⁻¹的比例分别为34.29%、42.59%,表明叶片硼会向果实中转移,叶片硼过量会导致果实硼含量的提高。

相关分析表明,果实硼含量与果实Ca/B比值呈极显著负相关(图2),当果实Ca/B比值<50时,果实硼含量随Ca/B比值的增加呈线性下降;当果实Ca/B比值为50~500,果实硼含量随Ca/B比值的增加而降低;当果实Ca/B比值>500时,其果实硼含量的变化

趋于平缓。

2.4 果实硼含量与蜜柚品质的关系

由表5可知,果实硼含量的提高会导致果实汁胞粒化率的提高。将果实硼含量进行<8 mg·kg⁻¹、8~16 mg·kg⁻¹和>16 mg·kg⁻¹分级,可以看出,不同硼含量分级间,果实汁胞粒化率的平均值差异不明显,但汁胞严重粒化(粒化率>40%)的程度随硼含量的提高而增加,果实硼含量8~16 mg·kg⁻¹和>16 mg·kg⁻¹

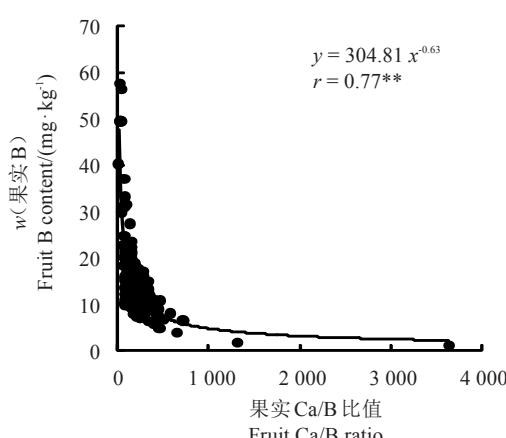


图2 蜜柚园果实Ca/B比值和果实硼含量的相关关系

Fig. 2 Relationship between fruit Ca/B ratio and fruit B content in samples from different pomelo orchard

样品的果实汁胞粒化率比例分别较硼含量 $<8\text{ mg}\cdot\text{kg}^{-1}$ 的样品提高了31.87%和31.89%。

果实粒化率随果实Ca/B比值的增加而降低(表6),将果实Ca/B比值按 <50 , $50\sim 500$, >500 进行分级,三级间粒化率的平均值差异不明显,但粒化率 $>40\%$ 的比例随Ca/B比值的提高而降低,果实Ca/B比值 >500 的果实粒化率比例较50~500和 <50 分别降低了27.47%和46.67%。

3 讨论

平和蜜柚园土壤有效硼高量($>1\text{ mg}\cdot\text{kg}^{-1}$)的比例为22.89%,叶片硼高量($>50\text{ mg}\cdot\text{kg}^{-1}$)的比例为74.84%,说明平和蜜柚土壤和树体均存在硼过量

表5 果实硼含量对蜜柚汁胞粒化率的影响

Table 5 Effects of fruit B content on pulp granulation incidence in pomelo

w(果实硼) Fruit B content/(mg·kg⁻¹)	果实粒化率 Fruit granulation percent/%			果实粒化率分级比例 Classification for granulation percent/%		
	平均值 Average/%	标准差 Standard deviation	变异系数 Coefficient of variation/%	<30	30~40	>40
<8	39.67	11.80	30.02	17.39	43.48	39.13
8~16	40.74	8.73	21.44	8.51	39.89	51.60
>16	40.54	8.57	21.15	4.84	43.55	51.61

表6 果实Ca/B比值对蜜柚果实粒化率的影响

Table 6 Effects of fruit Ca/B ratio on pulp granulation incidence in pomelo

果实Ca/B比值 Fruit Ca/B ratio	果实粒化率 Fruit granulation percent/%			果实粒化率分级比例 Classification for granulation percent/%		
	平均值 Average/%	标准差 Standard deviation	变异系数 Coefficient of variation/%	<30	30~40	>40
<50	41.11	17.03	17.03	0.00	20.00	80.00
50~500	40.69	22.12	22.12	8.56	38.91	52.53
>500	36.26	38.61	38.61	33.33	33.33	33.33

的问题,而叶片硼高量的比例明显高于土壤有效硼高量的比例,表明含硼叶面肥的不合理施用是造成叶片硼含量高的原因。硼中毒会导致椪柑叶片黄化、大量异常落叶^[28],与正常硼($10\text{ }\mu\text{mol}\cdot\text{L}^{-1}$)处理相比较,高硼($400\text{ }\mu\text{mol}\cdot\text{L}^{-1}$)胁迫柑橘类囊体基粒松散,叶绿素总量、蒸腾速率、气孔导度和光合作用极显著降低^[29],诱发叶片膜脂过氧化^[30]。

本研究结果表明,叶片硼过量会导致果实硼含量的提高,而果实硼积累提高了琯溪蜜柚汁胞的粒化率。硼提高果实汁胞粒化的可能原因是硼促进木质素和纤维素的合成,导致果实汁胞的木质化和纤维化。咖啡酸是木质素合成的前体,咖啡酸具有相邻顺式二元醇构型,硼酸的羟基能与咖啡酸的相邻

顺式二元醇络合,抑制其形成醌类,从而促进木质素的合成^[31]。Ghanati等^[32]发现,5 mmol·L⁻¹硼处理大豆幼苗的咖啡酸含量分别较0.01 mmol·L⁻¹和0.05 mmol·L⁻¹硼处理提高了33.33%和46.94%。Ghanati等^[33]研究表明,高硼增加烟草细胞木质素含量,硼浓度为10 mmol·L⁻¹和20 mmol·L⁻¹处理的木质素含量较对照($0.1\text{ mmol}\cdot\text{L}^{-1}$)分别增加了46.58%和68.65%。尿苷二磷酸葡萄糖(UDPG)是纤维素合成的前体,硼可促进UDPG合成,为纤维素的合成提供底物^[34]。

本研究结果还表明,提高果实Ca/B比值可降低果实汁胞粒化率,钙减轻果实汁胞粒化的可能原因是钙可以降低硼的吸收、减轻高硼胁迫对膜的危

害。高硼($0.45 \text{ mmol} \cdot \text{L}^{-1}$)胁迫下, $12 \text{ mmol} \cdot \text{L}^{-1}$ 钙处理猕猴桃的根、叶柄、叶缘和叶片硼含量分别较 $4 \text{ mmol} \cdot \text{L}^{-1}$ 钙处理降低了47.22%、28.30%、50.00%和56.25%^[23]。添加 $200 \text{ mg} \cdot \text{kg}^{-1}$ 钙处理时, $10 \text{ mg} \cdot \text{kg}^{-1}$ 和 $20 \text{ mg} \cdot \text{kg}^{-1}$ 硼处理小麦根系硼含量分别降低40.29%和53.30%,茎的硼含量分别降低了42.25%和57.69%^[24]。 $30 \text{ mmol} \cdot \text{L}^{-1}$ 钙显著提高高硼($5 \text{ mmol} \cdot \text{L}^{-1}$)处理萝卜的SOD、CAT、POD活性,降低MDA、 H_2O_2 含量和电解质渗透率^[35]。有关硼积累提高琯溪蜜柚果实汁胞粒化率的结论和机理还需进一步的研究。

4 结 论

平和县蜜柚园土壤和叶片均存在硼过量的问题,硼过量可能会增加蜜柚果实汁胞粒化的风险,施用含钙肥料、提高果实Ca/B比值可缓解果实汁胞粒化的程度。平和县蜜柚生产应限制含硼叶面肥的过量使用,增加含钙肥料的施用。

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