

基于 TPA 的猕猴桃质地差异分析及贮藏性评价

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摘要:【目的】探讨不同贮藏温度下不同品种猕猴桃果实质地差异及贮藏性能。【方法】以徐香、金丽、华特、甜华特果实为试材, 通过 TPA(Texture profile analysis, 质地多面分析)测试, 测定4个品种猕猴桃果实主要质地参数, 并对质地参数进行相关性分析, 贮藏指数比较和主成分分析。【结果】在25 °C和4 °C 2个贮藏温度下, 4个猕猴桃品种果实质地间存在差异。0 d时, 徐香、金丽果实TPA硬度、弹性、内聚性、咀嚼性、回复性明显高于华特、甜华特果实, 黏性却显著低于华特、甜华特果实。采后贮藏过程中, 4个猕猴桃品种果实硬度、内聚性、弹性、咀嚼性和回复性呈下降的总态势, 黏性呈上升的总态势, 但25 °C下华特、甜华特果实各质地参数变化较为平稳, 贮藏指数接近于0。此外, 4 °C低温贮藏可以有效减缓猕猴桃果实质地变化, 延长猕猴桃贮藏期。相关性分析表明, 猕猴桃果实硬度、内聚性、弹性、咀嚼性、回复性之间呈显著或极显著正相关; 对猕猴桃 TPA 测定数据进行主成分分析, 得到2个主成分, 累计方差贡献率为92.08%。【结论】不同品种猕猴桃果实在贮藏过程中果实质地变化存在差异, TPA质地参数间多呈显著正相关, 其中TPA硬度、咀嚼性、黏性是区分华特、甜华特果实和徐香、金丽果实的重要质地参数; 结合质地参数变化可得25 °C下华特、甜华特果实质地更稳定, 更耐贮藏, 而4 °C下, 徐香更耐贮藏。

关键词:猕猴桃; 质地多面分析; 质地; 贮藏性

中图分类号:S663.4

文献标志码:A

文章编号:1009-9980(2021)09-1579-11

Texture difference and storage characteristics evaluation based on texture profile analysis in kiwifruits

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Abstract:【Objective】The texture analyzer has been widely used in the study on texture characteristics of various fruits and vegetables, especially some fruits with post-ripening habit, which have obvious flesh texture changes during softening. The quantitative analysis can be realized by accurately transforming the complex and abstract taste of fruits into specific indexes that can reflect the properties of fruit texture, such as hardness, cohesiveness, resilience, adhesiveness and gumminess. The objective of this study was to compare the postharvest texture characteristics and storage properties among different kiwifruit cultivars so as to provide reference for the study on kiwifruit texture, storage and preservation.【Methods】The fruits of Xuxiang, Jinli, White and Sweet White were used as the test materials. Enough fruits were collected at commercial harvesting period and stored at two different temperatures (25 °C and 4 °C). The fruits stored at 25 °C were tested every 3 days, and the fruits stored at 4 °C were tested every 7 days. Six fruits were randomly sampled for texture profile analysis for each variety, respectively. Flesh texture properties including hardness, adhesiveness, cohesiveness, springiness, chewiness and resilience were measured by the texture analyzer (CT3-25K), using TA/100 probe. The parameters were set as follows: the pre-test and post-test speeds were 2 mm·s⁻¹ and the mid-test speed was 1 mm·s⁻¹, within 5 seconds interval between two compressions. The trigger force was 5 g and the target value was

收稿日期:2021-02-01 接受日期:2021-05-18

基金项目:国家自然科学基金青年基金(31801836);浙江省农业(果品)新品种选育重大科技专项(2016C02052-7)

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5 mm. The data processing and analysis and picture drawing were carried out using Excel 2019 and SPSS 19 software. 【Results】During both 25 °C and 4 °C storage, the overall change trend of texture parameters of four kiwifruit varieties were basically consistent. Among them, the TPA hardness, springiness, cohesiveness, chewiness and resilience of kiwifruits decreased, and the adhesiveness increased. At harvest period, the hardness, springiness, cohesiveness, chewiness and resilience of Xuxiang and Jinli were significantly higher than those of White and Sweet White. All the texture parameters of the four kiwifruit varieties changed dramatically in the early storage at 25 °C and the change of hardness was the most obvious. Within 6 days of storage, the hardness of Xuxiang, Jinli, White and Sweet White decreased by 60.06%, 90.30%, 22.48% and 17.11%, respectively. At the end of storage, the hardness, adhesiveness, springiness and chewiness of White and Sweet White were significantly higher than those of Xuxiang and Jinli. In general, the changes of the texture parameters of White and Sweet White were relatively smooth, especially in the later stage of storage, and the adhesiveness of the two varieties was always large. At 4 °C, the hardness of White and Sweet White increased slightly after one week of storage and then decreased, and the changes of texture parameters of Xuxiang and Jinli tended to be gentle after 5 weeks of storage. At the end of softening, compared with 25 °C, the hardness of Xuxiang and Jinli increased by 27.03% and 44.73%, the springiness increased by 12.42% and 17.11%, the chewiness increased by 1.26 times and 1.40 times, separately, while the hardness, springiness and chewiness of White and Sweet White did not significantly increase. The low temperature condition at 4 °C was more favorable for the storage of Xuxiang and Jinli, which effectively improved the springiness and chewiness of kiwifruit in the later stage of storage. Correlation analysis showed that there was a significant correlation between texture parameters with four kiwifruit varieties: TPA hardness, cohesiveness, springiness, chewiness, and resilience were significantly and positively correlated, but there was mostly negative correlation between the adhesiveness and other texture parameters. In addition, most of the storage indexes of White and Sweet White were close to 0, which indicated that their textures were more stable, and they had the best storage potential under 25 °C conditions. By PCA analysis, two principal components were extracted from 6 TPA texture indexes, and cumulative variance contribution rate was 92.08%. The two principal components could be used to distinguish these four kiwifruit varieties. 【Conclusion】The TPA hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience could be used as the main indexes for the evaluation on the kiwifruit texture. Flesh texture of four kiwifruit varieties was different during storage, and most of the TPA texture parameters showed significant and positive correlations. During 25 °C storage, the texture parameters of White and Sweet White changed very slowly, they were more resistant to storage, and Xuxiang was more resistant to storage at 4 °C. The TPA hardness, chewiness and adhesiveness were the important texture parameters to distinguish White and Sweet White from Xuxiang and Jinli.

Key words: Kiwifruit; Texture profile analysis; Texture; Storage property

猕猴桃作为“水果之王”，营养丰富，附加值高，广受消费者喜爱^[1,2]。同苹果、梨、香蕉、桃、番茄一样，猕猴桃也是典型的呼吸跃变型果实^[3-5]，生理后熟期明显，采后自然状态下较难长期贮藏，易软化腐烂而影响果实食用品质和商品价值。因此在生产中延长猕猴桃贮藏期并尽可能保证其最佳口感风味就变得尤为重要。一般来讲，软枣猕猴桃不耐贮藏，美味

猕猴桃较中华猕猴桃耐贮性好^[6]，而毛花猕猴桃可在蔓上软熟，可食期长，口感独特、风味浓厚^[7]，具有极大发展潜力与研究价值。

质地是鲜食和加工食品行业用来评估产品质量和可接受性的关键品质属性^[8]，果肉的软硬、粗腻、滑爽、脆嫩等都可以统称为果肉质地；不同种猕猴桃果实质地表现出多样化^[9]，影响果蔬的货架期及消

费者的消费倾向。研究不同种猕猴桃果实采后的质地表现对于育种者及消费者来说极具价值,可帮助育种者确定新个体的最佳亲本,满足消费者对猕猴桃不同质地口感的需求。TPA(Texture Profile Analysis,质地多面分析法)作为分析食品质地特性的有效手段,已得到国内外广泛的认可与应用。猕猴桃属于浆果类水果,采后贮藏过程中果实质地变化较为明显;TPA测试可以将猕猴桃抽象的口感质地得以定量分析,能对猕猴桃果实质地进行客观准确评价^[10,11]。曹森等^[12]和马超等^[13]通过TPA测试分别探讨了不同浓度1-MCP和臭氧处理对猕猴桃果实后熟质地的影响,结果表明,1-MCP和臭氧均能更好地维持果实的质构性能,并确定了最佳处理浓度。猕猴桃果实感官品评差异较大,且目前对于不同种猕猴桃果实质地的研究相对较少,基于TPA法的猕猴桃果实质地差异尚未明确,相关试验是围绕一个品种多个时期或多个品种一个时期展开的,均未对

不同种猕猴桃不同时期果肉质地变化进行比较分析。笔者在本研究中采用徐香、金丽、华特和甜华特4个不同品种猕猴桃果实为试材,通过TPA法研究25℃和4℃贮藏下果实采后质地变化规律,分析各质地参数之间相关性,并基于TPA各参数变化对不同品种猕猴桃贮藏性做出评价,为明确不同品种猕猴桃果实采后质地变化及耐贮性提供理论支持。

1 材料和方法

1.1 材料

试验材料为商业采收期采摘的4个品种猕猴桃果实,即徐香、金丽、华特、甜华特,均采于2019年(表1)。徐香猕猴桃为浙江省江山市主栽的美味猕猴桃品种,品质好,价格适中,市场需求大;金丽猕猴桃是从浙江省丽水市高山地区成功选育出的中华黄肉猕猴桃品种,果型大而美,酸甜可口^[14];华特猕猴桃是浙江省农业科学院从野生毛花猕猴桃中成功选

表1 不同品种猕猴桃采收期果实在性状比较

Table 1 Comparison on fruit characters of different kiwifruit varieties at harvest period

材料 Materials	种系 Species	果实形状 Fruit shape	单果质量 Single fruit weight/g	横径 Transverse diameter/mm	纵径 Longitudinal diameter/mm	w(可溶性固形物) Soluble solids content/%	采样时间 Sampling time	采样地点 Sampling place
徐香 Xuxiang	美味 <i>Actinidia deliciosa</i>	圆柱形 Cylindrical	82.80±6.33	49.25±2.37	63.89±4.70	7.23±0.86	10.30	浙江仙居 Xianju, Zhejiang
金丽 Jinli	中华 <i>Actinidia chinensis</i>	鸭卵形 Duck ovate	102.74±9.59	54.44±3.26	70.89±3.19	7.83±0.94	10.16	浙江丽水 Lishui, Zhejiang
华特 White	毛花 <i>Actinidia eriantha</i> Benth	细长圆柱形 Elongated cylindrical	58.35±7.70	34.74±2.56	82.75±4.93	12.32±0.63	10.30	浙江仙居 Xianju, Zhejiang
甜华特 Sweet White	毛花 <i>Actinidia eriantha</i> Benth	细长圆柱形 Elongated cylindrical	60.44±6.31	35.39±1.75	76.37±2.59	13.11±0.51	10.30	浙江仙居 Xianju, Zhejiang

育出的商业化栽培种^[15],甜华特猕猴桃则为该团队随后选育出的第2代新品,口感更甜。果实采收当天运回浙江省农业科学院园艺所实验室,散去田间热后挑选大小均匀、成熟度一致、无机械损伤的果实,放在纸箱中,用保鲜膜包装后分别放置在25℃和4℃条件下进行贮藏实验,相对湿度为(90±5%)。贮藏期间,25℃贮藏组每3 d取样一次,4℃贮藏组每周取样一次进行TPA测试,果实过熟失去商品价值时停止取样。

1.2 果实质构参数的测定

样品准备:为保证取样均匀,于果实赤道面处将果实横切成厚度约为1 cm厚的薄片,从中心柱处四等分割成1 cm³的正方体;每个单果测试4个点,每次随

机抽取6个猕猴桃样品用于测试,结果取平均值。

质构特性测试方法:参考卢丹等^[16]并作适当修改。将切好的果肉样品置于TAXT PLUS物性分析仪(英国Stable Micro System公司)测试平板上,选择TA/100压盘探头,直径为40 mm,采用TPA模式。参数设置如下:测前速率2 mm·s⁻¹,测试速率1 mm·s⁻¹,测后上行速率2 mm·s⁻¹,数据频率50点·s⁻¹,两次压缩间停顿5 s,触发点负荷5 g,目标值5 mm。由质地特征曲线得到评价猕猴桃果实贮藏期间果肉状况的质地参数:TPA硬度(hardness)、内聚性(cohesiveness)、弹性(Springiness)、黏性(adhesiveness)、咀嚼性(chewiness)、回复性(resilience)等;结果由Stable Microsystems公司提供的软件计算得到。猕猴桃果实

TPA典型质地特征曲线如图1所示。

1.3 数据处理

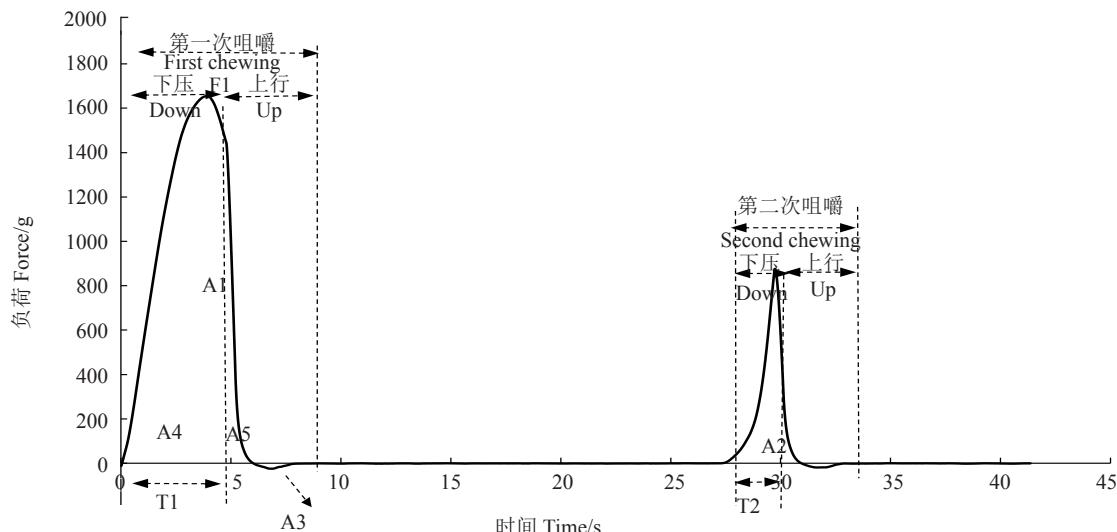
数据采用Excel软件(Microsoft office 2019)进行处理及绘图,利用SPSS 19.0软件进行方差分析(ANOVA)、Pearson相关性分析及PCA分析。

2 结果与分析

2.1 不同贮藏温度下猕猴桃采后质地参数的变化

2.1.1 硬度变化 硬度感官定义为牙齿挤压样品所

需的最大力量;在质构曲线中表示为第一压缩循环的最大负荷值,如图1 F1所示。采收时,4个品种猕猴桃果实硬度分别为10 650.5755、956.25、797.75 g,徐香、金丽果实硬度极显著高于华特、甜华特($p < 0.01$)。25 °C贮藏下,徐香、金丽各时期果实硬度差异性显著,其中采后3~6 d内果实硬度急剧下降,二者硬度分别下降了56.15%、87.37%;而华特、甜华特果实硬度下降缓慢,且在贮藏中后期保持相对稳定(图2-A)。贮藏结束时,徐香、金丽、华特和甜华特



F1. 第一次压缩循环的最大力量峰值;A1. 第一次压缩循环的正峰面积;A2. 第二次压缩循环的正峰面积;A3. 第一次压缩的负峰面积;A4. 第一次压缩循环中向下挤压阶段的正相区;A5. 第一次压缩循环中向上返回阶段的正相区;T1. 第一次压缩循环中从接触样品开始至目标值处所用的时间;T2. 第二次压缩循环中从接触样品开始至目标值处所用的时间。

F1. Peak force in the first compression cycle; A1. The positive area of the first compression cycle; A2. The positive area of the second compression cycle; A3. The negative area of the the first cycle; A4. Positive area of downward compression stage in first cycle; A5. Positive area of upward return stage in first cycle; T1. Time from the probe contacting the sample to the target value in the first cycle; T2. Time from the probe contacting the sample to the target value in the second cycle.

图1 猕猴桃TPA质地特征曲线

Fig. 1 Typical TPA curve of kiwifruit

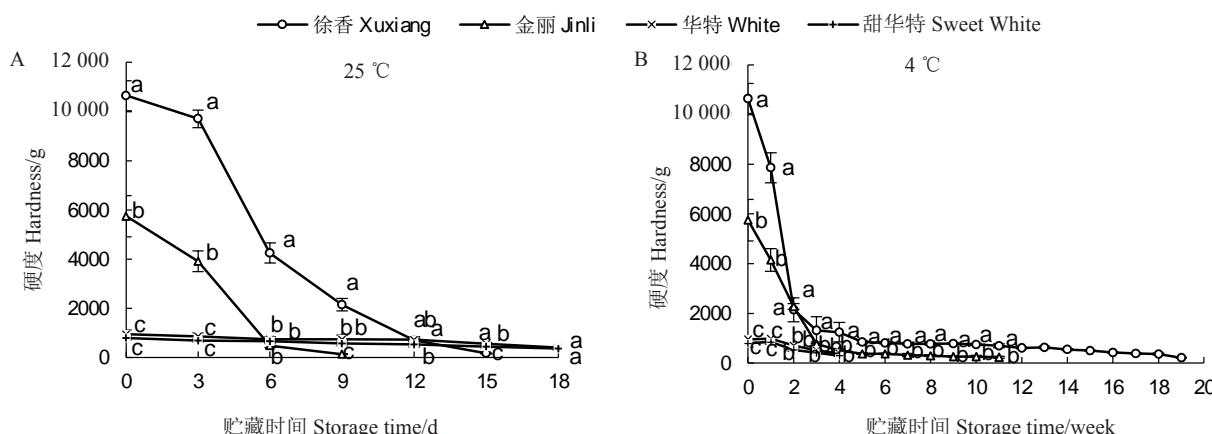


图2 不同贮藏温度下猕猴桃果实硬度的变化

Fig. 2 Changes of hardness of kiwifruit at different storage temperatures

果实硬度较0 d时分别下降了98.38%、97.18%、57.84%、54.34%,华特、甜华特果实硬度均极显著高于徐香、金丽,其中华特果实硬度可达徐香的2.34倍。4 °C贮藏下,徐香、金丽在采后前2周内果实硬度下降最快而后缓慢降低(图2-B),贮藏末期二者硬度分别为25 °C贮藏末期果实的1.27、1.53倍;华特、甜华特果实硬度在贮藏1周后开始显著降低($p < 0.05$),贮藏结束时其硬度较25 °C贮藏果实有所下降,但仍显著高于徐香、金丽。

2.1.2 黏性变化 黏性感官定义为克服食品表面同其他物质表面接触之间的吸引力所需要的能量,反映了食物对上腭、牙齿、舌头等接触面黏着的性质;在图1中以第一次压缩过程中产生的负峰面积A3表示。0 d时,徐香、金丽果实与华特、甜华特果实黏性之间存在较大差异,其黏性分别为19.33、20.25、37.25、40.5。在25 °C和4 °C贮藏条件下,4个品种猕猴桃采后贮藏期间果实黏性总体均呈上升的趋势

(图3-A、图3-B)。徐香、金丽果实黏性在贮藏前期迅速增加,后期趋于平缓,而华特、甜华特果实黏性在整个贮藏期内变化幅度不大(变动范围为6.71%~16.51%),且始终极显著高于徐香、金丽果实黏性($p < 0.01$)。与25 °C贮藏相比,4 °C低温贮藏明显推迟了徐香、金丽果实贮藏前期黏性的增加,特别是金丽在贮藏前6周始终保持较低的黏性,直到第7周才迅速增加;而徐香果实黏性在贮藏5周后便长期趋于稳定,且其黏性普遍高于金丽,华特、甜华特果实黏性变化不大。

2.1.3 内聚性变化 内聚性感官定义为样品内部的收缩力,收缩力越大,内聚性越强;在图1中以2次压缩过程中产生的硬度功的比值(面积A2/面积A1)表示。由图4-A和图4-B可知,两种贮藏温度下,4个品种猕猴桃果实内聚性总体均呈下降的趋势。采收时不同品种猕猴桃果实内聚性也有较大差异,其中,徐香果实内聚性最高,为0.21,甜华特最低,为

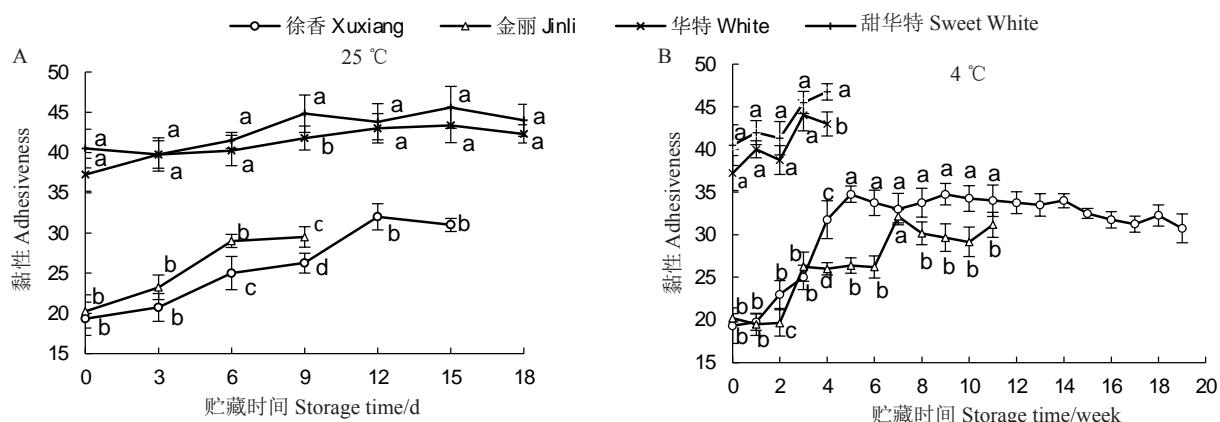


图3 不同贮藏温度下猕猴桃果实黏性的变化

Fig. 3 Changes of adhesiveness of kiwifruit at different storage temperatures

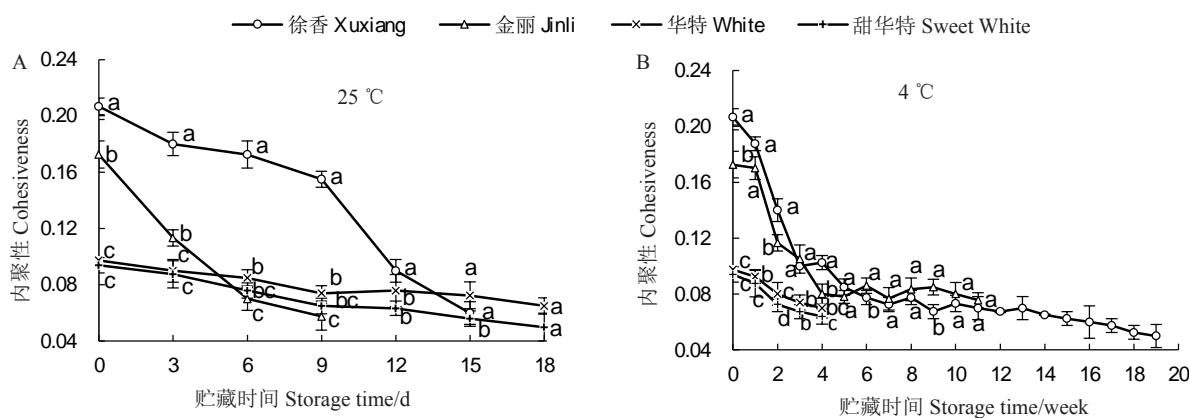


图4 不同贮藏温度下猕猴桃果实内聚性的变化

Fig. 4 Changes of cohesiveness of kiwifruit at different storage temperatures

0.09。25 ℃贮藏下,金丽果实内聚性呈直线型下降,贮藏前3 d,其内聚性从0.17下降至0.11,下降了34.3%;徐香果实内聚性在贮藏前期下降较慢,9~12 d内下降最多,下降了30.95%;而华特、甜华特果实内聚性在整个贮藏期间降幅均较小,贮藏结束时二者内聚性较0 d时分别降低了33.33%、39.53%。4 ℃下,徐香、金丽果实内聚性变化较一致,均在贮藏前期快速下降而后缓慢降低,金丽在贮藏6周后内聚性便高于徐香,华特在整个贮藏期间内聚性始终高于甜华特。贮藏末期,徐香、金丽、华特、甜华特果实内聚性分别为0.050、0.076、0.070、0.064,其中,金丽果实内聚性较25 ℃贮藏末期果实极显著增加($p < 0.01$),增加了31.68%,其他品种猕猴桃果实内聚性未见显著性变化。

2.1.4 弹性变化 弹性感官定义为食物在第一咬结

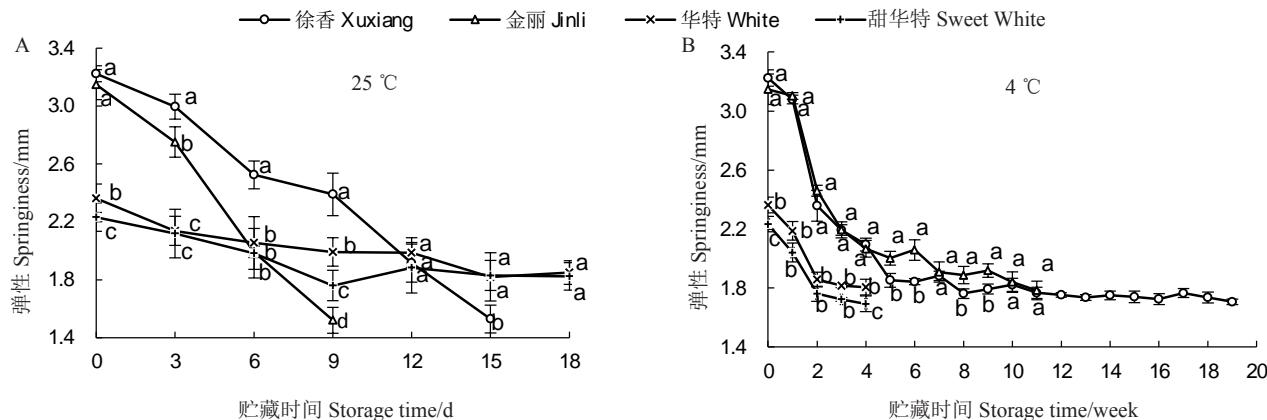


图5 不同贮藏温度下猕猴桃果实弹性的变化

Fig. 5 Changes of springiness of kiwifruit at different storage temperatures

2.1.5 咀嚼性变化 咀嚼性表示将固体食物咀嚼到可以吞咽的状态所需要的能量,通常以硬度、内聚性、弹性三者的乘积表示。采收时,徐香果实咀嚼性最高,其次为金丽,华特、甜华特果实咀嚼性极显著低于前两者($p < 0.01$);随着贮藏时间的延长,4个品种猕猴桃果实咀嚼性均不断降低,其变化与硬度变化趋势最为相似(图6)。25 ℃下,徐香、金丽果实咀嚼性分别由5939、3116 g·mm急剧下降至22、18 g·mm,二者均在采后3~6 d内降幅最为明显。华特、甜华特果实咀嚼性则缓慢下降,贮藏末期,二者咀嚼性分别为62、54 g·mm,显著高于徐香、金丽果实咀嚼性($p < 0.05$)。4 ℃下,各时期不同品种猕猴桃果实咀嚼性大小始终为:徐香>金丽>华特>甜华特。徐香、金丽果实在贮藏前期其咀嚼性均急剧

下降,金丽在贮藏3周时其咀嚼性已达可食程度,为147.25 g·mm;华特、甜华特果实咀嚼性在贮藏1~2周内降幅最大,这是果实在低温下硬度、内聚性、弹性综合作用的结果。贮藏末期,徐香、金丽咀嚼性分别是25 ℃贮藏末期果实的2.31、3.19倍,而华特、甜华特咀嚼性则有所降低,分别降低了17.80%、17.09%。4 ℃贮藏明显推迟了猕猴桃果实咀嚼性的降低,显著提高了贮藏末期徐香、金丽果实的咀嚼性,延长了果实食用期。

2.1.6 回复性变化 果肉组织受到压缩时快速恢复变形的能力即为猕猴桃的回复性,在图1中以第1次压缩过程中的可恢复功与硬度功的面积比(A5/A1)表示。25 ℃贮藏下,徐香、金丽果实回复性不断降低,华特、甜华特果实回复性变化缓慢,但总体均下

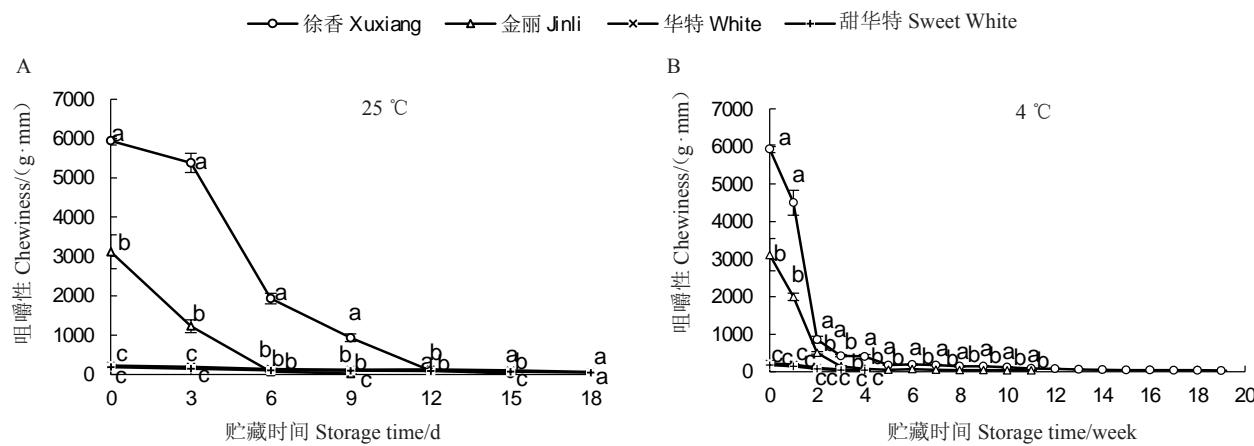


图6 不同贮藏温度下猕猴桃果实咀嚼性的变化

Fig. 6 Changes of chewiness of kiwifruit at different storage temperatures

降(图7-A);徐香果实回复性在贮藏3~6 d内下降最多,下降了30.56%,金丽果实回复性在贮藏0~3 d内降幅最大,下降了42.53%;贮藏末期,徐香、金丽、华特和甜华特回复性分别为0.025、0.023、0.029、0.024,华特果实回复性显著高于其他品种猕猴桃。4 °C下,除徐香猕猴桃在贮藏第4周时回复性急剧上

升外,其他品种猕猴桃回复性均呈下降趋势,且徐香果实回复性始终高于金丽,华特果实回复性始终高于甜华特(图7-B);贮藏结束时,华特、金丽果实回复性显著高于徐香、甜华特,其中金丽果实回复性为0.028,较25 °C贮藏末期果实提高了21.74%,4 °C低温贮藏显著减缓了金丽猕猴桃贮藏后期果肉回复性

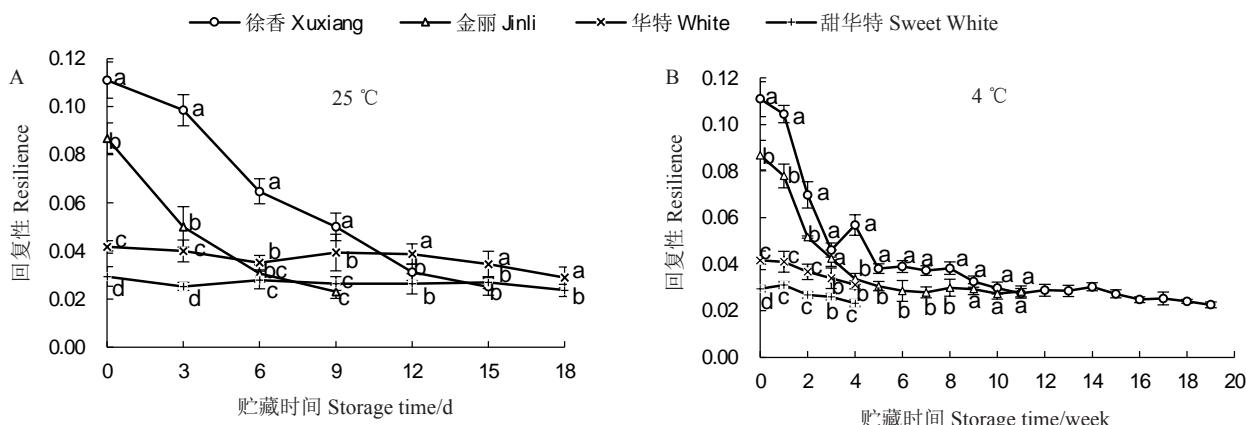


图7 不同贮藏温度下猕猴桃果实回复性的变化

Fig. 7 Changes of resilience of kiwifruit at different storage temperatures

的损失。

2.2 4种猕猴桃果实质构参数相关性分析

4个品种猕猴桃果实在贮藏过程中果肉TPA质地参数间相关性如表2所示。猕猴桃果实硬度、内聚性、弹性、咀嚼性、回复性之间相关性显著,弹性与黏性之间相关性因品种而异。徐香、金丽果肉各质地参数间相关性极显著($p < 0.01$),徐香相关性更强($r > 0.8$),二者果肉黏性与弹性之间均呈极显著负相关,相关系数分别为-0.872和-0.716;华特、甜华特果肉黏性与弹性之间相关性不显著($p >$

0.05),甜华特果肉各质地参数间相关性相对较弱。以上说明了随着猕猴桃果肉硬度的下降,其内聚性、弹性、咀嚼性、回复性亦逐渐减小。内聚性、弹性和回复性反映了果肉细胞间组织结构和分子间结合力,说明果肉硬度与果实细胞结构及内含物含量、状态密切相关;果肉硬度是最能直接反映果实咀嚼性的重要指标,4个品种猕猴桃果肉硬度与咀嚼性之间相关系数 r 分别为0.984、0.939、0.868、0.848,相关程度均为强相关。综合以上分析,TPA质地多面分析法可以较好地反映猕猴桃果肉质地特性,4个品

表 2 4 种猕猴桃果实 TPA 质地参数之间相关性

Table 2 Correlation among texture parameters of four kiwifruit varieties

参数 Parameter	品种 Variety	硬度 Hardness	内聚性 Cohesiveness	黏性 Adhesiveness	弹性 Springiness	咀嚼性 Chewiness	回复性 Resilience
硬度 Hardness	徐香 Xuxiang	1					
	金丽 Jinli		1				
	华特 White			1			
	甜华特 Sweet White				1		
内聚性 Cohesiveness	徐香 Xuxiang		0.927**	1			
	金丽 Jinli		0.749**		1		
	华特 White		0.590**			1	
	甜华特 Sweet White		0.575**				1
黏性 Adhesiveness	徐香 Xuxiang		-0.863**	-0.818**	1		
	金丽 Jinli		-0.707**	-0.670**		1	
	华特 White		-0.698**	-0.529**			1
	甜华特 Sweet White		-0.453**	-0.338*			
弹性 Springiness	徐香 Xuxiang		0.913**	0.898**	-0.872**	1	
	金丽 Jinli		0.832**	0.745**	-0.716**		1
	华特 White		0.494**	0.601**	-0.307		1
	甜华特 Sweet White		0.365*	0.492**	-0.347		1
咀嚼性 Chewiness	徐香 Xuxiang		0.984**	0.955**	-0.859**	0.930**	1
	金丽 Jinli		0.939**	0.735**	-0.740**	0.891**	
	华特 White		0.868**	0.734**	-0.625**	0.735**	
	甜华特 Sweet White		0.848**	0.531**	-0.485**	0.565**	
回复性 Resilience	徐香 Xuxiang		0.949**	0.926**	-0.870**	0.888**	0.963**
	金丽 Jinli		0.693**	0.677**	-0.623**	0.675**	0.732**
	华特 White		0.662**	0.717**	-0.730**	0.555**	0.776**
	甜华特 Sweet White		0.676**	0.505**	-0.326*	0.364*	0.597**

注: *指 $p < 0.05$, 表示差异性显著; **指 $p < 0.01$, 表示差异性极显著。

Note: * Significant at 0.05 levels; ** Significant at 0.01 levels.

种猕猴桃果实质地参数间大多呈极显著正相关。

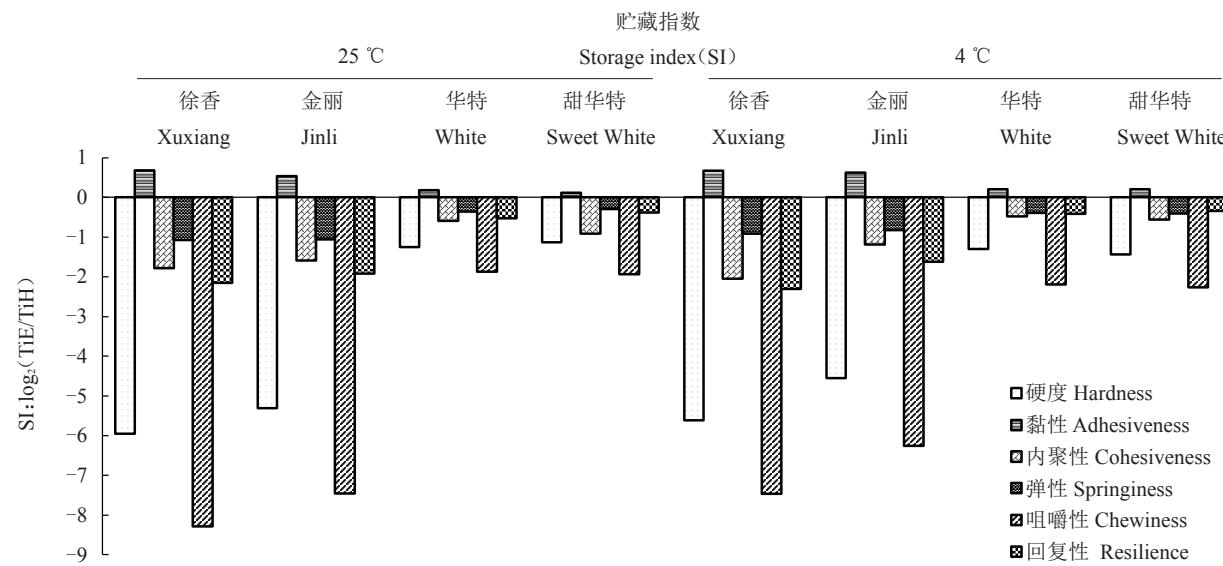
2.3 基于 TPA 质地参数的贮藏指数比较

前人曾对苹果、蓝莓进行了贮藏指数 SI (Storage Index) 的测定^[16-17], 以评估不同品种果实的贮藏潜力。贮藏指数, 最初是为了研究苹果果实采后的质地动态而定义的^[16], 以每个评估参数在 2 个阶段 (一般为贮藏前、后) 的比率的对数形式表示。SI > 0, 表示贮藏期间质地特征的增强, SI < 0, 表示质地性能的缺失, SI = 0 则表明果实结构性状保持稳定。据此, 笔者通过以上 TPA 质地参数计算得出本试验中 4 个品种猕猴桃果实的贮藏指数, 由图 8 可以很直观地了解到不同品种猕猴桃果实贮藏过程中果肉质地的变化。不论是 25 ℃ 贮藏还是 4 ℃ 贮藏, 4 个品种猕猴桃果实硬度和咀嚼性损失均最为严重 ($-8 < SI < -4$), 果肉黏性质地都有所增强, 这与 2.1 中结论一致。其中, 华特、甜华特果实贮藏指数较接近于 0, 特别是在黏性、内聚性、回复性等反映果肉细胞结构和分子间结合力指标上, 表明华特、甜华特果肉质地更稳定, 贮藏潜力较好; 如 25 ℃ 下华特

SI_{内聚性} 仅为徐香的 5.39%, SI_{回复性} 仅为徐香 13.02%, 相比之下, 徐香、金丽果实采后果肉质地损失更加严重, 贮藏潜力较差。4 ℃ 下, 徐香、金丽果实 SI_{硬度}、SI_{咀嚼性} 较 25 ℃ 贮藏相比均明显增加, 特别是金丽果实 SI_{内聚性}、SI_{弹性} 较 25 ℃ 贮藏分别增加了 25.05%、22.02%, 表明 4 ℃ 低温贮藏可明显减轻徐香、金丽果肉硬度、咀嚼性的损失, 更好地维持果肉内聚性、弹性。此外, 华特、甜华特果实质地特性虽较徐香、金丽更稳定, 但实际中后两者贮藏时间更久, 可能是采收期及贮藏期不同材料间的生理差异较大导致。由此可见, 贮藏指数虽然可以作为比较不同品种果实贮藏潜力的代表指标, 但并不等同于贮藏性。

2.4 猕猴桃不同质构参数的 PCA

通过对 4 个品种猕猴桃果实质构的 6 个特征指标进行主成分分析, 得到 2 个主成分 (图 9-A), 累计方差贡献率达 92.08%。其中, 硬度与咀嚼性在 PC1 正坐标处具有较高载荷, 距离最近, 表示硬度和咀嚼性可以作为第 1 主成分的代表指标, 且二者相关程度最高; 黏性在 PC2 负坐标处具有较大载荷, 表示第



图中 TiH 为收获时所测的质地参数, TiE 为贮藏结束时测得的相同参数值。

The TiH is the value of the texture parameter measured at harvest, and TiE is the value of the same parameter measured at the end of storage.

图8 4个猕猴桃品种果实质地动态的贮藏指数

Fig. 8 Storage index (SI) for the fruit texture dynamics of four kiwifruit cultivars

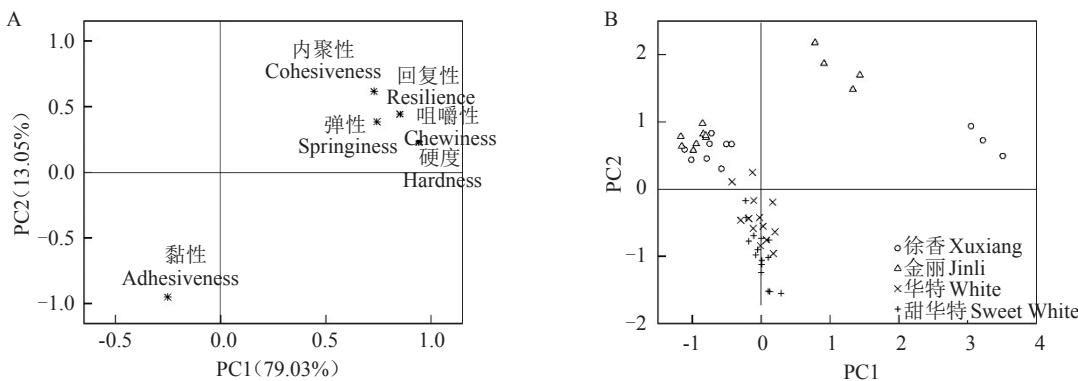


图9 猕猴桃 TPA 质地主成分因子载荷(A)及主成分得分(B)图

Fig. 9 PCA loadings (A) and scores charts (B) for TPA parameters of kiwifruit

2主成分主要反映了果实的黏性,且其与其他指标间相关程度较弱。并由此建立了2个主成分表达式： $F_1=0.466X_1+0.505X_2+0.031X_3+0.165X_4+0.479X_5+0.162X_6$, $F_2=-0.329X_1-0.985X_2+0.291X_3+0.072X_4-0.348X_5+0.111X_6$, 其中 $X_1, X_2, X_3, X_4, X_5, X_6$ 分别代表硬度、黏性、内聚性、弹性、咀嚼性、回复性的标准化值。将猕猴桃贮藏过程中对应的质地参数代入以上两个公式,得到4个品种猕猴桃果实的主成分得分(图9-B),且这2种主成分可以很好地把这4种猕猴桃区分开来。徐香、金丽猕猴桃主成分得分主要分布在PC1轴两侧及PC2正半轴处,而华特、甜华特猕猴桃则主要分布在PC1原点附近及PC2负半轴处,说明贮藏期间徐香、金丽果实硬度、咀嚼性

变化幅度大,华特、甜华特波动较小,且华特、甜华特果实黏性有别于徐香、金丽果实。

3 讨 论

TPA测试已成熟运用到苹果、梨、葡萄等水果贮藏期品质的评价中,果实采后贮藏过程中伴随着果肉质地的变化,TPA测试可以反映果肉组织的机械特性;明确果实采后质地特征变化,正确评价果实的贮藏能力,具有重要的基础意义。本试验中4个品种猕猴桃果实贮藏期间果肉硬度、弹性、内聚性、回复性、咀嚼性总体呈下降趋势,黏性呈上升的总态势,这与吴曼丹等^[18]在中华和美味猕猴桃上的研究结果一致。采收时,华特、甜华特果实质地(特别是

硬度、咀嚼性)较徐香、金丽有较大差异,与其低淀粉积累特性有一定关系^[19],25 ℃贮藏下华特、甜华特果实硬度下降相对平缓,贮藏期最长,这与前人在华特果实上的研究结果一致。果肉组织的机械特性与果肉细胞组织结构及内含物(如淀粉、纤维素、果胶)成分、状态有关^[20],特别是细胞壁果胶在诸多果蔬的结构特性方面发挥了重要作用,Huang等^[21]研究表明,较高的果胶含量可导致更高的硬度、黏性、弹性和咀嚼性,贮藏末期华特、甜华特果实硬度、黏性、弹性、咀嚼性等质地属性显著不同于徐香、金丽果实,表明4个品种猕猴桃果实生理结构及内含物存在较大差异。相关性分析表明,猕猴桃果实TPA硬度、弹性、内聚性、咀嚼性、回复性之间呈极显著正相关。后熟过程中,猕猴桃硬度不断降低,咀嚼性随之下降;同时,胞间由紧密变得松散,细胞间的连接紧密程度逐渐弱化,导致果实内聚性、回复性、弹性下降。由于猕猴桃具有流变特性^[22],在外力作用时表现出黏性;受压时,细胞内的液体发生渗透和黏滞,导致黏性有所增加。本试验所用探头横截面面积较大,硬果期时果肉细胞致密,因此样品与探头和测试平板间吸附力较小;软化时,果肉变得柔软多汁,返程过程中探头克服与样品间的吸附力增加,导致做功增加,黏性上升。故本试验中,猕猴桃果实硬度与内聚性、弹性、咀嚼性等呈显著正相关,与黏性呈显著负相关,且徐香、金丽果实间的相关性更强,这与张杨等^[23]结论一致;而与曹森等^[12]和马超等^[13]结果不同,可能是试验材料及操作方法不同导致。

果实软化实际上是果肉复合组织机械强度(弹性)降低的结果^[24],这在苹果^[25]、梨^[26]、葡萄^[27]等水果中得到了验证;Terasaki等^[28]发现在猕猴桃软化过程中弹性是持续下降的,并指出货架期短的品种在收获后弹性立即下降,果实软化速度呈指数增长。与本试验结果相一致:25 ℃贮藏下,特别是金丽猕猴桃各时期弹性变化均达到极显著差异($p < 0.01$),贮藏期最短。相比之下,毛花猕猴桃华特、甜华特果实各时期质地变化较为平缓,贮藏期更长。此外,华特、甜华特果实各贮藏指数更接近于0,其中 $|SI_{\text{黏性}}|$ 最小,说明果实黏性的变异幅度是最小的,变动范围在0%~12%。综合以上得出,25 ℃下,华特、甜华特贮藏性能最好,且贮藏期间黏性最为稳定;而4 ℃低温条件明显减轻了徐香、金丽果肉内聚性、弹性的损失,提高了贮藏末期果实的硬度与咀嚼性,有效延长

了贮藏期,此条件下,徐香贮藏性能最佳,贮藏期长达19周;金丽次之,可贮藏11周;华特、甜华特仅贮藏了4周。由此可见,猕猴桃贮藏性可能因品种及贮藏环境而异。耐贮性始终是浆果类果实生产经营中不容忽视的问题,特别是猕猴桃这种常温下极易软化的水果;本文中所涉及的贮藏指数虽不能完全代替贮藏性能,但在生产实践中仍具参考价值,采后管理中,可以参考每个品种的具体质地特性采取最佳贮藏方法,育种者也可以充分利用果实的质地属性选择最佳亲本,以提高新品种的贮藏性能。

4 结 论

笔者在本研究中通过对不同贮藏温度下不同品种猕猴桃果实进行TPA质地特性及贮藏性评价,结果表明,猕猴桃果实TPA各质地参数间相关性显著;25 ℃下,华特、甜华特最耐贮藏,4 ℃下,徐香最耐贮藏。PCA分析得出硬度、咀嚼性和黏性是区分华特、甜华特猕猴桃和徐香、金丽猕猴桃的重要质地参数。此外,华特、甜华特猕猴桃采后果实质地更稳定。

参考文献 References:

- [1] RICHARDSON D P, ANSELLI J, DRUMMOOD L N. The nutritional and health attributes of kiwifruit: A review[J]. European Journal of Nutrition, 2018, 57(8): 1-18.
- [2] SIVAKUMARAN S, HUFFMAN L, SIVAKUMARAN S, DRUMMOOD L. The nutritional composition of Zespri®; Sun Gold kiwifruit and Zespri®; sweet green kiwifruit[J]. Food Chemistry, 2016, 238: 195-199.
- [3] 梁泽,王蕾,杨明依,罗自生,徐艳群,李莉.定量蛋白质组学在果蔬采后商品化处理中的研究现状及进展[J].浙江大学学报(农业与生命科学版),2020,46(1):8-16.
LIANG Ze, WANG Lei, YANG Mingyi, LUO Zisheng, XU Yan-qun, LI Li. Status and progress in quantitative proteomic study of postharvest fruits and vegetables during commercial treatment[J]. Journal of Zhejiang University(Agriculture and Life Sciences), 2020, 46(1): 8-16.
- [4] THAKUR A K, SINGH A, PANDEY M. Inhibition of respiration, ethylene synthesis and cell wall softening enzyme activity in tomato fruit during ripening by ethanol[J]. Advances in Horticultural Science, 2000, 14(4): 176-181.
- [5] ZHU L, WANG W, SHI J, ZHANG W, SHEN Y, DU H, WU S. Hydrogen sulfide extends the postharvest life and enhances antioxidant activity of kiwifruit during storage[J]. Journal of the Science of Food and Agriculture, 2014, 94(13): 2699-2704.
- [6] 方金豹,钟彩虹.新中国果树科学研究70年:猕猴桃[J].果树学报,2019,36(10):1352-1359.
FANG Jinbao, ZHONG Caihong. Fruit scientific research in New China in the past 70 years: Kiwifruit[J]. Journal of Fruit Science, 2019, 36(10): 1352-1359.
- [7] 张慧琴,谢鸣,肖金平,周利秋,宋根华.毛花猕猴桃‘华特’果实发育特性研究[J].果树学报,2015,32(2):238-246.
ZHANG Huiqin, XIE Ming, XIAO Jinping, ZHOU Lixiu,

- SONG Genhua. Characterization of fruit development of the diploid kiwifruit, *Actinidia eriantha* 'White' [J]. Journal of Fruit Science, 2015, 32(2):238-246.
- [8] OROIAN M, PADURET S, AMARIEI S, GUTT G. Chemical composition and temperature influence on honey texture properties[J]. Journal of Food Science and Technology, 2016, 53(1):431-440.
- [9] SCHRÖDER R, VIRGIN- HARRIS T, BERESFORD M K, HALLETT I C. Kiwifruit texture - a pilot study[J]. Acta Horticulturae, 2018(1218):171-176.
- [10] 许牡丹,黄萌,马可纯,周丹,曹晴. 基于数学统计分析的猕猴桃品质评价指标筛选[J]. 食品科技, 2016, 41(6):310-314.
- XU Mudan, HUANG Meng, MA Kechun, ZHOU Dan, CAO Qing. Selection of kiwifruit quality evaluation indexes based on mathematical statistic[J]. Food Science and Technology, 2016, 41(6):310-314.
- [11] 卢丹,赵武奇,曾祥媛,吴妮,高贵田,张清安,张宝善,雷玉山. ‘海沃德’猕猴桃应力松弛特性与品质关系[J]. 中国农业科学, 2019, 52(14):2548-2558.
- LU Dan, ZHAO Wuqi, ZENG Xiangyuan, WU Ni, GAO Guitian, ZHANG Qingan, ZHANG Baoshan, LEI Yushan. The correlation between the stress relaxation characteristics and the quality of 'Haiwode' kiwifruit[J]. Scientia Agricultura Sinica, 2019, 52(14):2548-2558.
- [12] 曹森,李越,和岳,黄亚欣,张起,王瑞. 1-MCP对猕猴桃后熟质地品质的临界浓度研究[J]. 保鲜与加工, 2019, 19(6):27-33.
- CAO Sen, LI Yue, HE Yue, HUANG Yaxin, ZHANG Qi, WANG Rui. Study on the 1-MCP critical concentration on post-harvest ripening texture quality of kiwifruit[J]. Storage and Process, 2019, 19(6):27-33.
- [13] 马超,赵治兵,吴文能,曹森,陈泰安,王瑞. 不同浓度臭氧处理对采后猕猴桃货架期间质构性能的影响[J]. 保鲜与加工, 2018, 18(1):1-7.
- MA Chao, ZHAO Zhibing, WU Wenneng, CAO Sen, CHEN Taian, WANG Rui. Effects of different concentration of ozone on textural properties of kiwifruit during shelf life[J]. Storage and Process, 2018, 18(1):1-7.
- [14] 徐美青,叶秀萍,林华莉,江旭敏. 浅谈‘金丽’黄肉猕猴桃生态栽培管理技术[J]. 山西农经, 2020(13):97-98.
- XU Meiqing, YE Xiuping, LIN Huali, JIANG Xumin. Brief discussion on ecological cultivation and management techniques of 'Jinli' yellow-fleshed kiwifruit[J]. Shanxi Agricultural Economy, 2020(13):97-98.
- [15] 谢鸣,吴延军,蒋桂华,张庆朝,张慧琴,彭尚进,刘康猛. 大果毛花猕猴桃新品种‘华特’[J]. 园艺学报, 2008, 35(10):1555.
- XIE Ming, WU Yanjun, JIANG Guihua, ZHANG Qingchao, ZHANG Huiqin, PENG Shangjin, LIU Kangmeng. A new big fruit *Actinidia eriantha* Benth cultivar 'White' [J]. Acta Horticulturae Sinica, 2008, 35(10):1555.
- [16] COSTA F, CAPPELLIN L, FONTANARI M, LONGHI S, GUERRA W, MAGNAGO P, GASPERI F, BIASIOLO F. Texture dynamics during postharvest cold storage ripening in apple (*Malus × domestica* Borkh.)[J]. Postharvest Biology & Technology, 2012, 69:54-63.
- [17] LARA G, PAULA P, PAOLO L, FABRIZIO C. Texture profiling of blueberries (*Vaccinium* spp.) during fruit development, ripening and storage[J]. Postharvest Biology and Technology, 2013, 76:34-39.
- [18] 吴曼丹,陈瑜,金邦荃. 储藏期猕猴桃质构变化的研究及人工咀嚼的建立[J]. 食品工业科技, 2010, 31(12):146-148.
- WU Mindan, CHEN Yu, JIN Bangquan. Detection of texture properties of kiwifruits by texture profile analysis and simulation of mature chewing[J]. Science and Technology of Food Industry, 2010, 31(12):146-148.
- [19] 张慧琴,谢鸣,张琛,杨鲁琼,章镇,肖金平,周利秋. 猕猴桃果实发育过程中淀粉积累差异及其糖代谢特性[J]. 中国农业科学, 2014, 47(17):3453-3464.
- ZHANG Huiqin, XIE Ming, ZHANG Chen, YANG Luqiong, ZHANG Zhen, XIAO Jinping, ZHOU Liqiu. Difference in starch accumulation and characterization of sugar metabolism during fruit development of kiwifruit[J]. Scientia Agricultura Sinica, 2014, 47(17):3453-3464.
- [20] AL-HINAI K Z, GUIZANI N, SINGH V, RAHMAN M S, AL-SUBHI L. Instrumental texture profile analysis (TPA) of date-tamarind fruit leather with different types of hydrocolloids[J]. Food Science & Technology Research, 2013, 49(4):531-538.
- [21] HUANG X, HSIEH F H. Physical properties, sensory attributes, and consumer preference of pear fruit leather[J]. Journal of Food Science, 2005, 70(3):177-186.
- [22] 计宏伟,邵文全,孟宪文. 猕猴桃压缩力学行为及蠕变特性的试验研究[J]. 安徽农业科学, 2010, 38(3):1107-1109.
- JI Hongwei, SHAO Wenquan, MENG Xianwen. Experimental research on compression mechanical behaviors and creep property of kiwifruit[J]. Journal of Anhui Agricultural Sciences, 2010, 38(3):1107-1109.
- [23] 张杨,梁怡蕾,潘琦雯,张文. 猕猴桃感官评定与质地剖面分析的相关性[J]. 食品工业科技, 2018, 39(16):243-247.
- ZHANG Yang, LIANG Yilei, PAN Qiwen, ZHANG Wen. Correlation between the sensory evaluation and texture profile analysis of kiwifruit[J]. Science and Technology of Food Industry, 2018, 39(16):243-247.
- [24] TANIWAKI M, SAKURAI N. Evaluation of the internal quality of agriculture products using acoustic vibration technique[J]. Journal of the Japanese Society for Horticultural Science, 2010, 79:113-128.
- [25] 杨玲,丛佩华,王强,康国栋. 不同苹果品种在贮藏过程中果实质构的变化[J]. 果树学报, 2016, 33(11):1439-1446.
- YANG Ling, CONG Peihua, WANG Qiang, KANG Guodong. Texture changes of different apple varieties during storage[J]. Journal of Fruit Science, 2016, 33(11):1439-1446.
- [26] 王斐,姜淑苓,陈秋菊,欧春青,张文江,郝宁宁,马力,李连文. 脆肉梨果实成熟过程中质地性状的变化[J]. 果树学报, 2016, 33(8):950-958.
- WANG Fei, JIANG Shuling, CHEN Qiuju, OU Chunqing, ZHANG Wenjiang, HAO Ningning, MA Li, LI Lianwen. Changes in fruit texture of crisp-flesh pear during fruit ripening[J]. Journal of Fruit Science, 2016, 33(8): 950-958.
- [27] 李婷,安迪,鲍金平,臧运祥,万嗣宝,徐凯,郑伟尉. 基于果实质地参数的葡萄贮藏特性评价[J]. 核农学报, 2018, 32(11):2155-2161.
- LI Ting, AN Di, BAO Jinping, ZANG Yunxiang, WAN Sibao, XU Kai, ZHENG Weiwei. Evaluation on storage characteristics of different grape cultivars based on texture properties[J]. Journal of Nuclear Agricultural Sciences, 2018, 32(11):2155-2161.
- [28] TERASAKI S, SAKURAI N, KUROKI S, YAMAMOTO R, NEVINS D J. A new descriptive method for fruit firmness changes with various softening patterns of kiwifruit[J]. Postharvest Biology & Technology, 2013, 86:85-90.