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环剥对设施栽培不同枣品种生长发育和果实品质的影响

王亚兴[1,2]，石美娟[2]，刘军南[1,2]，王永康[2*]，薛晓芳[2]，任海燕[2]，苏万龙[2]，赵爱玲[2]，刘　丽[2]，李　毅[2]，李登科[2]

（[1]山西农业大学园艺学院，山西晋中 030800；[2]山西农业大学果树研究所·果树种质创制和利用山西省重点实验室，太原 030031）

摘　要：【目的】探讨环剥对不同枣品种树体生长发育、单株产量、果实品质、果实裂果和缩果的影响，为提高果实品质、明晰环剥后树体生长发育规律和降低果实裂果率提供理论依据。**【方法】**以冷棚栽培的早红蜜、迎秋红、蟠枣、六月鲜、临冬2号、龙蟠冬枣、北京酸枣和冷白玉8个鲜食枣品种为试材，在盛花期进行环剥，测定树体生长量、果实可溶性固形物含量、可滴定酸含量、单株产量、裂果率和缩果率。**【结果】**环剥显著提高各品种的单株产量和单果质量，提高除临冬2号以外所有品种果实的可溶性固形物含量；降低早红蜜裂果率15.02%，以及迎秋红、临冬2号和龙蟠冬枣26.19%、13.15%、9.94%的缩果率；提升蟠枣、六月鲜和冷白玉2.22%、6.25%、22.65%的缩果率以及冷白玉54.65%的裂果率。不同品种单果质量的增加比例为早红蜜24.3%、迎秋红19.0%、蟠枣24.3%、六月鲜74.5%、临冬2号68.4%、龙蟠冬枣31.8%、北京酸枣76.6%、冷白玉32.1%。对除临冬2号和龙蟠冬枣以外的其他品种树高生长量的抑制率为冷白玉＞六月鲜＞迎秋红＞蟠枣＞北京酸枣＞早红蜜，但对不同品种的干粗、冠幅和二次枝长度及二次枝粗度的生长具有不同的影响。二次枝粗度生长量与可溶性固形物含量呈显著负相关关系。各品种环剥适用度为临冬2号＞冷白玉＞蟠枣＞六月鲜＞北京酸枣＞龙蟠冬枣＞早红蜜＞迎秋红。**【结论】**环剥有助于提高各个品种的单株产量与单果质量，可提高除临冬2号以外所有品种的可溶性固形物含量，有效抑制除临冬2号和龙蟠冬枣以外各品种的树高生长，但对不同品种的裂果率和缩果率影响不同，对不同品种的干粗、冠幅和二次枝长度及二次枝粗度的生长具有差异性的影响。临冬2号、冷白玉、蟠枣和六月鲜较适合环剥，早红蜜和迎秋红宜作省力化栽培品种。

关键词：枣；环剥；生长发育；果实品质；裂果

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Effects of girdling on tree growth and development, and fruit quality of different jujube varieties under protected cultivation

WANG Yaxing[1, 2], SHI Meijuan[2], LIU Junnan[1, 2], WANG Yongkang[2*], XUE Xiaofang[2], REN Haiyan[2], SU Wanlong[2], ZHAO Ailing[2], LIU Li[2], LI Yi[2], LI Dengke[2]

([1]College of Horticulture, Shanxi Agricultural University, Jinzhong 030800, Shanxi, China; [2]Fruit Tree Research Institute of Shanxi Agricultural University/Shanxi Key Laboratory of Creation and Utilization of Fruit Tree Germplasm, Taiyuan 030031, Shanxi, China)

Abstract:【Objective】Girdling is an important measure to preserve flowers and fruits and improve fruit quality in the cultivation process, but it’s time-consuming and laborious. Most of the studies on girdling used a single variety of materials, and there was a lack of research on the fruit quality and fruit cracking of different varieties. Eight different jujube varieties were used as test materials to explore the effects of girdling on tree growth and development, yield per plant, fruit quality and fruit cracking of

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作者简介：王亚兴，男，在读硕士研究生，研究方向为枣树栽培技术。E-mail：1982946233@qq.com

*__通信作者__ Author for correspondence. E-mail：274322374@qq.com

different jujube varieties, so as to provide theoretical basis for improving fruit quality, clarifying the pattern of tree growth and development after girdling, and reducing fruit cracking rate.【Methods】Eight fresh jujube varieties, including Zaohongmi, Yingqiuhong, Panzao, Liuyuexian, Lindong 2, Longpandongzao, Beijingsuanzao and Lengbaiyu, were taken as test materials, which were cultivated in a cold shed in Taigu District of Shanxi Province. The selected materials were healthy without pests and diseases and grew in a consistent manner. Girdling was carried out at the full-bloom stage of each variety. The tree growth, fruit soluble solids, titratable acid, yield per plant, fruit cracking rate and fruit shrinkage rate of the stripped and unstripped varieties were measured and compared. At the full-bloom stage, a secondary branch was left at the base of the trunk for girdling, and the girdling width was 1/6 of the trunk thickness. Each plant of each variety was repeated five times. The phloem was stripped to the xylem without damaging the xylem, and no girdling was set as the control group (CK). The fruit cracking rate is the number of cracking fruits per plant divided by the total number of fruits per plant, and the fruit shrinkage rate determination method is the same as the fruit cracking rate determination method. The measurement method of tree growth is to measure the growth and development index of the tree before the girdling, and to measure it again after the tree stopped growing. As for other fruit quality and traits, refer to the ‘jujube germplasm resources description specifications and data standards’.【Results】Girdling significantly increased the single fruit weight of each variety. Among them, the increase efficacy of single fruit weight of different varieties was as follows: Lindong 2＞Beijingsuanzao＞Liuyuexian＞Panzao＞Lengbaiyu＞Longpandongzao＞Yingqiuhong＞Zaohongmi, namely 10.66 g＞8.14 g＞6.39 g＞4.55 g＞3.6 g＞3.18 g＞2.16 g＞1.46 g. The longitudinal diameter of the fruit of Zaohongmi, Panzao, Lindong 2 and Lengbaiyu was significantly different from that of the fruit without girdling, and the longitudinal diameter of the fruit after girdling was larger than that of the fruit without girdling. The fruit transverse diameter showed that the fruit transverse diameter of flat jujube, Liuyuexian, Lindong 2, Beijingsuanzao and Lengbaiyu after girdling was larger than that of the fruit without girdling and the difference was significant. The fruit lateral diameter of Zaohongmi, Yingqiuhong, Panzao, Lindong 2, Beijingsuanzao and Lengbaiyu had significant difference before and after girdling. The fruit lateral diameter of Lindong 2 and Beijingsuanzao increased the most. Girdling increased the soluble solids content of fruits of all varieties except Lindong 2, and the increase effect of soluble solids content was 0.90%–5.65%. It had different effects on the change of titratable acid contents of different varieties. The titratable acid contents of Yingqiuhong, Longpandongzao, Beijingsuanzao and Lengbaiyu increased by 0.19%, 0.12%, 0.33% and 0.44%, respectively, after girdling, while the titratable acid contents of Zaohongmi, Panzao, Liuyuexian and Lindong 2 decreased by 0.07%, 0.02%, 0.21% and 0.36%, respectively. The fruit cracking rate of Zaohongmi was reduced by 15.02%, and the fruit shrinkage rates of Yingqiuhong, Lindong 2 and Longpandongzao were reduced by 26.19%, 13.15% and 9.94%, respectively, while the fruit shrinkage rates of Panzao, Liuyuexian and Lengbaiyuwere increased by 2.22%, 6.25% and 22.65%, respectively, compared with the control. Except for Lindong 2 and Longpandongzao, the inhibition effect of tree height growth of each variety was as follows: Lengbaiyu> Liuyuexian＞Yingqiuhong＞Panzao＞Beijingsuanzao＞Zaohongmi, that is, 9.3 cm＞6.9 cm＞6.2 cm＞3.1 cm＞0.6 cm＞0.5 cm. Girdling could significantly increase the yield per plant of each variety by 384.42 g–4 166.9 g. The effect of increasing yield was: Lengbaiyu＞Liuyuexian＞Beijingsuanzao＞Longpandongzao＞Lindong 2＞Panzao＞Yingqiuhong＞Zaohongmi, that is, 4 166.9 g＞3 835.4 g＞3 518.6 g＞2 401.1 g＞2 029.8 g＞1 693.7 g＞1 422.69 g＞384.42 g. The effects on the growth of stem diameter, crown width, secondary branch length and secondary branch diameter of different varieties were different. There was a significant positive correlation between single fruit weight and fruit longitudinal diameter, and a significant positive correlation between single fruit weight and fruit transverse diameter. The growth of secondary branch diameter was significantly and negatively correlated with soluble solids. The suitability degree of girdling for each variety was as follows: Lindong 2＞Lengbaiyu＞Panzao＞Liuyuexian＞Beijingsuanzao＞Longpandongzao＞Zaohongmi＞Yingqiuhong. 【Conclusion】 Girdling helps to improve the yield per plant and single fruit weight of each variety, increase the soluble solids content of each variety except Lindong 2, and effectively inhibit the tree height growth of each variety, but has different effects on the cracking rate and shriveling rate of different varieties. And there are differences in the growth of stem diameter, crown width, secondary branch length and secondary branch diameter of different varieties. Lindong 2, Lengbaiyu, Panzao and Liuyuexian are more suitable for girdling, while Zaohongmi and Yingqiuhong are suitable for labor-saving cultivation varieties. No (less) girdling is the main measure of labor-saving cultivation, and the varieties with easy fruit setting can be reduced or exempted from girdling. The varieties that must be stripped should be stripped as reasonably as possible, which is labor-saving and effective.

Key words: Chinese jujube; Girdling; Growth and development; Fruit quality; Fruit cracking

枣（*Ziziphus jujuba* Mill.）为鼠李科（Rhamnaceae）枣属（*Ziziphus* Mill.）植物，是中国特色果树和重要生态经济林树种[1]。随着中国农业现代化的发展，枣栽培逐渐向规模化、自动化和科技化发展模式转变，传统的乔化栽培和粗放管理被逐渐摒弃[2]。目前全国设施主栽品种为冬枣，品种单一，成熟期也晚。树势强、自然坐果差等因素，常常导致产量不高。环剥是缓和树势、促花保果的主要栽培技术之一。前人对环剥的方式方法[3]、时期[4]、宽度[5]和化学药剂处理及补光处理和环剥结合[6-7]对光合特性及果实品质等方面的影响进行了研究。结果表明，环剥主要依靠影响源库关系[8-9]和截流环剥口以上光合产物[10]来提高产量[11]、保花保果[5]、提高果实品质[12]。对于裂果和缩果的研究也有很多，主要是研究矿质元素[13-16]、激素[17-18]和基因等对裂果和缩果的影响及机制[19-20]。矿质元素缺乏、降水和高温是裂果的诱因[21-22]。硼[23-24]和钙[24]元素不足、高温[24]、果实膨大期遭遇阴雨低温[25]与病菌感染[26]等则会导致果实缩果。目前关于环剥处理对不同品种树体生长发育、果实裂果和缩果影响的研究较少。

环剥对不同品种的影响效果不同，例如，环剥对鲜食葡萄形态、理化和感官特性的影响因品种而异[27]。胡长久等[6]的补光与环剥试验结果表明，环剥处理之后葡萄果实单粒质量及纵横径均显著减小，但并不能确定环剥对所有的果树或品种都能起到增加产量和提高果实品质的效果。仇振华等[5]研究发现，当环剥宽度在干粗的1/6时，单株产量、果实的坐果率、纵横径、单果质量均为最大值。关于环剥的研究主要是针对单一品种。本研究以早红蜜、迎秋红、蟠枣、六月鲜、临冬2号、龙蟠冬枣、北京酸枣和冷白玉8个设施栽培鲜食枣品种为试材，探讨环剥对树体生长发育、果实品质、单株产量、坐果率、果实裂果和缩果的影响，并从中筛选出较适合环剥与不适合环剥的鲜食枣品种，为明晰环剥后树体的生长发育规律、减轻裂果和缩果对总体产量的影响，以及在栽培过程中科学控制树体生长、土肥水等栽培管理提供理论基础和实践依据。

1 材料和方法

1.1 试验地概况与试验材料

试验地点在山西省晋中市太谷区的避雨冷棚中，北纬37°38'，东经112°48'，海拔830 m，年均温10.6 ℃，无霜期160~180 d，年降水量400~600 mm，属典型黄土高原气候土壤生态条件。棚内进行常规土肥水管理，水肥供应充足，棚内环境控制措施按照DB14/T1583—2024执行。所选枣品种均为主干形树形且均为嫁接苗，砧木为壶瓶枣，株行距1.3 m×2.0 m。鲜食品种包含：早红蜜（ZHM）、迎秋红（YQH）、蟠枣（PZ）、六月鲜（LYX）、临冬2号（LD 2）、龙蟠冬枣（LPDZ）、北京酸枣（BJSZ）和冷白玉（LBY），树龄3~4年，试材栽培在同一棚内，生长环境和管理条件保持一致。

1.2 测定指标与方法

盛花期在主干基部留1个二次枝，在距二次枝

上方2 cm处进行环剥，环剥宽度为干粗的1/6，单株5次重复。设置对照（CK）为不环剥处理。树高等树体生长发育指标在环剥前测量1次，在树体停止生长后测量1次。果实脆熟期采集样品，果实品质等性状指标参照《枣种质资源描述规范和数据标准》。

1.3　数据处理与分析

采用Excel 2019处理数据，差异显著性分析（独立样本t检验）及主成分分析采用IBM SPSS Statistics 26.0，相关性分析及作图采用GraphPad Prism 8.2.1软件和Excel 2019。

2　结果与分析

2.1　环剥对树势的影响

环剥后，除临冬2号和龙蟠冬枣的树高生长量大于对照外，其余品种均小于对照（表1）。可能原因是临冬2号和龙蟠冬枣均依靠枣头顶芽发生新枣头生长，环剥可以抑制树高的生长但不能抑制新枣头的产生与生长。对除临冬2号和龙蟠冬枣以外的其他品种树高生长量的抑制率大小为冷白玉＞六月鲜＞迎秋红＞蟠枣＞北京酸枣＞早红蜜，即9.3 cm＞6.9 cm＞6.2 cm＞3.1 cm＞0.6 cm＞0.5 cm。六月鲜、临冬2号和龙蟠冬枣的主干粗生长量大于对照，早红蜜、迎秋红、蟠枣、北京酸枣和冷白玉的主干粗生长量均小于对照；蟠枣、六月鲜、临冬2号和北京酸枣的冠幅生长量均大于对照，而早红蜜、迎秋红、龙蟠冬枣和冷白玉均小于对照；除临冬2号和龙蟠冬枣的二次枝长度生长量大于对照外，其余品种二次枝长度生长量均小于对照；除早红蜜和龙蟠冬枣的二次枝粗度生长量大于对照外，其余品种的二次枝粗度生长量均小于对照。

综上所述，环剥对除临冬2号和龙蟠冬枣以外其余品种的树高生长量表现出抑制效果，而对干粗、冠幅和二次枝长度及二次枝粗度的生长具有不同的影响。

2.2　环剥对产量及裂果、缩果的影响

由单株产量、裂果率、缩果率调查结果（图1）可知，环剥明显提高各品种单株产量384.42~4 166.9 g，增产效果为冷白玉＞六月鲜＞北京酸枣＞龙蟠冬枣＞临冬2号＞蟠枣＞迎秋红＞早红蜜，即4 166.9 g＞3 835.4 g>3 518.6 g>2 401.1 g>2 029.8 g>1 693.7 g＞1 422.7 g＞384.4 g。环剥在各品种上增加单株产量的作用效果表现一致。相比对照，环剥降低早红蜜15.02%的裂果率，增加冷白玉54.65%裂果率，而对其余品种裂果率无差异性影响；降低迎秋红、临冬2号和龙蟠冬枣26.19%、13.15%、9.94%的缩果率；增高蟠枣、六月鲜和冷白玉2.22%、6.25%、22.65%的缩果率，而对其余品种缩果率无差异性影响。可能原因是产量增加导致硼和钙元素消耗突增，果实吸收硼、钙元素不足导致缩果，以及硼[28]、钙[28-29]、镁[30]和钾[29]元素供应不足导致裂果率升高。

表1　环剥后各品种树体生长情况

Table 1　Growth status of tree bodies of various varieties after girdling

品种 Variety	树势 Tree growth potential	处理与对照 Treatment and control	树高生长量 Tree height increment/cm	主干粗生长量 Accretion of trunk diameter/mm	冠幅生长量 Crown width increment/cm	二次枝长度生长量 Growth increment of secondary branch length/cm	二次枝粗度生长量 Growth increment of secondary branch diameter/mm
早红蜜 Zaohongmi	中庸 Moderation	环剥 Girdling	27.20	7.81	42.70	6.30	1.21
		CK	27.70	9.74	72.30	6.75	1.17
迎秋红 Yingqiuhong	中庸 Moderation	环剥 Girdling	19.80	2.79	22.50	5.80	1.15
		CK	26.00	3.55	30.65	15.93	1.28
蟠枣 Panzao	中庸 Moderation	环剥 Girdling	25.40	4.78	27.00	2.70	1.01
		CK	28.50	6.72	25.80	4.50	2.48
六月鲜 Liuyuexian	强 Strong	环剥 Girdling	22.60	9.28	52.10	1.30	1.73
		CK	29.50	8.62	41.80	4.75	2.21
临冬2号 Lindong 2	弱 Weak	环剥 Girdling	54.00	8.72	30.30	7.71	1.49
		CK	11.70	6.24	13.40	1.97	2.44
龙蟠冬枣 Longpandongzao	弱 Weak	环剥 Girdling	28.80	7.81	15.20	2.83	1.42
		CK	8.50	7.25	22.30	0.75	0.58
北京酸枣 Beijingsuanzao	中庸 Moderation	环剥 Girdling	19.40	3.42	28.10	2.60	0.56
		CK	20.00	8.03	25.30	2.80	1.96
冷白玉 Lengbaiyu	强 Strong	环剥 Girdling	49.00	9.19	72.60	1.75	1.92
		CK	58.30	9.52	88.00	4.75	3.00

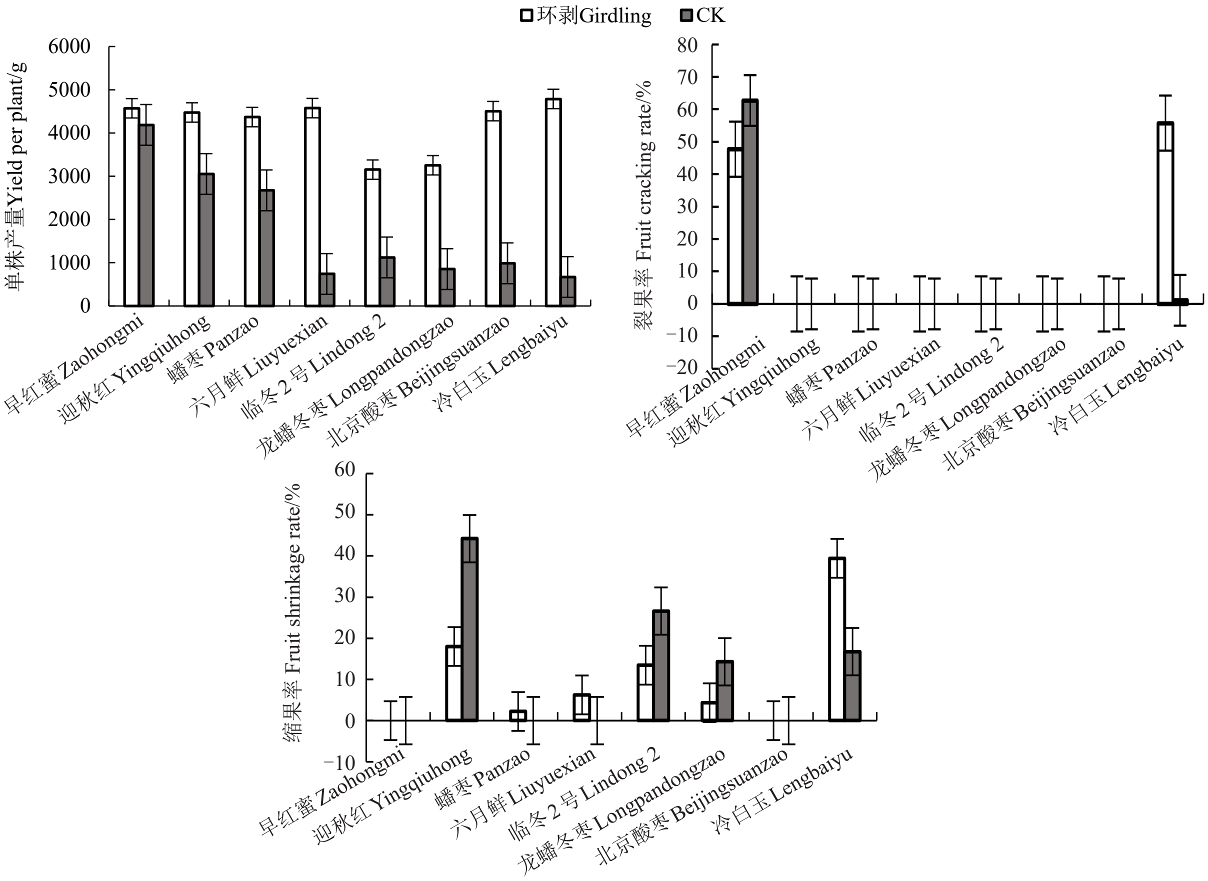


图1 单株产量、裂果、缩果情况

Fig. 1 Single plant yield, fruit cracking and fruit shrivelling conditions

2.3 环剥对果实品质的影响

2.3.1 环剥对果实外观品质的影响 由各品种果实外观品质测定结果（表2）及差异分析结果可知，环剥与未环剥所结果实单果质量差异显著，各品种均

表2 果实外观品质测定结果

Table 2 Measurement results of the fruit appearance quality

品种 Variety	处理与对照 Treatment and control	单果质量 Fruit mass/g	果实纵径 Fruit length/mm	果实横径 Fruit width/mm	果形指数 Shape index	果实侧径 Fruit lateral diameter/mm
早红蜜 Zaohongmi	环剥 Girdling	7.48±1.45*	27.85±2.00*	23.25±1.49	1.20±0.06	19.23±0.91*
	CK	6.02±0.94	26.04±1.80	22.56±1.22	1.16±0.06	21.02±0.99
迎秋红 Yingqiuhong	环剥 Girdling	13.53±2.02*	33.24±1.53	28.13±1.30	1.18±0.03	30.56±1.15*
	CK	11.37±1.23	33.69±1.35	28.72±1.65	1.18±0.04	28.17±1.64
蟠枣 Panzao	环剥 Girdling	23.27±1.24*	33.74±1.10*	37.57±1.10*	0.90±0.04*	35.87±1.23*
	CK	18.72±1.60	30.82±1.05	36.27±1.07	0.85±0.04	33.66±1.49
六月鲜 Liuyuexian	环剥 Girdling	14.97±4.40*	30.98±1.75	26.69±1.49*	1.16±0.03*	21.69±4.16
	CK	8.58±1.79	29.30±6.22	23.68±2.06	1.33±0.05	22.32±1.72
临冬2号 Lindong 2	环剥 Girdling	26.25±4.85*	33.63±2.77*	37.66±2.41*	0.89±0.06*	35.88±2.00*
	CK	15.59±1.66	29.75±1.40	29.83±2.26	1.00±0.09	28.27±1.91
龙蟠冬枣 Longpandongzao	环剥 Girdling	13.24±0.81*	26.01±4.47	29.68±1.57	0.88±0.17	28.43±0.69
	CK	10.06±2.77	23.93±3.52	27.75±2.63	0.86±0.09	26.20±3.12
北京酸枣 Beijingsuanzao	环剥 Girdling	18.76±2.24*	30.18±1.63	33.53±3.33*	0.91±0.11*	32.30±2.65*
	CK	10.62±1.05	31.31±1.33	25.62±0.88	1.22±0.05	23.82±0.65
冷白玉 Lengbaiyu	环剥 Girdling	14.82±1.76*	35.79±1.85*	28.31±1.21*	1.26±0.03*	26.47±1.27*
	CK	11.22±1.59	30.95±3.38	26.73±1.45	1.16±0.10	24.37±1.41

注：数字后的*表示在 0.05 水平上差异显著。

Note: The asterisk (*) after the numbers indicates a significant difference at the 0.05 level.

表现为环剥后单果质量大于对照（CK），增加效果为临冬2号＞北京酸枣＞六月鲜＞蟠枣＞冷白玉＞龙蟠冬枣＞迎秋红＞早红蜜，即10.66 g＞8.14 g＞6.39 g＞4.55 g＞3.60 g＞3.18 g＞2.16 g＞1.46 g。环剥后早红蜜、蟠枣、临冬2号、冷白玉的果实纵径显著大于对照，其中冷白玉和临冬2号纵径增加效果最好，分别为4.84 mm和3.88 mm，早红蜜纵径增加最小、为1.81 mm，迎秋红和北京酸枣的果实纵径小于对照，但差异不显著。蟠枣、六月鲜、临冬2号、北京酸枣、冷白玉的果实横径显著大于对照，其中以北京酸枣和临冬2号果实横径增加最大，分别为7.92 mm和7.83 mm，迎秋红果实横径小于对照，但差异不显著。蟠枣、六月鲜、临冬2号、北京酸枣、冷白玉的果形指数与对照差异显著。环剥后早红蜜、迎秋红、蟠枣、临冬2号、北京酸枣、冷白玉的果实侧径与对照差异显著，其中北京酸枣和临冬2号果实侧径增加最大，分别为8.48 mm和7.61 mm，早红蜜果实侧径显著小于对照。

综上所述，环剥可明显增加各品种果实单果质量，但对果实纵横径、侧径指标及果形指数的影响不同。

2.3.2　环剥对果实内在品质的影响　由果实内在品质测定结果（图2）可知：环剥后除临冬2号以外的其他品种的可溶性固形物含量均高于对照，提高0.90%~5.65%，其中以冷白玉增加效果最好，为5.65%，其次北京酸枣为4.83%，表明环剥可有效提高果实可溶性固形物含量。临冬2号则降低了1.3%，可能是由于其本身树势较弱，环剥降低叶片的光合效率，减少了可溶性固形物的合成。环剥后迎秋红、龙蟠冬枣、北京酸枣和冷白玉的可滴定酸含量分别增加了0.19%、0.12%、0.33%、0.44%，早红蜜、蟠枣、六月鲜和临冬2号的可滴定酸含量分别降低了0.07%、0.02%、0.21%、0.36%，表明环剥对于不同品种的可滴定酸含量的变化具有不同的作用效果。

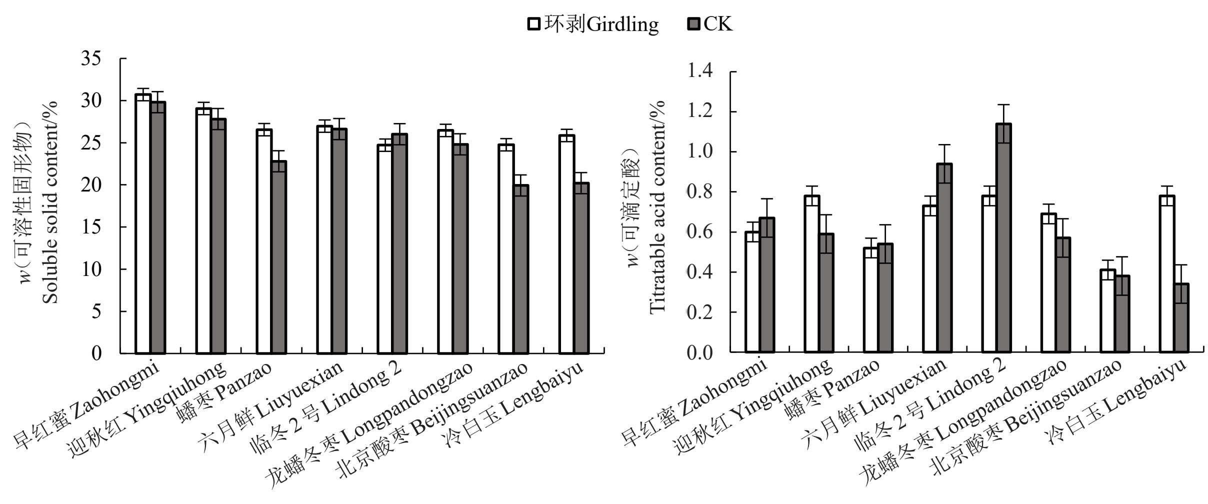


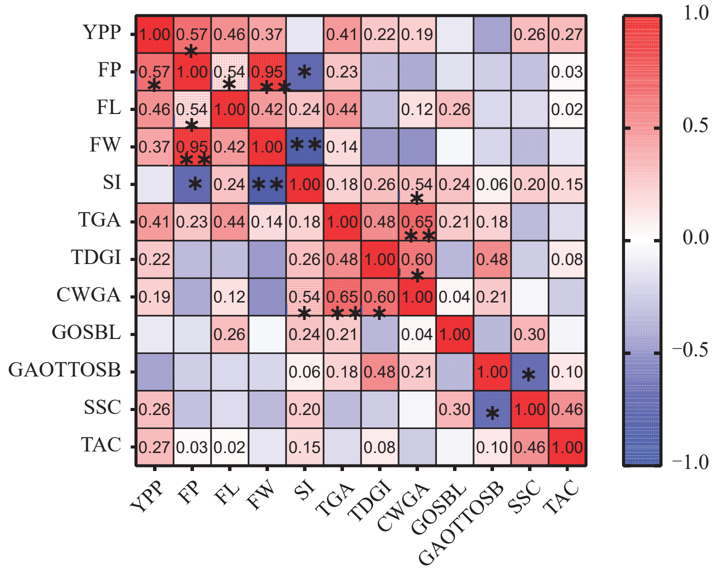
图2　可溶性固形物与可滴定酸含量

Fig. 2　Contents of soluble solids content and titratable acidity

2.4　环剥对各品种生长指标及果实品质影响的综合评价

2.4.1　相关性分析　由相关性分析（图3）可知同一品种单株产量与单果质量呈显著正相关。单果质量与果实纵径呈显著正相关，与果实横径呈极显著正相关，与果形指数呈显著负相关。果形指数与果实横径呈极显著负相关，与冠幅生长量呈显著正相关，说明果实横径是影响果形指数的主要因素，而冠幅的生长，即枣吊和二次枝长度的生长有利于增加果实横径。冠幅生长量与树高生长量呈极显著正相关，与主干生长量呈显著正相关，表明品种树势强弱与冠幅有直接的关系，冠幅的生长有利于干粗的生长。二次枝粗度生长量与可溶性固形物含量呈显著负相关，说明二次枝粗度的生长可能会降低果实可溶性固形物含量。

2.4.2　主成分分析　根据相关性分析结果，剔除相关性较低的指标（可滴定酸、二次枝长度生长量）进行主成分分析，提取特征值大于1的主成分。结果显示（表3），从10个指标中提取出4个主成分，累计



注 . * 在 0.05 级别(双尾),相关性显著。** 在 0.01 级别(双尾),相关性极显著。YPP. 单株产量;FP. 单果质量;FL. 果实纵径;FW. 果实横径;SI. 果形指数;TGA. 树高生长量;TDGI. 干粗生长量;CWGA. 冠幅生长量;GOSBL. 二次枝长度生长量;GAOTTOSB. 二次枝粗度生长量;SSC. 可溶性固形物含量;TAC. 可滴定酸含量。

Note. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is extremely significant at the 0.01 level (2-tailed). YPP. Yield per plant; FP. Fruit mass per fruit; FL. Fruit longitudinal diameter; FW. Fruit transverse diameter; SI. Fruit shape index; TGA. Tree height growth increment; TDGI. Trunk diameter growth increment; CWGA. Crown width growth increment; GOSBL. Growth increment of the length of the secondary branches; GAOTTOSB. Growth increment of the thickness of the secondary branches; SSC. Soluble solids content; TAC. Titratable acid content.

图 3 各品种生长指标及果实品质相关性分析

Fig. 3 Correlation analysis of growth indicators and fruit quality among different varieties

方差贡献率为90.187%,能代表大部分指标信息。主成分1特征值2.990,贡献率29.904%,包含单果质量与果实横径,其中果实横径载荷值最大;主成分2特征值2.395,贡献率23.94%,包含单株产量、树高生长量、干粗生长量和冠幅生长量,归纳为生长指标因子;主成分3特征值1.882,贡献率18.821%,包含可溶性固形物含量,归纳为果实内在品质因子;主成分4特征值1.751,贡献率17.513%,包含果实纵径,归纳为果形指数因子。

表 3 旋转后的主成分载荷矩阵

Table 3 Rotated Principal Component Loading Matrix

指标 Indicator	主成分1 PC1	主成分2 PC2	主成分3 PC3	主成分4 PC4
单株产量 Yield per plant	0.455	0.574	0.545	0.263
单果质量 Fruit mass	0.900	0.030	0.046	0.401
果实纵径 Fruit length	0.159	0.110	0.049	0.963
果实横径 Fruit width	0.929	−0.129	−0.044	0.304
果形指数 Shape index	−0.880	0.223	0.078	0.345
树高生长量 Tree height increment	0.091	0.789	−0.164	0.414
干粗生长量 Accretion of trunk diameter	−0.179	0.840	−0.231	−0.358
冠幅生长量 Crown width increment	−0.445	0.772	−0.064	0.151
二次枝粗度生长量 Growth increment of secondary branch diameter	−0.122	0.238	−0.839	−0.182
可溶性固形物含量 Soluable sold content	−0.242	−0.081	0.886	−0.164
特征值 Eigenvalue	2.990	2.395	1.882	1.751
方差贡献率 Contribution rate/%	29.904	23.949	18.821	17.513
累计方差贡献率 Cumulative contribution rate/%	29.904	53.852	72.674	90.187

根据主成分分析结果,以各个主成分贡献率为权重,构建8个品种环剥前后的综合评价模型:F=0.33×F1+0.27×F2+0.21×F3+0.19×F4。F为该品种综合得分,F1~F4为各主成分得分,得分高低反映各品种适合环剥的程度。结果(表4)显示,综合得分排名前3依次为环剥后的临冬2号、冷白玉和蟠枣,得分最低的为未环剥龙蟠冬枣。环剥后的各品种排名为临冬2号>冷白玉>蟠枣>六月鲜>北京酸枣>龙蟠冬枣>早红蜜>迎秋红。即各品种环剥适宜度为临冬2号>冷白玉>蟠枣>六月鲜>北京酸枣>龙蟠冬枣>早红蜜>迎秋红。

综上所述,临冬2号、冷白玉、蟠枣和六月鲜较适合环剥,早红蜜和迎秋红宜作省力化栽培品种。

表4　不同品种环剥与对照综合得分及排名

Table 4　Comprehensive scores and ranks of girdling and control groups for different varieties

品种 Variety	序号 No.	处理与对照 Treatment and control	F1	F2	F3	F4	综合得分 Comprehensive score	排名 Rank
早红蜜 Zaohongmi	1	环剥 Girdling	−0.977	0.256	1.329	−0.726	−0.119	9
	2	CK	−1.043	0.996	1.194	−1.330	−0.090	8
迎秋红 Yingqiuhong	3	环剥 Girdling	−0.650	−1.382	0.841	1.140	−0.186	10
	4	CK	−0.788	−1.166	0.380	1.245	−0.251	12
蟠枣 Panzao	5	环剥 Girdling	1.313	−0.556	0.564	0.818	0.564	3
	6	CK	1.230	−0.265	−1.205	−0.110	0.065	6
六月鲜 Liuyuexian	7	环剥 Girdling	−0.085	0.913	0.701	−0.199	0.323	4
	8	CK	−1.358	0.010	−0.422	−0.061	−0.548	14
临冬2号 Lindong 2	9	环剥 Girdling	2.066	1.403	0.342	0.545	1.237	1
	10	CK	0.317	−0.814	−0.437	−0.445	−0.289	13
龙蟠冬枣 Longpandongzao	11	环剥 Girdling	0.696	−0.064	0.290	−1.435	−0.004	7
	12	CK	0.246	−0.728	−0.901	−2.053	−0.699	16
北京酸枣 Beijingsuanzao	13	环剥 Girdling	0.838	−0.999	0.611	0.298	0.198	5
	14	CK	−0.787	−0.692	−1.445	0.433	−0.663	15
冷白玉 Lengbaiyu	15	环剥 Girdling	−0.316	1.708	0.336	1.338	0.679	2
	16	CK	−0.701	1.379	−2.177	0.541	−0.216	11

3　讨　论

较旺的树势往往会因果实吸收营养不足而品质下降，本研究结果表明，环剥对除临冬2号和龙蟠冬枣以外品种的树高生长表现出抑制效果，与前人研究结果较一致[31-32]，而对干粗、冠幅和二次枝长度及二次枝粗度的生长具有不同的影响效果，因此在栽培和生产过程中应根据环剥后各品种树体生长发育规律制定不同的施肥和管理措施。另外，虽然环剥降低裂果率和缩果率效果明显，但环剥后产量增加可能导致营养供应不足和环境问题，进而引起果实裂果和缩果的情况发生。后续应加强对矿质元素导致裂果和缩果问题的研究。

环剥处理前期可提高叶片叶绿素含量和净光合速率[33]，从而提高叶片光合作用效率，促进可溶性固形物含量增加，且影响铁（Fe）在叶片中的含量[34-35]，而铁元素作为合成叶绿素的必需元素，缺铁可能导致叶片中叶绿素含量下降。高Fe环境下，拟南芥cDNA中*NnMTP10*基因过量表达会导致输出的根质外体中过量的Fe被细胞壁截留，从而减少了Fe向地上部的运输[36]。而环剥后临冬2号可溶性固形物含量降低，分析可能是环剥后刺激了cDNA中*NnMTP10*基因过量表达，抑制了Fe向地上部的运输，进而抑制了临冬2号叶片叶绿素的合成，从而降低了叶片光合作用效率。鉴于环剥可提高临冬2号的单果质量且其本身可溶性固形物含量较高，针对临冬2号的环剥技术仍有待探索和提高。

在生产实践中更加注重环剥增产和提高果实品质的效果。本研究发现，环剥提高冷白玉产量的效果最好，其次为六月鲜，对早红蜜的增产效果最差。环剥可降低冷白玉和六月鲜的主干生长，抑制其较旺的树势，而早红蜜树势本就中庸，且单果质量增加幅度较小，因此冷白玉和六月鲜最适合环剥，早红蜜最不适合环剥。免（少）环剥是省力化栽培的主要措施，容易坐果的品种可减免环剥。迎秋红早熟且树势中庸，因此早红蜜和迎秋红是适宜省力化栽培的品种。

4　结　论

环剥可提高枣果实单株产量及单果质量，有效抑制除临冬2号和龙蟠冬枣以外其余品种树高生长，对其他生长指标、裂果率和缩果率影响不同，明显提高除临冬2号以外品种果实的可溶性固形物含量。各品种环剥适用度为临冬2号＞冷白玉＞蟠枣＞六月鲜＞北京酸枣＞龙蟠冬枣＞早红蜜＞迎秋红。其中临冬2号、冷白玉、蟠枣和六月鲜较适合环剥，早红蜜和迎秋红宜作省力化栽培品种。

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