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不同可溶性固形物含量‘鸭梨’耐贮性差异比较

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摘 要:【目的】研究果实可溶性固形物含量(SSC)等果实内在品质差异对耐贮性的影响,明确‘鸭梨’SSC等内在品质贮藏期的变化规律及其对贮藏后期果实生理病害发生的影响。**【方法】**利用近红外光谱果实品质无损快速检测设备,对同期采收‘鸭梨’SSC进行无损检测,依据所有样本SSC正态分布情况,将所有果实分为SSC<10.0%、SSC:10.0%~10.9%、SSC:11.0%~11.9%及SSC≥12.0% 4个级别,将果实缓慢降温后(8 ℃入库,每3 d降1 ℃),于-0.5 ℃、相对湿度85.0%~90.0%条件下正常贮藏,分别于贮藏4、6和8个月取样,调查不同SSC‘鸭梨’果实取出当天和货架10 d后生理病害发生情况,测定相关生理品质指标变化情况,并进行相关性分析。**【结果】**贮藏6和8个月后,不同SSC‘鸭梨’贮藏品质及生理病害发生情况差异明显,SSC相对较高的果实贮藏后期果实黑心指数显著降低,且SSC与黑心指数呈显著负相关($p < 0.05$);不同SSC级别间果实虎皮指数无明显变化规律;同时贮藏后期,SSC相对较高的果实级别其可滴定酸含量(TA)和抗坏血酸含量(AA)相对较高;但与采收时相比,随着贮藏期的延长,果实中可滴定酸和抗坏血酸含量均显著降低,贮藏4、6和8个月后,各组别果实平均可滴定酸和抗坏血酸含量与采收时相比分别下降45.32%和49.96%、51.46%和54.43%、53.80%和68.34%;另外,贮藏后期各组别间果实呼吸和乙烯代谢差异明显,贮藏8个月后,果实呼吸强度从大到小依次为(SSC≥12.0%)>(SSC:11.0%~11.9%)>(SSC:10.0%~10.9%)>(SSC<10.0%);乙烯代谢规律与呼吸代谢变化规律基本一致。**【结论】**较高可溶性固形物含量(SSC>11.0%)‘鸭梨’果实贮藏后期黑心病发生情况显著减轻,SSC与黑心指数呈显著负相关;可滴定酸、抗坏血酸含量及呼吸和乙烯代谢速率与‘鸭梨’黑心指数呈显著相关,可作为‘鸭梨’黑心病采后重要的预警及防控指标。

关键词: 梨;品质;糖度;褐变;无损检测

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The comparison of storage ability of ‘Yali’ pear in different soluble solids contents grades

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Abstracts:【Objective**】**‘Yali’ pear (*Pyrus bretschneideri* Rehd.) is one of the traditional pear cultivar in China, quality of ‘Yali’ pear could be maintained for almost 6−8 months under optimal storage conditions, but the fruit were very sensitive to carbon dioxide and low temperature, which caused core and flesh browning during long period storage, and caused a huge economic loss to commercial companies. And the susceptibility of pear to browning depends a lot on fruit internal quality, the fruits harvested in different area and orchards had a totally different susceptibility on browning, and the browning incidence was different in different year based on climatic conditions. Besides that, the individual fruit internal quality was different from one to another, and led to a different browning sensitivity. Due to the complicated preharvest factors, it is difficult to make the direct relationship between preharvest quality and post-harvest disorder. Sugar is one important major nutrition compounds in fruits, which afford the necessary energy to fruits during storage. In this study, in order to better understanding the effects of

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fruit sugar and some other preharvest quality characters on the fruit post-harvest storage ability and the disorder, illuminating the direct relationship of internal quality and browning disorder of ‘Yali’ pear, and providing scientific basis for controlling and predicting browning disorder technique, the fruits were classified to different groups based on soluble solids contents using non-destructive detection technique, and the relationships of browning disorder and internal quality during long period storage were investigated.【Methods】According the non-destructive detect results, the fruits were divided into SSC＜10.0%, SSC 10.0%−10.9%, SSC 11.0%−11.9% and SSC≥12.0% four different groups according to the soluble solids contents, which were taken as a key factor of internal quality, by non-destructive sugar tester (SACMI, Italy) based on the NIR reflectance spectroscopy, and then the fruits were placed into a storage room kept at 8 ℃, and the temperature was decreased by 1 ℃ for every 3 days until the temperature was reduced to −0.5 ℃, and the relative humidity was maintained at 85.0%−90.0%. The fruits were sampled after storage for 4, 6 and 8 months and under shelf (20 ℃) for 10 days, the core browning and superficial scald incidence were studied, and changes of fruit color, firmness, soluble solids contents, titration acid, ascorbic acid, respiration intensity and ethylene production of different SSC groups were determined, and the correlations between them were analyzed.【Results】The different SSC groups showed significantly differences in browning disorders incidence during the long periods storage (> 6 months), the higher SSC content, the lower core browning incidence, and showed a significantly negative correlation ($p < 0.05$); SSC＜9.0% groups showed a higher superficial scalds incidence than SSC 10.0%−10.9%, SSC 11.0%−11.9% and SSC≥12.0% groups, but the superficial scald incidence did not have a obvious correlation with SSC grades; at the meanwhile, there were positive correlation among titratable acid and ascorbic acid with SSC grades, and with the increase of storage time and shelf life, the core browning index increased rapidly, and the content of titration acid (TA) and ascorbic acid (AA) in fruit decreased significantly, compared with the harvest date, the average content of TA and AA declined by 45.32% and 49.96%, 51.46% and 54.43%, 53.80% and 68.34% after storage for 4, 6 and 8 months respectively, and showed a further decline during shelf-life period; in addition, the respiration intensity and ethylene production in different SSC groups showed significantly difference during long-periods storage, especially after storage for 8 months, SSC≥12.0% groups showed a significantly higher respiration intensity than other groups, and maintain relative stabilization during the whole shelf periods, the average respiration rate and ethylene release rate were followed by the order of (SSC≥12.0%)>(SSC 11.0%−11.9%)>(SSC 10.0%−10.9%)>(SSC＜10.0%).【Conclusion】The higher soluble solids contents in ‘Yali’ pear could significantly reduce the core browning incidence in long-periods storage, they have a significantly negative correlation; besides that, the fruits weight, TA, AA and respiration and ethylene rate were all significantly correlated with core browning, which may be made as important prediction and controlling characters of core browning incidence in ‘Yali’ pear.

Key words: Pear; Quality; Sugar; Browning disorder; Non-destructive detection

‘鸭梨’是我国传统主栽梨品种，但在采后贮藏过程中果皮和果心组织易发生褐变，一旦褐变，果实商品价值严重下降，经济损失巨大[1]。褐变是梨果实上一种常见的生理病害，在不同梨品种上均有相关报道[2-4]，一般发生于长期贮藏过程中，因此常常被认为是一种典型的采后问题，不当的采后处理，如过早或过晚采收[5]、降温速率过快[6-7]、贮藏环境二氧化碳浓度过高[8]等均会诱发梨组织褐变的发生，通过优化采后贮藏条件可以一定程度上降低组织褐变的发生[9-10]，但从根本上解决果实生理病害很大程度上仍取决于果实采前品质的提升[11-13]，因此明确果实采前品质及其采后变化规律对果实耐贮性的影响，进而建立果实采后生理病害防控预警技术体系，对产业健康发展具有重要意义。果实生长季节温度、降

雨，果园树龄、土壤、水肥、果实生长部位等因素共同决定了果实采收时的最终品质，从而也决定了果实对采后贮藏过程中的组织褐变敏感性[14]；不同生长地域和管理水平的果园果实对低温、二氧化碳及衰老等因素诱导的组织褐变的敏感性存在较大差异，例如生长于冷凉地区的‘Conference’果实比生长于相对温暖地区果实对褐变更敏感[15]；生长于树梢的‘Conference’果实更易发生褐变[16-17]；采前喷施硼肥可以一定程度上降低‘Conference’褐变发生率[18]；同时前人研究发现，果实大小、维生素C含量、酚类物质含量及果实内外气体交换效率等均与梨果实组织褐变敏感性关系密切[19-21]，但由于采前自然条件复杂，果实单果品质差异大，而且衡量果实内在品质的参数指标众多，难以建立有效精准的采前品质与采后耐贮性的直接作用关系。

果实中可溶性糖的种类和含量不仅决定了果实的风味和品质，而且还是重要的能源物质，是众多代谢通路的中间产物及重要底物，作为信号分子参与调控植物的发育、成熟和衰老等多个过程[22]；研究发现，NO处理主要通过调控梨和桃贮藏期间果实糖代谢，抑制蔗糖含量降低，进而延缓果实衰老[23-24]。因此，笔者拟利用基于近红外光谱检测技术的果实品质无损快速检测仪，以‘鸭梨’可溶性固形物含量（soluble solids contents，SSC）为切入点，根据SSC无损检测结果，按照含糖量高低将‘鸭梨’果实进行分级，后转入冷藏，定期调查不同SSC级别果实组织褐变发生情况并测定其他内在品质变化情况，建立基于糖度差异的各种品质指标与组织褐变的相关关系；探讨果实糖度等内在品质差异对‘鸭梨’采后贮藏过程中品质变化及组织褐变的影响，进一步明确梨组织褐变发生机制，筛选精度高的‘鸭梨’采后组织褐变预判关键品质指标，并为生产中‘鸭梨’组织褐变防控与预警技术提供科学依据。

1 材料和方法

1.1 材料与处理

‘鸭梨’试材于2013年9月20日采自河北省石家庄市晋州市周家庄九队管理水平较好的商品果园，采收次日运回实验室。选取无病虫害、无磕碰伤的果实进行处理。

利用果实品质无损快速检测仪（NCS001A，SACMI，意大利），分别测定果实赤道部位对称两点可溶性固形物含量（SSC），取平均值，建立所有果实SSC正态分布直方图，根据SSC整体分布情况，将果实分为SSC＜10.0%、SSC：10.0%~10.9%、SSC：11.0%~11.9%及SSC≥12.0% 4个级别，将分级后的果实分别置于塑料盘中，外套高CO_2渗透塑料薄膜（不扎口），置于8 ℃试验冷库进行缓慢降温处理（每3 d降1 ℃），直至环境温度降至−0.5 ℃并保持，库内相对湿度为85.0%~90.0%。分别于贮藏4、6及8个月后取样，开展果实组织褐变调查与生理品质测定，每次每个处理取果实70个，其中15个果实用于生理病害调查，15个果实用于生理品质测定，9个果实用于测定呼吸强度和乙烯产生速率，剩余果实置于20 ℃恒温箱（SANYO，日本），10 d后测定。

1.2 测定指标与方法

1.2.1 果皮颜色 利用色差计（CR-400，MINOLTA，日本）测定果实赤道部位对称两点，其中L^*值表示果实亮度从明亮（L^*=100）到黑（L^*=0）之间的变化。a^*值表示颜色从绿色（$-a^*$）到红色（$+a^*$）的变化，绝对值越大表示相应绿和红色越重。b^*值表示黄色和蓝色之间的变化。$h°$值表示色角度，其中0°表示红紫，90°表示黄色，180°表示蓝绿，270°表示蓝色。C值表示色饱和度（$C=[a^{*2}+b^{*2}]/2$）[25]。

1.2.2 硬度、可溶性固形物含量、单果质量、失水率 利用果实质构仪（GS-15，FTA2，南非）测定果实赤道部位对称两点去皮硬度，探头直径11 mm；利用折光仪（PR-101，ATAGO，日本）测定果实可溶性固形物含量；利用电子天平（KD-400，TANITA，中国）测定果实单果质量。失水率/%=（采收时平均单果质量−贮藏后平均单果质量）/采收时平均单果质量×100。

1.2.3 可滴定酸与抗坏血酸含量 使用自动智能电位滴定仪（808 Titrando，瑞典），分别用0.1 $mol \cdot L^{-1}$ NaOH标准液和2,6-二氯靛酚吲哚酚钠盐滴定。

1.2.4 呼吸强度和乙烯产生速率 果实呼吸强度和乙烯产生速率测定均采用SP-9890气相色谱仪（山东，鲁南瑞虹仪器公司）测定，以 $mg \cdot kg^{-1} \cdot h^{-1}$ 和 $\mu L \cdot kg^{-1} \cdot h^{-1}$ 计，色谱参数为进样器80 ℃，柱炉100 ℃，检测器160 ℃，转化炉360 ℃。每个处理3次重复，每个重复用果9个。

1.2.5 果心褐变与虎皮病 虎皮指数按褐变面积占果皮面积的百分比，共分为5级：果皮无褐变为0级；褐变面积≤25%为1级；25%＜褐变面积≤50%为2

级；50%＜褐变面积≤75%为3级；褐变面积＞75%为4级。虎皮病指数=[∑（虎皮级数×该级果数）/（调查总果数×4）]×100%。

黑心指数：沿果实赤道线作横切，按褐变面积占果心面积的百分比，共分为5级：果心无褐变为0级；褐变面积≤25%为1级；25%＜褐变面积≤50%为2级；50%＜褐变面积≤75%为3级；褐变面积＞75%为4级。黑心指数=[∑（黑心级数×该级果数）/（调查总果数×4]×100%。

1.2.6　数据处理　采用SPSS 13.0数据分析软件进行方差分析和相关系数分析，利用Excel进行试验数据处理与作图。

2　结果与分析

2.1　生理病害发生情况

2.1.1　黑心指数　结果（图1）表明，SSC＜10.0%级别黑心病发生时间最早，贮藏6个月时即开始出现，并随着贮藏期的延长，黑心指数呈增加趋势，并且显著高于其他SSC级别；SSC≥12.0%级别‘鸭梨’黑心病发生时间最晚，仅在贮藏8个月+10 d后个别果实果心变暗；整体来看，各组别贮藏期间黑心指数从高到低依次是（SSC＜10.0%）>（SSC：10.0%~10.9%）>（SSC：11.0%~11.9%）>（SSC≥12.0%），其中SSC＜10.0%和SSC：10.0%~10.9%组别果实黑心指数显著高于SSC：11.0%~11.9%和SSC≥12.0%组别；SSC>11.0%‘鸭梨’果实贮藏后期（>6个月）黑心病的发生显著减轻，贮藏8个月+10 d后，其平均黑心指数仍＜5.0%。

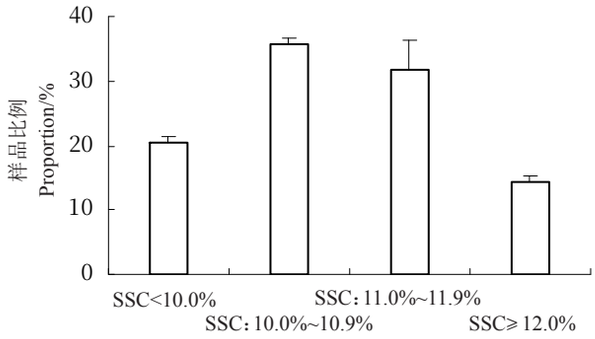


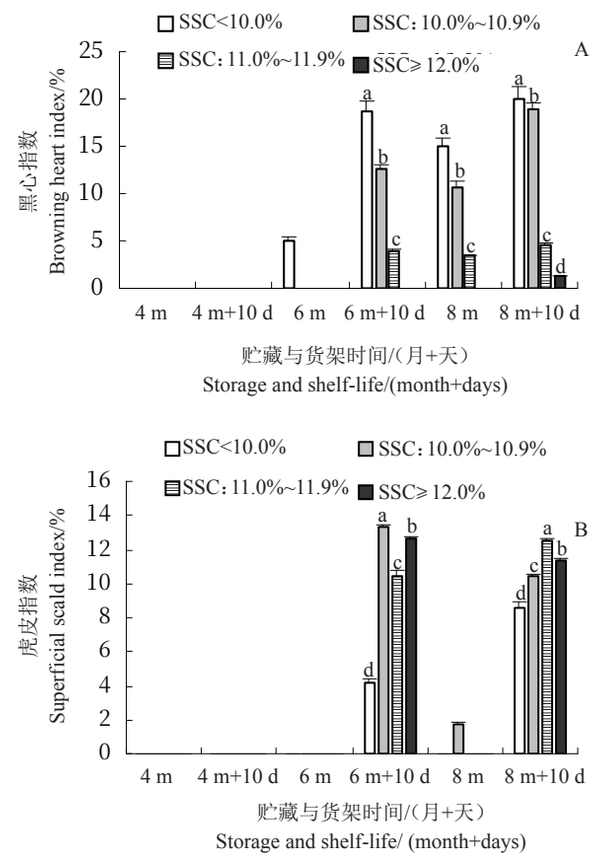
图1　不同SSC级别‘鸭梨’样品比例

Fig. 1 The proportion of ‘Yali’ pear in different SSC groups

2.1.2　虎皮指数　果实在冷藏期间无虎皮或仅有轻微虎皮（8个月），货架期间（20 ℃）各组别‘鸭梨’虎皮病发生不断加重；贮藏6个月+10 d，各级别果实开始发生不同程度虎皮；8个月+10 d，SSC＜10.0%级别虎皮指数最低，SSC：11.0%~11.9%级别虎皮指数最高；整体来看，‘鸭梨’SSC高低与虎皮病的发生无明显相关性。

2.2　主要生理品质指标变化差异比较

2.2.1　单果质量、失水率、硬度、可溶性固形物含量差异比较　如图2所示，不同SSC级别‘鸭梨’果实平均单果质量差异显著，与SSC级别呈正相关，SSC≥12.0%级别果实平均单果质量显著高于SSC＜10.0%和SSC：10.0%~10.9%级别（$p < 0.05$）；随着贮藏期的延长，果实平均单果质量均不断下降；果实失水率与SSC级别呈正相关，贮藏至8个月+10 d，（SSC＜10.0%）、（SSC：10.0%~10.9%）、（SSC：11.0%~11.9%）及（SSC≥12.0%）4组果实平均失水率分别



不同小写字母表示在 p ＜0.05 差异显著。下同。

The different small letters indicated significant difference at p ＜ 0.05. The same below.

图2　不同SSC级别‘鸭梨’贮藏与货架期黑心指数与虎皮指数

Fig. 2 Browning heart index and superficial scald index of ‘Yali’ pear in different SSC groups during storage and shelf-life periods

为27.69%、21.05%、18.51%及16.42%。可溶性固形物含量有损测定结果与无损预测结果基本一致，不同级别间可溶性固形物含量均差异显著（$p < 0.05$），可见利用无损检测技术可完全实现按照SSC含量对‘鸭梨’进行准确分级；不同SSC级别‘鸭梨’果实贮藏期间硬度和可溶性固形物含量无明显变化规律（表1）。

2.2.2 可滴定酸和抗坏血酸含量 果实可滴定酸含量和抗坏血酸含量与果实SSC级别呈正相关，且SSC≥12.0%和SSC：11.0%~11.9%级别果实可滴定酸和抗坏血酸含量显著高于SSC：10.0%~10.9%和SSC＜10.0%；随着贮藏期的延长，各级别果实可滴定酸与抗坏血酸含量不断降低，与采收时相比，贮藏4、6和8个月，果实平均可滴定酸和抗坏血酸含量与采收时相比分别下降45.32%和49.96%、51.46%和54.43%、53.80%和68.34%，货架期10 d，各级别可滴定酸和抗坏血酸含量均进一步快速降低；贮藏8个月+10 d，不同SSC级别间可滴定酸含量差异明显，而抗坏血酸含量差异不显著（表1）。

2.2.3 果皮色泽 不同贮藏与货架期，SSC级别与L^*值和$-a^*$绝对值呈负相关，与b^*值呈正相关，说明SSC级别越高，果皮白度与果面亮度越低，果皮颜色越黄；其中SSC≥12.0%级别L^*值和$-a^*$绝对值显著低于其他级别，而b^*值则显著高于其他级别；同时，$h°$色调角与SSC级别成负相关，$h°$=90°表示黄色，$h°$越大表示颜色越黄，同时SSC级别越高，C值越高，果实色饱和度越大。另外，随着贮藏期的延长，贮藏至8个月和8个月+10 d后，各级别果实L^*值进一步降低，果面变暗，a^*负值绝对值、b^*、$h°$及C值则明显升高，果皮底色变暗、转黄，果实色饱和度增加。

2.2.4 呼吸强度和乙烯产生速率 研究发现，不同SSC级别‘鸭梨’果实不同贮藏期和货架10 d后果实呼吸强度和乙烯释放速率差异明显，随着贮藏时间的延长，各级别间果实呼吸强度和乙烯释放速率差异不断增大，贮藏8个月后，果实呼吸强度与乙烯释放速率与SSC级别呈正相关，SSC≥12.0%和SSC：11.0%~11.9%级别果实呼吸强度和乙烯释放速率差异显著高于SSC：10.0%~10.9%和SSC＜10.0%（图3）。

2.3 生理病害与品质指标相关性分析

结果（表2）表明，‘鸭梨’贮藏6个月+10 d和8个月+10 d后，黑心指数与SSC分别呈极显著（$p < 0.01$）和显著负相关（$p < 0.05$），与平均单果质量呈显著负相关；另外，贮藏6个月+10 d时，黑心指数与抗坏血酸和$h°$呈显著负相关；贮藏8个月+10 d时，黑心指数与呼吸强度及乙烯释放速率呈显著负相关。‘鸭梨’虎皮病发生指数与各品质指标间无明显相关性。

3 讨 论

黑心病是梨上一种常见的生理病害，‘酥梨’‘黄金’‘Bartlett’及‘d’Anjou’等梨品种上均有相关报道[26-29]。Larrigaudière等[30]按照发生特点的不同将黑心病分为两类，一类是胁迫型黑心，即由于受到冷胁迫或高二氧化碳胁迫，一般于贮藏2个月后即发生，呈水浸状褐变（browning heart，BH）；另一类是由于衰老造成的（core breakdown，CB），一般于贮藏6月后开始发生，主要表现为果心呈黑褐色，组织塌陷形成空腔，种子发芽等；‘鸭梨’衰老型黑心的发生与果实成熟度密切相关，采收过晚，成熟度过高，果实黑心发病程度越重[6]。本研究中，‘鸭梨’于贮藏6个月后开始发生黑心，属于典型的衰老型黑心症状；同期采收不同SSC级别果实在贮藏后期黑心指数差异明显，黑心指数与SSC呈显著负相关；同期采收果实（成熟度基本一致）中相对较高的可溶性固形物含量可明显延长果实贮藏寿命，延缓果实衰老，降低衰老型黑心病的发生。当‘鸭梨’果实SSC>11.0%时，贮藏后期黑心病发生情况明显较轻，因此采收时果实SSC含量可作为预测‘鸭梨’后期黑心病的发生的一项重要指标。同时，本研究中伴随着贮藏期的延长和黑心指数的增长，可滴定酸和抗坏血酸含量均显著下降；而相对较高SSC级别果实可延缓可滴定酸和抗坏血酸含量的降解，一定程度上降低黑心病的发生，这与前人研究结果基本一致[14]。

黑心病等组织褐变发生的直接原因是细胞膜完整性被破坏[31-32]；维持细胞生物膜正常生物合成代谢需要能量，Rawyler等[33]研究发现当ATP产生速率低于10 μmol·g^{-1}·h^{-1}时，马铃薯细胞完整性将会受到破坏；Saquet等[34]也发现‘Conference’梨和‘Jonagold’苹果组织褐变的发生与ATP含量、ATP∶ADP比值等能量代谢水平关系密切；同时，能量过低将无法维持抗氧化酶系统稳定性，造成活性氧（ROS）过量积累，膜质过氧化水平加重，DNA被破坏，蛋白质被氧化，细胞最终死亡，诱发褐变[35]。本研究中，较高SSC级

表 1　不同 SSC 级别果实不同贮藏时期主要品质指标分析比较（2013—2014）

Table 1 The comparison and analysis of fruit quality in different storage time among different SSC groups (2013—2014)

测定指标 Testing index	处理 Treatment	基础值 Basic values	贮藏时间 Storage times					
			4 个月 4 months	4 个月+10 d 4 months+10 d	6 个月 6 months	6 个月+10 d 6 months+10 d	8 个月 8 months	8 个月+10 d 8 months+10 d
单果质量 Fruit mass/g	SSC＜10.0%	230.200±19.580 a	209.930±17.620 a	195.730±15.700 a	178.730±20.800 a	175.220±17.560 a	194.360±15.200 a	192.400±13.120 a
	SSC：10.0%~10.9%	239.600±21.220 a	210.330±27.040 a	199.930±19.240 ab	196.130±13.070 b	193.220±14.960 b	196.800±15.830 a	195.250±10.480 a
	SSC：11.0%~11.9%	252.600±26.530 b	220.930±21.800 ab	205.710±17.420 ab	209.730±11.140 bc	202.110±20.860 c	205.140±16.690 ab	199.420±18.090 a
	SSC≥12.0%	281.000±25.660 c	231.000±23.950 b	209.270±14.910 b	213.500±28.750 c	208.350±18.120 c	218.500±27.320 b	203.180±15.520 b
硬度 Firmness/(kg·cm^{-2})	SSC＜10.0%	6.230±0.526 a	5.930±0.419 a	5.240±0.404 ab	5.640±0.593 a	5.150±0.424 a	5.390±0.563 a	5.150±0.305 ab
	SSC：10.0%~10.9%	5.670±0.518 b	5.740±0.456 a	5.270±0.441 a	5.520±0.595 a	5.180±0.460 a	5.050±0.394 b	5.060±0.349 b
	SSC：11.0%~11.9%	5.650±0.534 b	5.790±0.516 a	5.040±0.329 b	5.640±0.567 a	4.900±0.384 b	5.310±0.288 a	5.250±0.325 a
	SSC≥12.0%	5.490±0.465 b	5.500±0.310 b	5.290±0.437 a	5.480±0.860 a	5.210±0.336 a	5.400±0.351 a	5.090±0.224 ab
w（可溶性固形物） Soluble solids content/%	SSC＜10.0%	10.360±0.352 a	10.370±0.326 a	9.800±0.316 a	10.160±0.424 a	9.650±0.417 a	9.720±0.279 a	9.800±0.323 a
	SSC：10.0%~10.9%	10.860±0.329 a	10.920±0.316 b	11.010±0.381 b	10.350±0.306 b	10.000±0.543 b	10.350±0.322 b	10.270±0.447 b
	SSC：11.0%~11.9%	11.530±0.317 b	11.520±0.277 c	11.340±0.253 b	11.250±0.375 c	11.100±0.340 c	10.790±0.373 c	10.820±0.256 c
	SSC≥12.0%	12.310±0.507 c	12.320±0.413 d	12.270±0.353 c	12.400±0.343 d	11.370±0.367 d	11.660±0.317 d	11.390±0.410 d
w（可滴定酸） Titratable acid content/%	SSC＜10.0%	0.103±0.002 a	0.087±0.001 a	0.033±0.001 a	0.072±0.003 a	0.035±0.001 a	0.072±0.003 a	0.036±0.001 a
	SSC：10.0%~10.9%	0.105±0.001 a	0.090±0.001 b	0.036±0.000 a	0.076±0.002 a	0.036±0.001 a	0.075±0.000 b	0.037±0.001 a
	SSC：11.0%~11.9%	0.116±0.005 b	0.095±0.001 c	0.056±0.000 b	0.083±0.002 b	0.047±0.001 b	0.081±0.002 c	0.046±0.001 b
	SSC≥12.0%	0.129±0.007 c	0.104±0.001 d	0.063±0.001 c	0.101±0.001 c	0.059±0.000 c	0.091±0.000 d	0.077±0.002 c
w（抗坏血酸） Ascorbic acid content/ (mg·100 g^{-1})	SSC＜10.0%	3.527±0.023 a	2.572±0.031 a	2.971±0.024 a	2.656±0.018 a	2.312±0.022 a	2.176±0.018 a	1.055±0.035 a
	SSC：10.0%~10.9%	3.685±0.056 a	2.852±0.054 b	2.619±0.045 a	2.959±0.029 ab	2.459±0.025 a	2.339±0.092 a	1.983±0.012 a
	SSC：11.0%~11.9%	4.152±0.089 b	3.507±0.133 c	2.875±0.013 a	3.297±0.039 b	2.796±0.019 b	1.865±0.022 b	1.668±0.036 b
	SSC≥12.0%	4.766±0.103 c	4.461±0.184 d	2.912±0.018 a	3.338±0.072 c	2.883±0.033 b	2.092±0.045 a	1.876±0.055 ab
*L**	SSC＜10.0%	87.220±0.902 a	87.020±0.820 a	86.260±0.869 a	86.780±0.970 a	84.960±1.319 a	86.820±1.328 ab	85.610±0.933 a
	SSC：10.0%~10.9%	87.000±0.897 a	86.960±1.022 a	86.230±0.655 a	86.340±1.610 ab	84.890±2.562 a	86.680±1.754 ab	84.760±1.357 ab
	SSC：11.0%~11.9%	87.780±0.959 a	86.550±1.047 ab	85.660±1.231 a	86.020±1.080 ab	84.310±1.511 a	86.530±1.137 a	83.880±1.374 bc
	SSC≥12.0%	87.200±1.158 a	86.280±1.294 b	85.270±1.388 b	85.630±1.466 b	84.590±0.990 a	85.210±1.396 b	83.420±1.476 c
*a**	SSC＜10.0%	−2.910±0.469 a	−2.830±0.415 a	−2.650±0.578 a	−2.860±0.405 a	−2.510±0.518 a	−7.040±0.566 a	−7.540±0.372 a
	SSC：10.0%~10.9%	−2.870±0.408 a	−2.810±0.422 a	−2.610±0.550 a	−2.630±0.565 ab	−2.230±0.360 a	−7.260±0.820 a	−6.930±0.728 b
	SSC：11.0%~11.9%	−2.850±0.413 a	−2.580±0.410 b	−2.350±0.322 b	−2.260±0.519 bc	−2.110±0.582 a	−7.140±0.496 a	−6.450±0.752 bc
	SSC≥12.0%	−2.810±0.490 a	−2.540±0.482 b	−2.320±0.655 b	−2.050±0.867 c	−2.100±0.570 a	−6.340±0.888 b	−6.080±1.039 c
*b**	SSC ＜10.0%	31.690±1.854 a	32.920±2.103 ab	34.560±1.206 a	32.250±1.505 a	35.500±0.952 a	36.990±1.845 a	38.380±1.729 a
	SSC：10.0%~10.9%	31.380±1.686 ab	32.370±1.546 a	34.330±1.313 a	33.680±2.151 b	36.430±2.204 a	36.670±1.741 a	39.500±2.069 ab
	SSC：11.0%~11.9%	32.600±1.576 b	33.620±1.630 b	36.230±1.426 b	33.300±1.640 ab	36.400±2.287 a	37.550±1.194 a	39.810±2.315 ab
	SSC≥12.0%	34.150±1.509 c	34.500±1.444 c	36.120±1.022 b	35.230±2.000 c	37.030±0.804 a	39.010±1.027 b	41.090±2.057 b
C	SSC＜10.0%	33.380±2.188 a	33.040±2.082 ab	35.890±1.477 a	32.380±1.475 a	35.590±0.933 a	37.660±1.778 a	39.120±1.706 a
	SSC：10.0%~10.9%	33.180±2.057 a	32.500±1.534 b	34.560±2.221 b	33.790±2.117 b	36.520±2.174 a	37.390±1.612 a	40.110±1.977 ab
	SSC：11.0%~11.9%	34.150±1.866 b	33.720±1.612 a	36.250±1.256 a	33.390±1.625 ab	36.470±2.260 a	38.230±1.104 a	40.340±2.242 ab
	SSC≥12.0%	34.790±1.420 b	34.600±1.430 c	35.110±1.986 b	35.300±1.974 c	37.100±0.793 a	39.530±0.851 b	41.560±1.914 b
h°	SSC＜10.0%	93.740±0.989 a	94.950±0.888 a	93.260±0.988 a	95.090±0.890 a	94.060±0.892 a	100.820±1.145 a	101.140±0.966 a
	SSC：10.0%~10.9%	93.950±0.847 a	94.980±0.817 a	93.580±1.056 a	94.510±1.155 ab	93.590±2.132 a	101.260±1.574 a	100.000±1.351 b
	SSC：11.0%~11.9%	94.750±0.815 ab	94.410±0.814 b	94.150±1.017 b	93.910±0.971 bc	93.360±1.063 a	100.790±1.018 a	99.260±1.333 bc
	SSC≥12.0%	95.290±0.857 b	94.230±0.862 b	94.110±1.132 b	93.380±1.507 c	93.270±0.906 a	99.250±1.410 b	98.480±1.745 c

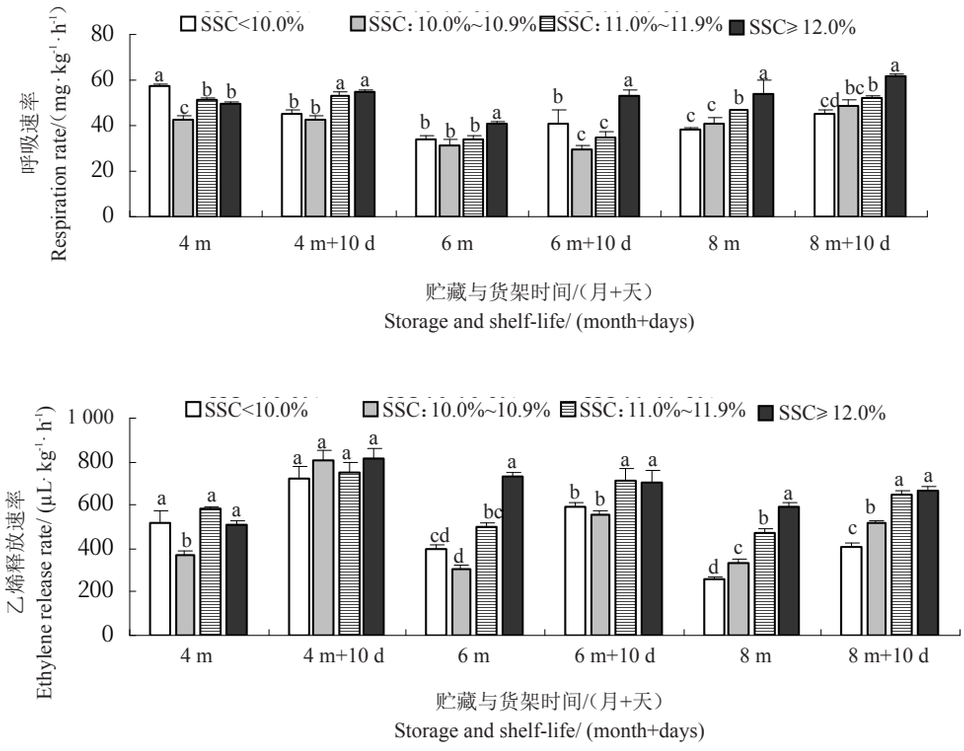


图 3 不同 SSC 级别‘鸭梨’贮藏 4、6 及 8 个月后货架呼吸强度与乙烯产生速率

Fig. 3 The respiration intensity and ethylene production rate of ‘Yali’ pear in different SSC groups during shelf-life periods after storage for 4，6 and 8 months

表 2 不同贮藏货架时期果实生理品质指标与组织褐变指数的相关性分析

Table 2 The correlation analysis of fruit tissue browning and physiological quality indicators in different storage and shelf-life time

	贮藏时间 Storage time			
	6个月+10 d 6 months+10 d		8个月+10 d 8 months+10 d	
	黑心指数 Heart browning index	虎皮指数 Superficial scald index	黑心指数 Heart browning index	虎皮指数 Superficial scald index
单果质量 Fruit mass	−0.971*	0.812	−0.968*	0.804
硬度 Firmness	0.232	−0.816	0.324	0.392
可溶性固形物含量 Soluble solids content	−0.991**	−0.239	−0.955*	0.805
可滴定酸含量 Titratable acid content	−0.935	0.463	−0.852	0.476
抗坏血酸含量 Ascorbic acid content	−0.996**	0.588	-0.424	0.924
呼吸强度 Respiration intensity	−0.740	0.138	−0.972*	0.819
乙烯释放速率 Ethylene release rate	−0.809	0.124	−0.987*	0.853
*L**	0.819	−0.349	0.949	−0.891
*a**	0.919	−0.838	0.934	−0.872
*b**	−0.894	0.887	−0.870	0.735
C	−0.886	0.893	−0.859	0.714
h°	−0.960*	−0.821	−0.921	−0.856

注：*. 显著相关（$p < 0.05$），**. 极显著相关（$p < 0.01$）。

Note: *. Significant relationship ($p < 0.05$), **. Highly significant relationship ($p < 0.01$).

别‘鸭梨’贮藏后期果实呼吸强度相对较高，且相对稳定，能量供应相对充分，黑心病发生情况整体较轻，由此可见，采后贮藏过程中，一方面需尽量降低果实呼吸强度延缓果实衰老，另一方面，也应保持适度的呼吸强度，保障必须能量供给，进而保持细胞正常生理代谢，降低生理病害的发生。另外，鞠志国等[36]认为，‘莱阳茌梨’褐变过程中，由于细胞膜完整性遭到破坏，酚类物质与PPO细胞区域化分布被打破，使果实酚类物质与PPO相接触而产生褐变，因此不同SSC级别果实中酚类物质含量变化差异仍需进一步研究验证。

4　结　论

可溶性固形物含量相对较高的‘鸭梨’贮藏后期果实黑心病发生显著减轻，SSC级别与黑心指数呈显著负相关（$p<0.05$）；可滴定酸、抗坏血酸含量及呼吸和乙烯代谢速率等与‘鸭梨’黑心指数呈显著相关，可做为‘鸭梨’黑心病采后重要的预警及防控指标。

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