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超高压处理对不同果蔬结构和性质的影响*

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摘要:超高压处理用于提高食品的安全性和贮藏性已被广泛用于果蔬制品,但主要限于流态食品,原因是超高压处理可能会影响到固态食品的结构。为了探究超高压处理对不同品种的果蔬结构和性质的影响,选择了 5 种具有不同的密度、含水量、微观结构和质构特性的果蔬,采用不同的超高压处理条件,分析在不同压力大小和保压时间条件下,果蔬结构和性质的变化情况。结果表明:果蔬的质地会影响其耐压特性,当果蔬质地柔软、空泡结构较少时,耐压性较好;反之,果蔬的体积容易被压缩,由于组织结构的差异,不同果蔬受压时体积变化差异很大;密度大、初始硬度大的果蔬受超高压处理后硬度等质构指标下降幅度更大。保压时间的延长会进一步破坏果蔬的质构和结构。

关键词:超高压;果蔬;结构;性质

中图分类号:TS255.1;O521.2　　　　**文献标识码**:A

超高压对食品的处理是等静压加工,具有各向均匀性的特点,使被加工原料处于受力平衡状态,只要食品原料具有一定的弹性,体积能够在一定程度上伸缩,就适合采用超高压处理[1-2]。由于一般超高压采用的压力较高(100～600 MPa),同时果蔬的组织一般较软[3],经超高压处理后,固体形式的果蔬组织会受到不同程度的损伤,导致细胞壁和中胶层的结构以及胞内生物大分子的组成和数量发生变化[4-5],造成果蔬的体积、质量、色泽和质构方面的变化[6-8]。目前有关超高压对果蔬结构和性质变化的研究多集中在细胞壁果胶变化及影响其变化的相关内源酶上,主要取决于细胞膜、细胞壁和细胞间隙的完整性[9]。Basak 等[10]研究了不同压力大小及保压时间对苹果、梨、橙子、胡萝卜、芹菜、青椒和红椒的硬度的影响,结果发现随着压力的增加,硬度会迅速降低,而在保压期间,硬度会进一步降低或逐渐恢复,并认为果胶甲酯酶活性是硬度增加的主要原因。Deroeck 等[11]研究发现,相比于热处理,高压协同高温处理的胡萝卜的果胶甲酯化程度显着降低,质构显示出最小的软化现象,且细胞间的粘附变化很小。Tangwongchai 等[12]研究了高压处理(200～600 MPa、20 min)对樱桃番茄的结构和关键软化酶(果胶甲酯酶和聚半乳糖醛酸酶)的影响,认为由压力引起的樱桃番茄的结构变化涉及至少两个相关现象,与液固组分相比,气相(空气)的压缩性更大,施加压力可以使其产生紧凑的结构;当压力解除时,组织中溶解和压缩的气体将在大气压下重新快速膨胀形成气泡,导致细胞膜渗透性增加,从而促进水分的渗出和增强酶作用,细胞区室化消失,组织变形软化,而参与进一步软化的酶主要是聚半乳糖醛酸酶,其在 500 MPa 及以上压力条件下失活。前者主要指压力导致的(细胞和组织)结构变化,后者指结构变化导致的物理和化学变化,后者的变化又会加剧前者的变化,但前者的变化(结构的受损)程度决定了后者的变化;前者的变化程度不仅取决于处理的压力,还受果蔬的种类和特性影响。目前关于超高压处理对液体介质下不同果蔬受超高压处理后结构及品质变化研究较少[13],而且多以研究单一品种的果蔬为主,

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缺乏横向对比，较少探讨和比较不同果蔬在超高压处理后的不同变化。

不同品种的果蔬具有不同的组织结构，所以超高压对其质构等品质的影响存在很大的差异。因此本研究分析了不同超高压处理条件对果肉结构和性质的影响，同时比较了不同果蔬在相同条件下进行超高压处理受到影响的差异，以推动高静压技术在果蔬加工中的应用并为开发果蔬罐头或含果肉饮料新型工艺提供理论依据。

1　材料与方法

1.1　材料与设备

原料：包括荔枝、提子、胡萝卜、梨、苹果 5 种果蔬。均选用市售新鲜产品，选择相似的外观、成熟度和大小尺寸，其中成熟度主要以硬度和可溶性固形物含量为确定指标。荔枝为“桂味”品种，广东本地产；提子为青提，产地智利；胡萝卜为广东本地产；梨为皇冠梨，产地河北；苹果为红富士，产地山东烟台。白砂糖，食品级。

试验仪器与设备：uuPF/5 L/800 MPa 超高静压处理设备（包头科发新型高技术食品机械有限公司），Dz-280/2SD 真空封口机（东莞市金桥科技有限公司），DHG-9070A 电热恒温鼓风干燥箱（海培因实验仪器有限公司），TA-XT2 质构仪（Stable Micro Systems Ltd，England），PL203 电子天平（梅特勒－托利多仪器（上海）有限公司），FR-600 多功能自动薄膜封口机（上海申原包装机械厂），EVO 18 Special Edition 扫描电镜（SEM/EDS）（德国卡尔蔡司有限公司），Alphal-4Lplus 真空冷冻干燥机（德国 Christ 公司），WYZ 阿贝折光仪（上海仪电物理光学仪器有限公司）。

1.2　试验方法

1.2.1　原料处理

选择 5 种果蔬作为实验原料：荔枝、提子、胡萝卜、梨和苹果。处理时将鲜荔枝去壳去皮后，沿径向方向将荔枝果肉制成直径 10 mm、高 5 mm 的圆柱形样品；将提子和胡萝卜切去两头后，沿中心取样，制成直径 10 mm、高 5 mm 的圆柱形样品，其中提子制样时选择大小相似、质量相近（±1 g）的样品，取样时避免取到果皮；梨和苹果沿轴向取样，避免取到果心和果核，制成直径 10 mm、高 5 mm 的圆柱形样品。随后将样品装入密封袋中，密封袋采用聚乙烯塑料袋（10 cm×13 cm）两层密封（不留顶隙），随后加入糖液，用密封机将密封袋封口，随后进行超高压处理。样品处理示意图如图 1 所示，经过压力处理后，果蔬的形态会发生变化，果蔬内部物质会与液体介质直接发生交换。

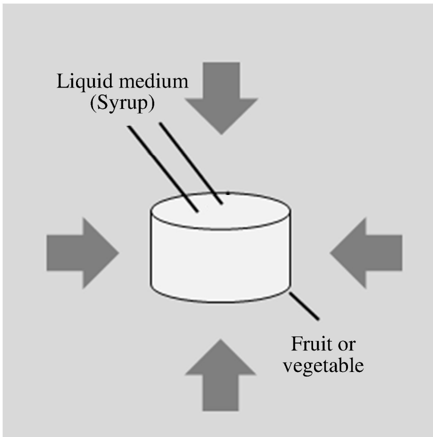


图 1　样品处理示意图

Fig. 1　Schematic representation of treated samples

样品选用不同的糖液作为介质，调配时使用蒸馏水和蔗糖（食品级）作为原料，根据果蔬本身的糖度作为糖液的糖度进行调配，以减小由于果肉及糖液的糖度差异而造成的渗透作用影响。其中荔枝 18.34°Brix，提子为 14.05°Brix，胡萝卜糖度为 7.47°Brix，梨为 10.52°Brix，苹果为 12.79°Brix。

常见的果蔬处理压力为 300～500 MPa，同时由于设备能力限制，本研究选择的最高压力为500 MPa。探究压力大小对果蔬的影响时，选择压力分别为 200、300、400 和 500 MPa，保压时间为5 min作为处理条件；探究保压时间对果蔬影响时，选择 5、10、15 和 20 min，处理压力为 400 MPa 作为处理条件，果蔬样品选择成熟度相近，大小尺寸相似，果蔬样品的质量为(50±3)g，果蔬与糖液的质量比为 1∶5。

1.2.2　体积变化率

采用排水法测定果蔬处理前后的体积,每个样品测定 3 次(误差小于 0.1 mL),每组样品做 3 次平行,以新鲜果蔬作为对照样,计算体积变化率[14]

$$\Delta V=\frac{V_1-V_0}{V_0}\times 100\% \tag{1}$$

式中:ΔV 表示体积变化率,%;V_0 表示高压处理前果蔬的体积,mL;V_1 表示高压处理后果蔬的体积,mL。

1.2.3　质量变化率

用吸水纸将处理完成的样品完全吸干表面水分,用天平称量其质量,每个样品测定 3 次(误差小于 0.01 g),每组样品做 3 次平行,以新鲜果蔬作为对照样,计算质量变化率[14]

$$\Delta M=\frac{M_1-M_0}{M_0}\times 100\% \tag{2}$$

式中:ΔM 表示质量变化率,%;M_0 表示高压处理前果蔬的质量,g;M_1 表示高压处理后果蔬的质量,g。

1.2.4　质构分析

测定时试样置于 TA.XT2i 质构仪 P/36R 探头下做压缩试验。参数设置为:预压速度 1.0 mm/s,下压速度 0.5 mm/s,压后上行速度 10.0 mm/s,压缩率 40%。选择硬度和回复性作为反映果蔬质构特性的 2 个指标[15]。为了方便比较,以未经超高压处理的果蔬作为对照样,将果蔬的硬度和回复性 2 个指标均换算为百分数。

1.2.5　微观结构

采用真空冷冻干燥机对经超高压处理后的果蔬样品进行干燥,用刀片将样品切成 5 mm×5 mm×1 mm 的长方体,在 SEM 样品台上涂上一层导电胶,将切好的样品粘于此胶上,对样品横断面喷金后采用扫描电镜拍摄仪进行测试。加速电压为 10 kV,选择放大 200 倍拍摄显微照片[16]。

1.2.6　数据分析

方差分析和显著性分析应用 SPSS 21.0 和 Excel 2010 进行数据分析,其中采用新复极差分析法 Duncan 进行显著性分析,置信区间取 95%。

2　结果与讨论

2.1　不同果蔬的结构与性质

5 种果蔬的密度由大到小的顺序为:荔枝、提子、胡萝卜、梨和苹果,它们还具有不同水分含量和可溶性固形物含量。5 种果蔬的性质和质构指标如表 1 所示,微观结构如图 2 所示。

表 1　5 种果蔬的性质与质构指标

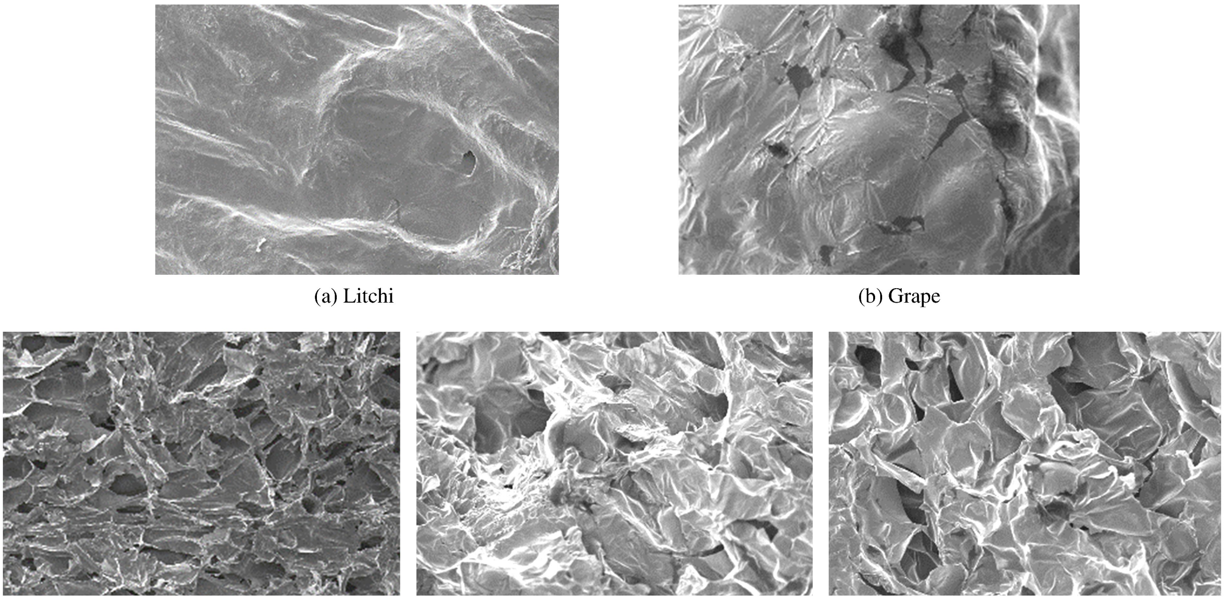
Table 1　Properties and texture values of 5 kinds of fruits and vegetables

	Density/(g·mL^{-1})	Water content/%	Soluble solids/°Brix	Hardness/g	Resilience
Litchi	1.063±0.005^a	82.004±0.037^a	18.34±0.21^a	1193.8±40.15^a	0.124±0.015^a
Grape	1.038±0.021^b	84.641±0.015^b	14.05±0.35^b	204.02±15.45^b	0.037±0.005^b
Carrot	1.028±0.017^b	88.490±0.012^c	7.47±0.13^c	13737.24±375.72^c	0.457±0.037^c
Pear	0.986±0.007^c	88.672±0.028^c	10.52±0.26^d	2470.24±54.28^d	0.077±0.016^d
Apple	0.861±0.012^d	82.703±0.027^d	12.79±0.33^e	3151.40±85.47^e	0.161±0.024^e

Note: Superscript letters in each column indicate statistically significant difference ($P<0.05$).

果蔬的质构主要由细胞壁和胞间层的结构决定,细胞壁主要由纤维素、半纤维素、果胶质、木质素等聚合物构成,果胶质在中胶层中起粘连相邻细胞的作用[17]。不同品种的果蔬在细胞壁和胞间层的结构上并不一致,核果类的荔枝和浆果类的提子纤维素含量低于 0.5%,细胞壁的机械强度较弱,属于质地柔软型果蔬;而根菜类的胡萝卜、仁果类的梨和苹果纤维素含量高于 2.0%,细胞壁的硬度较大,属于质地硬脆型果蔬[3]。结合表 1 和图 2,可以发现,这 5 种果蔬的密度和硬度等指标不存在线性相关关系。

荔枝和提子的密度较大,但硬度较小,原因是它们属于柔软型果蔬,且可溶性固形物含量较高、组织结构较为紧密。如图 2,提子的孔洞少且小,荔枝截面光滑,基本无孔隙,存在的空泡结构较少因而密度较大;梨和苹果的微观结构存在很多的空泡结构,孔隙较大,因此它们的密度也最低;胡萝卜具有密集的空泡结构,组织网络交错,层次丰富,密度较大,因而胡萝卜的硬度很大。



(a) Litchi　(b) Grape　(c) Carrot　(d) Pear　(e) Apple

图 2　5 种果蔬的微观结构

Fig. 2　Microstructure of 5 kinds of fruits and vegetables

选择这 5 种具有不同密度、水分含量、可溶性固形物、质构特性和微观结构的果蔬作为实验对象,可以更好地横向比较具有不同组织结构的果蔬受超高压处理后的变化情况,了解不同果蔬的受压特性。

2.2　压力大小对果蔬结构和性质的影响

一般认为,压力越大,果蔬受压缩的程度也越大,形变也越大,结构因此也会受到更大的破坏。采用不同的压力处理荔枝、提子、胡萝卜、梨和苹果 5 种果蔬,探究其结构变化情况。

图 3、图 4 分别表示采用 200～500 MPa 处理这 5 种果蔬后体积和质量的变化情况,具有不同上标者表示差异显著($P<0.05$)。

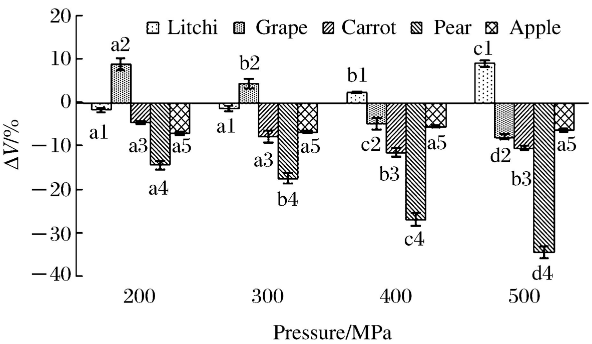


图 3　不同果蔬受压力处理后体积变化

Fig. 3　Volume change of different fruits and vegetables after HPP

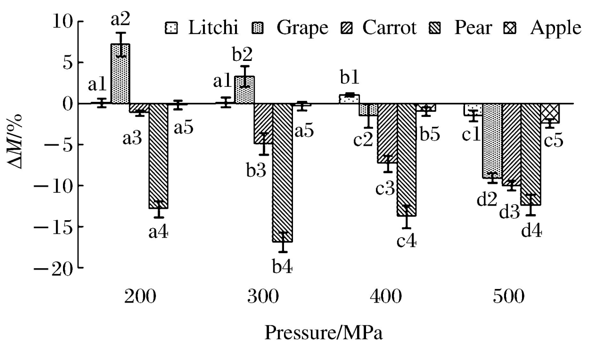


图 4　不同果蔬受压力处理后质量变化

Fig. 4　Weight changes of different fruits and vegetables after HPP

结果发现，经过超高压处理后，质地柔软的荔枝和提子会出现体积和质量增加的现象，但其变化规律不一致。荔枝在 200～300 MPa 处理后，质量和体积基本不发生变化，说明在此压力下，果肉结构基本上不受超高压的影响，出现了轻微的压缩，说明荔枝的耐压能力较强。在 400～500 MPa 时，荔枝的体积随着压力的增大而增大，质量则先增大后减小，说明加压降压过程使荔枝结构的气体重新分配，细胞空隙增大，细胞膜通透性改变，细胞内可溶性物质和液体介质均会进入荔枝细胞空隙，使体积膨胀[18-19]，而内溶物的加剧流出又会造成了荔枝质量的下降。提子在 200～300 MPa 处理后体积出现增大，质量增加，说明液体介质也会进入提子细胞间隙的空泡结构并使其体积膨胀；而在 400～500 MPa 下，提子结构无法耐受高压，组织发生坍缩，原本体积膨胀的提子体积变为压缩，导致果肉的质量和体积减小。质地硬脆的胡萝卜、梨和苹果的体积均被压缩，质量下降，但变化率差别较大，说明它们的结构受到了不同程度的影响。随着压力的增大，梨的体积缩小程度越来越大，最大超过 30%，说明梨的空泡结构很多，组织结构承压性弱，受压时形变量最大，最容易被压缩；苹果的密度最小，空泡结构也较多，但在不同压力下体积变化不大，这可能是因为其耐压性很弱，在 200 MPa 时结构已被完全破坏，随着压力的增大变化不明显；胡萝卜的体积随着压力的增大而逐渐被压缩，到 400 MPa 以上体积基本不变，说明 400 MPa 时胡萝卜的结构被完全破坏。

果蔬的体积和质量发生变化是因为果蔬细胞内部可溶性物质、气体与液体介质之间发生了物质交换[7]，但由于果蔬本身组织特性的差异，其细胞结构被破坏的程度不一致，物质交换程度也不一样。质地柔软的提子和荔枝在超高压处理时会出现体积和质量增大的情况，说明两种果肉结构具有一定的弹性，受压会发生膨胀；而质地硬脆的胡萝卜、梨和苹果在超高压处理时体积和质量只会减少，说明这 3 种果肉结构因含较多空泡，超高压处理后，细胞形态发生皱缩。

不同压力处理对 5 种果蔬的硬度的影响如图 5 所示，图中具有不同上标者表示差异显著($P<0.05$)。从图 5 可以看出，质地柔软的荔枝和提子在 200 MPa 时硬度下降程度最大，随着压力的增大，它们的硬度呈现逐渐回升的情况，这可能是由于细胞膜破裂，细胞内外压力差减小，细胞形态得以恢复和细胞壁果胶酯化度的下降引起的[20]。而质地硬脆的胡萝卜、梨和苹果硬度的变化规律不一致。苹果的硬度随着压力的增大变化不大，胡萝卜的硬度随着压力的增大而逐渐减小，但当压力大于 400 MPa 后，胡萝卜的硬度不再继续下降。

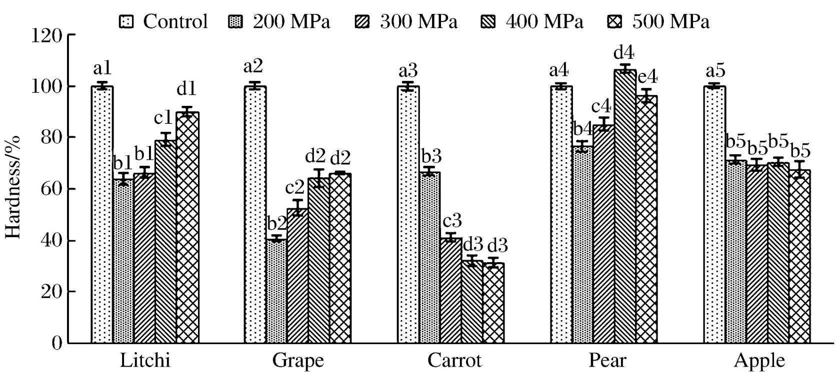


图 5　不同压力大小对果蔬硬度的影响

Fig. 5　Effects of different pressure on hardness of fruits and vegetables

Trejo 等[21]认为植物承压时可能存在一定的压力临界值，当压力大于该值后，植物组织将不再被压缩。说明在本实验条件下，苹果组织中的空气在 200 MPa 压力作用下全部排出，而在 200 MPa 压力以上时，组织不再被压缩，即表现为硬度不会进一步下降[22]，而胡萝卜的压力临界值为 400 MPa。梨随着压力的增大，硬度也呈现逐渐回升的情况，原因是相比于胡萝卜和苹果，梨的体积下降的更为明显，并随着压力的增大，其体积越被压缩，组织更为紧密，从而使硬度增加；当压力增加到 500 MPa 时，细胞结构受损严重，又表现为硬度的下降。果蔬的硬度变化与自身的密度呈现一定的关联，荔枝、提子和胡萝

卜3种密度较大的果蔬硬度受超高压处理影响而下降的程度明显要大于密度小的果蔬，硬度的变化与果蔬的含水量则没有明显的相关性；与此同时，果蔬的初始硬度也是影响因素之一，初始硬度最大的胡萝卜在不同压力处理后，硬度降低了40%～70%，下降幅度明显高于其他4种水果。

很多研究表明，果蔬制品的硬度会随着压力的增大而逐渐降低，因为压力的增大，破坏了细胞膜、细胞壁等结构，使果蔬细胞结构变形或破裂，从而影响果蔬的质构[23]；但当果蔬的结构破坏到一定程度，果胶甲酯酶(PME)从细胞中释放并与底物充分接触，使高甲酯化果胶去甲基而形成低甲酯化果胶，低甲酯化果胶通过共价键与金属离子结合，增大果蔬的硬度[12,24-25]。另一方面，超高压处理后的果蔬，细胞间结合更加紧实[26]，从而有可能使硬度等质构指标增大。同时，本研究的果蔬则是在高糖度、高酸性的液体环境中，这种液体环境也可能在高的压力条件下对果肉的质构起增强作用[27]。

图6表示不同压力对果蔬回复性的影响，图中具有不同上标者表示差异显著($P<0.05$)。可以看出，超高压处理对质地柔软的荔枝和提子回复性的影响规律不一致。对荔枝来说，随着压力的增大，回复性逐渐回升，到500 MPa时出现最大值，高于对照样；对于提子来说，随着压力的增大，回复性逐渐增强，且增强幅度很大。这也表明荔枝和提子的结构具有一定的弹性，尤其是提子，在超高压处理后还能增强其回复性。超高压处理对质地硬脆的果蔬回复性起负面影响，但其作用较小。超高压处理对梨的回复性影响不大，但会使苹果和胡萝卜的回复性下降，且压力越高，下降幅度越大。

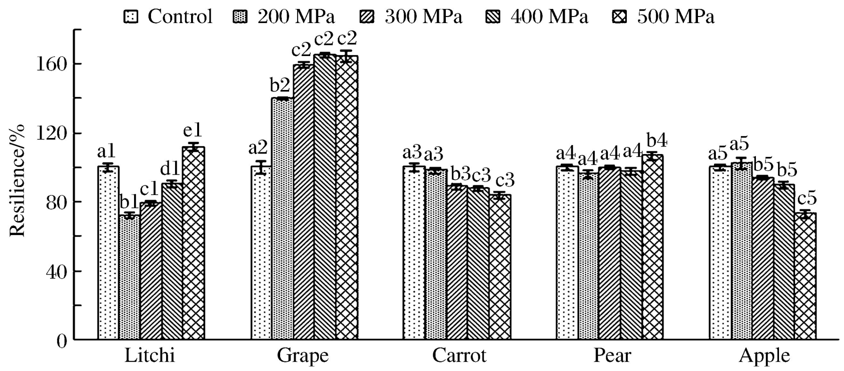


图6　不同压力大小对果蔬回复性的影响

Fig. 6　Effects of different pressure on resilience of fruits and vegetables

图7表示不同压力大小对5种果蔬处理5 min后的微观结构，不同的果蔬在超高压处理后微观结构出现不同的变化：荔枝在200 MPa下孔隙开始增大增多，随着压力增大，果肉片状裂纹增多，果肉组织被破坏程度逐渐加深[28]；提子在200 MPa的条件下微观结构变化不大，而在300和400 MPa的情况下果肉的孔隙则变得越来越大，说明压力的增大对提子的结构造成了很大的破坏；胡萝卜随着压力的增大，其多孔网络结构被打破，出现裂痕和更大的破损，因而其硬度等指标也随之出现了下降；梨在压力逐渐增大的情况下，孔隙增大增多，但结构同时被压缩而变得扁平，部分组织更为紧密，从而出现硬度先降低后升高的现象；苹果在200 MPa时结构变化不明显，随着压力的增大，苹果的孔隙增大，到400 MPa时，结构已经完全被破坏，结构被压缩而变得扁平。

综上所述，果蔬的质地会影响其耐压特性[21]。结合5种果蔬的体积变化可以看出，质地柔软、截面空泡孔隙结构较少的荔枝和提子具有更好的耐压特性，经200～300 MPa的超高压处理后体积和质量没有发生较大的变化，400～500 MPa下荔枝果肉体积才开始发生变化，体积增大；提子是随着压力的增大体积呈现先增大后减小的趋势；而质地硬脆、孔隙较多的胡萝卜、梨和苹果在不同压力处理下均呈现体积减小的趋势，且由于其组织结构的不同，梨的果肉最易被压缩，苹果耐压性弱，但果肉不易被压缩，胡萝卜组织结构致密，具有一定的耐压性。

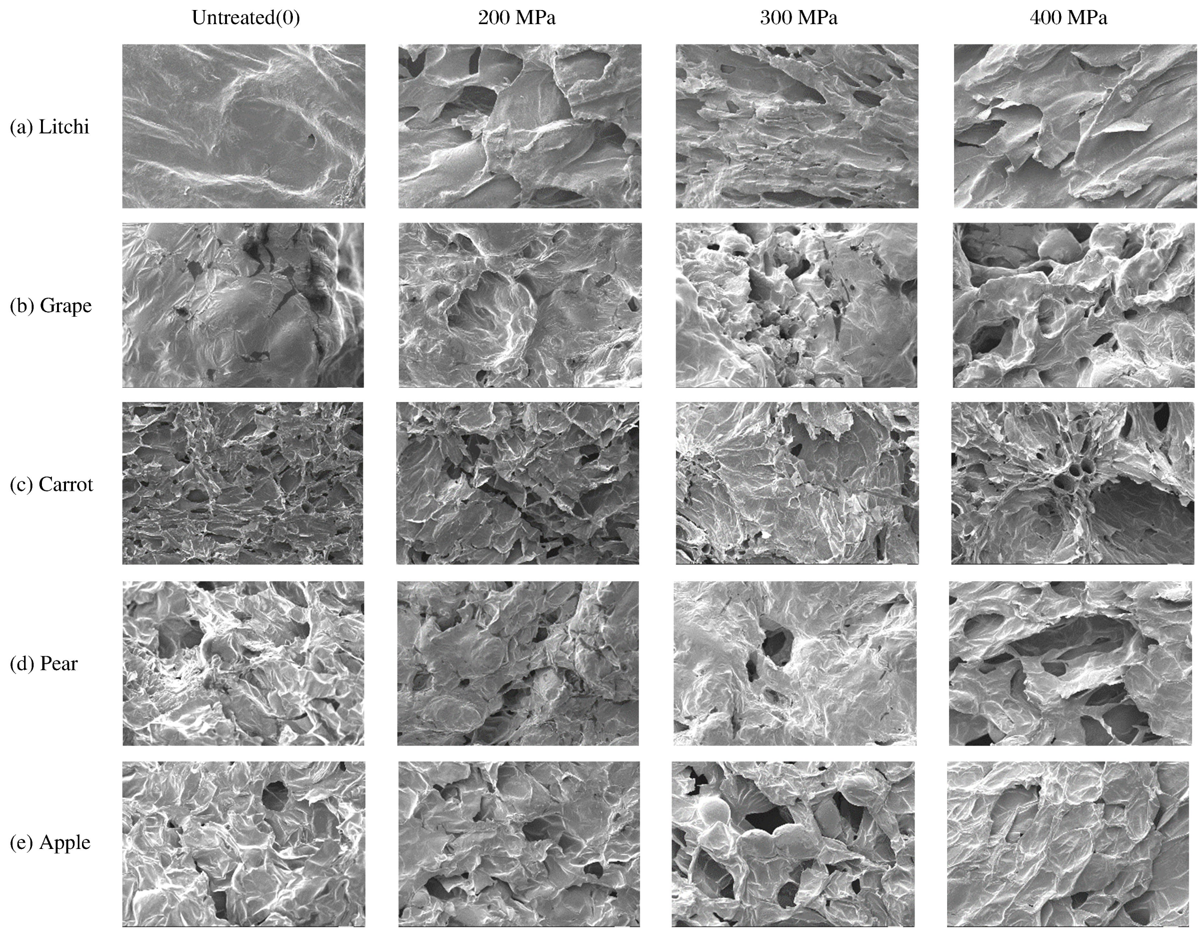


图 7　不同压力对 5 种果蔬处理 5 min 后的微观结构

Fig. 7　Microstructure of 5 kinds of fruits and vegetables treated for 5 min under different pressures

2.3　保压时间对果蔬结构和性质的影响

实验中发现不同的压力处理时间对果蔬的体积和质量影响较小,没有显著性差异($P<0.05$)(数据未列出),说明相同压力下处理时间的长短对于果蔬的体积和质量影响不大,造成果蔬质构指标降低的主要的原因是长时间的压力处理对于果肉本身结构的破坏加剧而造成的。

400 MPa 下对 5 种果蔬分别处理 5、10、15 和 20 min 后果蔬的硬度和回复性的变化情况如图 8、图 9所示,图中具有不同上标者表示差异显著($P<0.05$)。

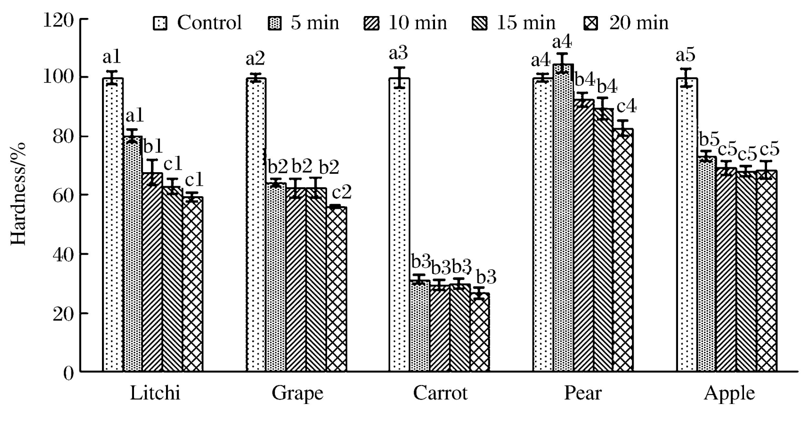


图 8　400 MPa 下不同保压时间对果蔬硬度的影响

Fig. 8　Effects of different holding times on hardness of fruits and vegetables under 400 MPa

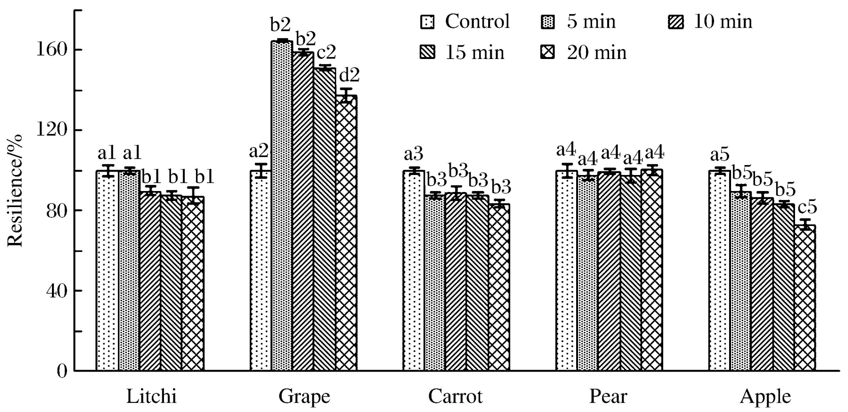


图 9　400 MPa 下不同保压时间对果蔬回复性的影响

Fig. 9　Effects of different holding times on resilience of fruits and vegetables under 400 MPa

由图 8 可以看出，梨和荔枝的硬度随着保压时间的延长而逐渐减小，苹果、提子和胡萝卜受保压时间的影响较小，随着保压时间的延长，硬度变化不大。

由图 9 看出，保压时间对果蔬的回复性影响不大，但整体来说还是随着时间的延长果蔬的回复性逐渐减小。

由以上结果可以看出，随着保压时间的延长，除胡萝卜的质构受保压时间的影响较小以外，其余 4 种果蔬的硬度和回复性均呈现下降的趋势，结合图 9 可以看出，延长处理时间会进一步破坏果蔬的结构。

图 10 显示经 400 MPa 处理、不同保压时间的 5 种果蔬的微观结构变化情况。

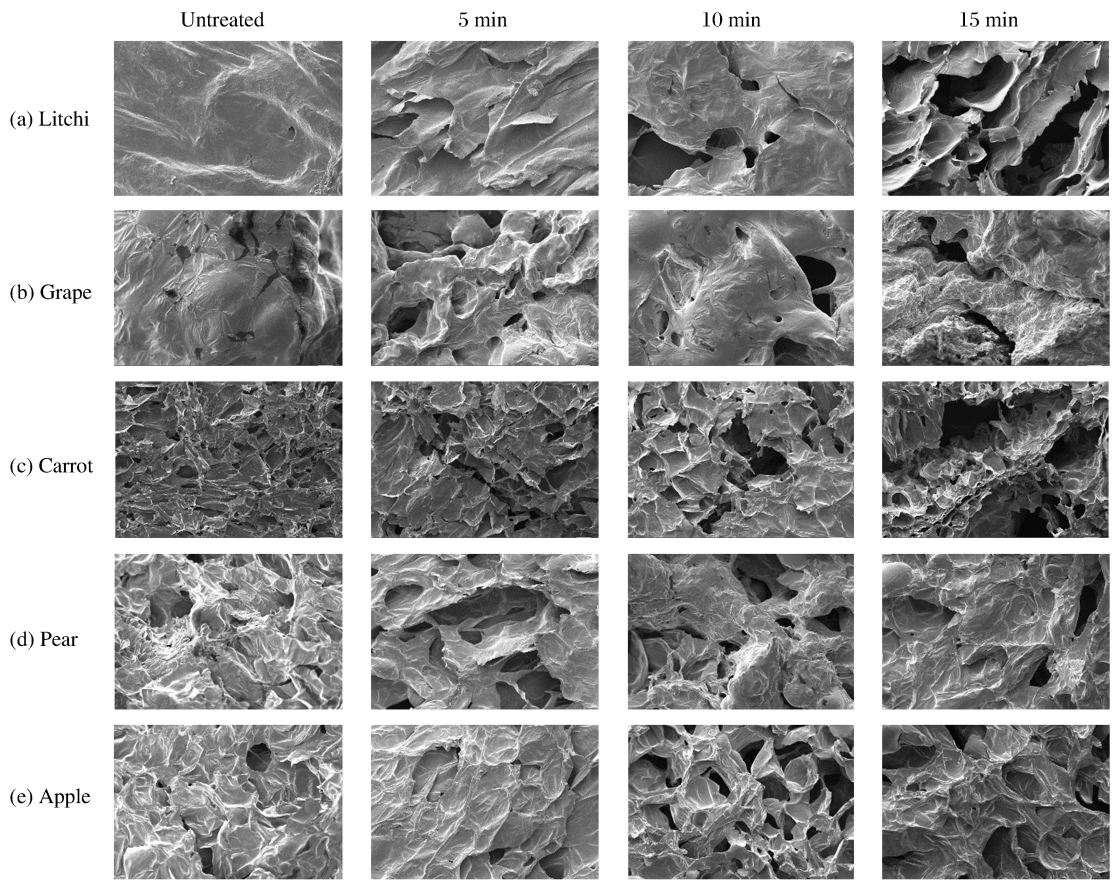


图 10　400 MPa 下不同保压时间对 5 种果蔬的微观结构影响

Fig. 10　Effects of different holding times on microstructure of 5 kinds of fruits and vegetables under 400 MPa

随着保压时间的延长,5 种果蔬的微观结构均出现了更严重的破坏,说明延长保压时间对果蔬的结构会造成更大的破坏,主要表现为果肉裂纹和孔隙的增大和增多。但不同果蔬受到的影响程度不同,其中,提子、梨和苹果受到的影响要小于荔枝和胡萝卜受到的影响,荔枝原本平整的结构经超高压处理后出现片状的裂纹,随着保压时间的延长,裂纹开始出现断裂并逐渐扩大;胡萝卜原本致密的结构在超高压处理后开始出现孔洞,保压时间越长,孔洞也越大;提子经超高压处理后,果肉的层次结构逐渐消失,果肉表面变得粗糙;梨和苹果的结构随着保压时间的延长,原本的富有层次的结构消失,被压得扁平,同时孔洞增多。因此,在生产加工过程中,在保证加工需要的情况下,应采用尽可能少的保压时间,以减小果蔬结构受到的影响。

3　结　论

选取密度、含水量、可溶性固形物含量、微观结构以及硬度、回复性存在差异的梨、苹果、荔枝、提子、胡萝卜这 5 种有代表性的果蔬作为实验对象,研究了不同压力大小和不同保压时间对果蔬结构和性质的影响。

(1) 果蔬的质地会影响其耐压特性。质地柔软、果肉截面孔隙和空泡较少的荔枝和提子具有一定的耐压性,质地硬脆、孔隙和空泡结构较多的梨、苹果和胡萝卜受压时会被压缩。由于它们的组织结构不同,耐压程度也不同,其中梨最容易被压缩,压缩率最高;苹果耐压性弱,低压时结构已被压缩,增压不会引起其体积缩小;胡萝卜由于结构致密,具有一定的耐压性。从微观结构看,所有果蔬的果肉都会随着压力的增大而变得孔隙增多增大。果蔬的密度和初始硬度这两种性质影响处理后的质构指标变化,密度和初始硬度越大,处理后果蔬的硬度等指标下降幅度也越大。

(2) 随着保压时间的延长,除胡萝卜的质构受保压时间的影响较小以外,其余 4 种果蔬的硬度、回复性均呈现下降的趋势,延长处理时间会进一步破坏果蔬的结构。

综上分析可以得出,针对包含果蔬固体和液体介质(糖液)的产品,超高压处理是一个可行的加工手段。压力大小主要根据果蔬的耐受压力进行选择,在保证加工需要的情况下,应采用尽可能少的保压时间,以减小果蔬结构受到的影响。

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Effect of High Pressure Processing on Texture and Quality of Fruits and Vegetables

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Abstract: In order to explore the effects of high pressure on the texture and quality of fruits and vegetables in different varieties, we selected 5 kinds of fruits and vegetables with different density, water content, microstructure and texture to analyze their data under different conditions of ultrahigh pressure treatment. The results showed that the texture of fruits and vegetables could affect their pressure resistance. Softer texture and less vacuolar structure exerted a good influence on pressure resistance whereas the volume of fruits and vegetables was apt to be compressed with more vacuolar structure and harder texture. There is great difference in volume variation because fruits and vegetables have different textures. The texture index would decrease more obviously after high pressure treatment, when the fruits and vegetables have higher density and greater hardness. The prolongation of the holding time will further damage the texture and structure of fruits and vegetables.

Keywords: high pressure; fruits and vegetables; texture; quality

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Effect of High Pressure Processing with Different Holding Time on the Quality of Pomfret (*Pampus argenteus*) Fillets*

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Abstract: The aim of this work was to evaluate the effect of high pressure processing (HPP) with different holding time on the quality of pomfret (*Pampus argenteus*) during cold storage. Different processing times (10, 20 and 30 min) at 200 MPa were applied and HPP treated pomfret were compared with untreated samples. Microbiological parameter (total viable count (TVC)), physicochemical (pH and total volatile base nitrogen (TVB-N), color difference, water holding capacity (WHC), texture profile analysis (TPA)) and sensory evaluation were performed respectively after the application of high pressure treatment on pomfret at the interval of 2 d (2 days). The significant difference ($P<0.05$) regarding the results have been observed between HPP and CK group after 2 d storage on the values of TVC, pH, TVB-N, ΔE(Total color difference), WHC, TPA and sensory score. The controlled groups were the first to present signs of degradation reaching rejection threshold values for all evaluated parameters. The shelf life of CK group was only 4－5 d. HPP treatment has shown to be effective in inhibiting microorganism growth, protein degradation and the drip loss in samples and the texture characteristic of samples can be better maintained. The results of correlation analysis of different groups suggested that the correlation between ΔE, pH, TVB-N and TVC were significant. The shelf-life of treated pomfret samples can be extended from 4 d to 8－12 d and the optimal condition of fresh keeping effects was 200 MPa and 30 min.

Keywords: high pressure processing (HPP); *pampus argenteus*; refrigerated storage; quality change

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Pomfret (*Pampus argenteus*), also named as butterfish, belongs to marine fish of Pompanos, which is mainly distributed in the Yellow Sea, Bohai Sea, East China Sea and South China Sea. Pomfret is rich with unsaturated fatty acid and microelement, such as selenium and magnesium, which has a potential protective effect on hyperlipidemia, high cholesterol, coronary atherosclerosis and other cardiovascular diseases[1]. Pomfret possesses high nutritional, edible and economic values, which is one of the important commercial species along the coast of China[2]. Nevertheless, similiar to other aquatic products, pomfret is easy to be spoiled during industrial processing, and hence, the quality of the pomfret could be reduced due to the influence of geography, climate, fishing season and equipment conditions[3]. Therefore, the use of high pressure processing (HPP) treatment on preservation of pomfret fillets during cold storage has great research significance and application value.

HPP is a non-thermal food preservation method and an alternative to traditional heat processing. It could minimize the quality decrease and nutrition losses without changing the structure of covalent bond or causing other undesirable changes associated with thermal processing, so the nutritional components of small molecular in bio-materials can be well kept[4-7]. HPP leads to a lot of changes in cell membranes, ribosomes, enzymes and thus affects the biochemical activity of microorganisms[8]. Previous works have demonstrated that the shelf life of fatty fish species under frozen storage condition could be prolonged by HPP treatments as a pre-treatment before freezing. The inhibition of lipid hydrolysis was also reported in Atlantic mackerel[9] and horse mackerel under the HPP conditions. The use of HPP has been approved by FDA and USDA, which is considered as a dependable technology in food processing. Hence, high pressure is a promising and novel technology to suppress the growth of microorganism[10-11], which has the potential effect to extend the shelf life of seafood[12].

HPP technology for food processing is to put food material into a high pressure vessel where liquid such as water is used as the medium to transfer pressure. Then, a certain time in isostatic pressing process (100－1 000 MPa) could be maintained, which led to the death of microorganisms and the denaturation of protein so as to cause the damage of non-covalent bond in food. Therefore, HPP technology has an effect method for inactivating enzyme, improving food quality and extending the shelf life[13]. But in previous research, the results show that HPP at 250－300 MPa can result in unwanted changes in fish products such as acceleration of lipid oxidation, discolouration and cooked appearance[14]. HPP at 200 MPa can increase the shelf life of herring and haddock to at least 13 days. The objective of present work was to study the effect of different holding time at 200 MPa HPP treatment in the quality change of pomfret fillets so as to find the optimal holding time with HPP for prolonging the shelf life of pomfret fillets.

1　Material and Methods

1.1　Sample and Pretreatments

Fresh pomfret (*Pampus argenteus*) samples were obtained directly from the local fish market (Luchao Harbor, Shanghai, China) with a mean weight varying from 200 g to 250 g in October 2016. Samples were delivered to the laboratory on ice within 30 min. After being gutted, washed, filleted and trimmed in a water-ice mixture, 100 g fillets (15 cm in length and 10 cm in width) were separated into 4 lots randomly.

1.2　High Pressure Processing (HPP) Treatment

Pomfret fillets were individually placed in polyethylene/polyamide bags and vacuum-packed. The samples were treated in a high-pressure processor (HPP. L2-600/2 Ultra High Temperature Sterilizing Machine, Huatai Sen-miao, Tianjin, China). The pressure transmission fluid was mainly produced from potable water. Pressure come-up time was approximately 10 s/8 MPa and pressure release time between 10 and 15 s. The initial water temperature was 10 ℃ and the increase in temperature due to adiabatic heating was approximately 2 ℃/100 MPa. Samples were pressure-treated in batches with 200 MPa in 10, 20and 30 min at 20 ℃, respectively, which were designed as sample HPP10, HPP20 and HPP30 respectively. The control samples were held for 10 min at ambient pressure (0.1 MPa) at 20 ℃ (CK). To avoid quality changes of fillets, the samples were kept on ice and pressurization treatments were performed as soon as the fillets were prepared. After HPP treatments, the samples were immediately stored at 4 ℃ and analyzed in triplicate after 0 (fresh meat), 2, 4, 6, 8, 10, 12 d of storage.

1.3　Microbiological Analysis

Bacterial counts were determined using the spread plate method with GB/T 4789.2—2016. Decimal dilutions of samples were prepared in sterile 0.1%(w/v) peptone solution in duplicate. From this dilution, other decimal dilutions were obtained and 1 mL of three dilutions was transferred in triplicate to Petri dishes containing 15 mL commercial plate count agar (Land-Bridge Technology Ltd, Beijing, China). Total viable counts (TVC) were determined by counting the number of colony-forming units after incubation at 30 ℃ for 72 h. Microbial analyses were carried out on day 0, 2, 4, 6, 8, 10 and 12 for each pressure treatment and for the corresponding control samples. Results were expressed as lg CFU/g (Colony Forming Units).

1.4　Physicochemical Analyses

1.4.1　PH Value

PH value was measured using a digital 320 pH metre (Mettler Toledo, Zurich, Switzerland) to demonstrate the hygienic standard of fish and other aquatic products according to GB/T 5009.45—2003.

1.4.2　Total Volatile Base Nitrogen (TVB-N)

TVB-N values were determined by FOSS method with the Kjeltec 2300 (FOSS, Hiller, Denmark) and expressed in mg nitrogen per 100 g fish sample.

1.4.3　Instrumental Color

Instrumental color was measured with the Color Difference Meter (CR-400, Konica Minolta (China) Investment Ltd, Shanghai, China) on the reflectance mode for the pomfret fillets in different groups. Color was expressed in L^*, a^* and b^* values. Readings were reported in L^* (lightness), a^* (red±green), b^* (yellow±blue) and ΔE for total color difference. The calculation of ΔE was made with the following equation.

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2} \tag{1}$$

where L_0^*, a_0^*, b_0^* are the values for untreated pomfret fillets and L^*, a^*, b^* are the values of samples with HPP.

1.4.4　Water Holding Capacity (WHC)

WHC was measured with the modified method of Sánchez-Alonso et al[15]. Briefly, a 5 g piece of fillet (W_s) wrapped in a filter paper was centrifuged (800 r/min, 10 min, 10 ℃). After centrifugation, the filter paper was removed and the fillet was weighted (W_f). W_{WHC} was expressed as gram of water in fillet after centrifugation per 100 g of water initially present in fillets.

$$W_{WHC}(\%)=(W_s-W_f)/W_s\times100\% \tag{2}$$

1.4.5 Texture Profile Analysis (TPA)

TPA was carried out so as to know the effect of pressure with different holding time on the mechanical properties related to the sensory properties of human, which performed using the TA. XT texture analyzer (Stable Micro Systems Ltd, Surrey, UK). A flat-ended cylinder (P/6) with a diameter of 6 mm was used and the size of the fillets was 10 mm×10 mm×10 mm. The flat-ended cylinder approached samples at a speed of 1 mm/s and penetrated into fillets to a sample depth of 50% of the thickness of sample. Then, the force was reduced and the fillet was allowed to rebound 5 s with the cylinder just touching the surface. The load sensor type is Auto-5 g, the data collection rate is 200. After this, the cylinder was pressed on the fillets for triple time. Two parameters were then calculated: the hardness and chewiness. Hardness is the peak force of the first compression cycle, while the chewiness is the energy required to masticate solid food to a state of readiness for swallowing, obtained from the calculation of hardness, cohesiveness and springiness.

1.4.6 Sensory Evaluation

The sensory evaluation of Pomfret fillets was shown in Table 1[16], which was made by the evaluation methods of marine fish. Sensory score of the sample was performed according to color, odor, texture and appearance by five members trained panelists from the laboratory using the method[17] with some modifications. Each assessor scored for each parameter from 1 to a maximum of 5, where 5 represented the freshest quality. Scores of separate characteristics were evaluated respectively, then summed to give the comprehensive sensory evaluation. Panelists were asked to describe whether the samples were acceptable or not, which was used to determine the shelf life of pomfret fillets.

Table 1　Sensory evaluation of pomfret (*Pampus argenteus*) fillets

Grade	Color	Odor	Texture	Appearance
Best(5)	Extremely bright	Fresh flavor	Extremely firm	Rich in elasticity
Better(4)	Very bright	Fresh seaweed flavor	Very firm	Very elasticity
Normal(3)	Moderately bright	Moderate seaweed flavor	Moderately firm	Moderate elasticity
Worse(2)	Slightly dull	No flavor	Slightly soft	Slightly elasticity
Worst(1)	Very dull	Spoiled flavor	Very soft	Inelastic

1.5 Statistical Analysis

Statistical analysis was conducted using origin (Pro) 7.5 (OriginLab Corporation, USA). All pressure treatments and measurements were conducted in triplicate. The results were expressed as mean±*S.D.*. The average and standard deviation of the data corresponding to the elemental composition analysis, ΔE, WHC, TVB-N and TVC were calculated and one-factor analysis of variance (ANOVA) was performed for each of the parameters measured as a function of the storage time.

2 Results and Discussion

2.1 Microbiological Analysis

Total viable count (TVC) is one of the most representative indexes for quality assessment. Variations of TVC in pomfret fillets during refrigerated storage were shown in Fig. 1.

The TVC in control fillets was 5.50 lg CFU/g in initial storage and increased to 6.35 lg CFU/g by day 3 (Fig. 1). HPP is effective for reducing the number of microorganism compared with that of CK one. Fillets in CK group had reached the unacceptable limits in day 10 (7.17 lg CFU/g), but TVC of HPP20 treated fillets reached at 5.96 lg CFU/g. HPP30 almost doubled the shelf life to 12 d, HPP10 and HPP20 can prolong the shelf life of pomfret fillets for at least 10 d and 12 d, respectively. Cell membranes, in particular, were employed as the main target for high pressure inactivation of bacteria, and also, influenced the permeability of cell. Thus, it could further interfere with its transmission mechanism which brings about the lack of nutrients, the change of pH value and finally due to the death of cell [18]. The TVC of fillets was decreased along with the longer holding time. The effectiveness of HPP for inhibiting the microorganism growth of seafood was reported previously and had the similar results in this research, including albacore tuna[19], cold-smoked salmon[20] and sea bass[21]. Bugueňo[22] observed cold smoked salmon when subjected to HPP (250 MPa for both 5 and 10 min) and reported that the control fillets can keep the acceptable limits for only 6 weeks based on the results of sensory evaluation and microbiological analysis, but the fillets in HPP treatment can be extended the shelf life for another 2 weeks.

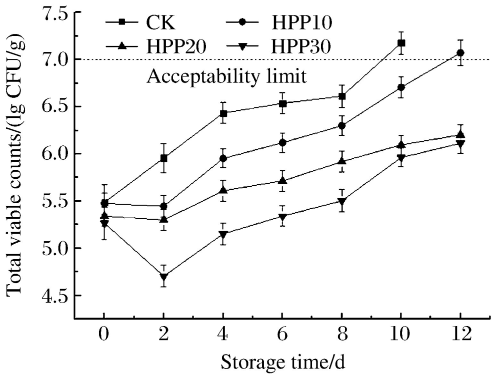

Fig. 1　Variations of TVC in pomfret fillets during refrigerated storage

As defined by the International Commission of Microbiological Standards for Foods, the maximum acceptable limit of microbial parameters in fresh and refrigerated aquatic products is 7 lg CFU/g. Briones *et al*[12] also reported that 550 MPa HPP treatments for 3 min can decreased the number of mesophilic aerobic and psychrophilic bacteria in abalone apparently, thus the shelf life of abalone in HPP treatment group increased more than 30 d compared with the control one.

2.2　pH Value

PH value, one of the most frequently used physical quality control methods for aquatic products, is affected by the changes in the concentrations of free hydrogen and hydroxyl ions due to the shifts of oxidation-reduction balance in food for the activity of microorganisms and enzymes. pH value is mainly determined by free carboxyl and amino groups with low molecular weight compounds, such as proteins, nucleic acids, and polysaccharides[4].

Table 2 showed that pH value of CK group decreased slowly for the first 4 d and increased from then on. However, pH values in treated group was lower than that of CK group and did not exceeded the acceptability limit. PH value of pomfret fillets in untreatment group was higher than that of HPP treated group from day 6 significantly and fillets with HPP treatments were lower than 7.00 during storage. In general, pH value of aquatic products had a sharp increase at the end of storage time and exceeded 7.00. The results were in agreement with Qian *et al*[1] who used agueous extracts to keep fish fresh and found that pH value had a consistent increase from day 0 while the pH value of aquatic products treated by HPP was lower than 7.00 generally. Therefore, ultra-high pressure treatment can restrain the increase of pH value during storage effectively. An increase in pH values show the accumulation of alkaline substances, such as ammonium compounds mainly derived from microbial activities. A decrease in pH value might be attributed to the inhibition of bacterial growth by HPP treatment in the pomfret fillets muscle. The post mortem metabolism of nitrogenous compounds is mainly related to the decline of fish quality.

Table 2　Variations of pH value, TVB-N, ΔE and WHC in pomfret fillets during refrigerated storage

Storage time/d	pH value				TVB-N/(mg N/100 g)			
	CK	HPP10	HPP20	HPP30	CK	HPP10	HPP20	HPP30
0	6.92 ± 0.02^{bB}	6.91 ± 0.01^{bC}	6.90 ± 0.02^{aA}	6.92 ± 0.01^{aA}	19.24 ± 1.98^{aA}	18.16 ± 0.51^{aB}	14.49 ± 2.11^{aC}	13.93 ± 0.89^{abC}
2	6.86 ± 0.00^{bcC}	6.88 ± 0.05^{aA}	6.87 ± 0.06^{aB}	6.90 ± 0.01^{aB}	23.49 ± 1.80^{acB}	19.72 ± 1.87^{acC}	15.70 ± 0.74^{acA}	14.24 ± 0.96^{abA}
4	6.87 ± 0.00^{bcB}	6.86 ± 0.02^{aC}	6.82 ± 0.01^{bA}	6.88 ± 0.06^{bA}	30.48 ± 4.07^{bA}	21.20 ± 1.27^{bC}	19.69 ± 0.10^{bB}	17.31 ± 0.64^{cB}
6	7.00 ± 0.01^{aA}	6.94 ± 0.00^{bC}	6.84 ± 0.00^{bB}	6.90 ± 0.01^{bB}	35.53 ± 3.65^{cA}	27.23 ± 1.54^{cC}	23.50 ± 2.35^{cB}	22.06 ± 0.88^{abB}
8	7.15 ± 0.01^{aA}	6.74 ± 0.01^{cC}	6.72 ± 0.01^{cB}	6.78 ± 0.04^{cB}	39.45 ± 3.90^{bA}	30.47 ± 0.42^{bC}	28.02 ± 0.66^{bB}	24.67 ± 0.65^{cB}
10	7.27 ± 0.04^{cA}	6.62 ± 0.01^{bC}	6.69 ± 0.01^{bB}	6.63 ± 0.02^{bB}	45.10 ± 2.82^{aA}	38.16 ± 0.60^{aC}	31.92 ± 1.05^{aB}	26.71 ± 1.80^{aB}
12	7.39 ± 0.022^{cA}	6.62 ± 0.01^{cC}	6.66 ± 0.04^{cB}	6.67 ± 0.00^{cB}	49.44 ± 4.42^{aB}	45.40 ± 2.04^{aA}	37.87 ± 6.32^{aC}	28.12 ± 0.61^{aC}
Storage time/d	ΔE				w_{WHC}/%			
	CK	HPP10	HPP20	HPP30	CK	HPP10	HPP20	HPP30
0	51.23 ± 0.68^{aA}	47.22 ± 6.30^{aB}	41.88 ± 0.42^{bB}	38.80 ± 1.55^{bC}	9.23 ± 1.01^{bC}	11.05 ± 1.48^{bB}	12.47 ± 1.33^{bB}	15.04 ± 1.29^{bA}
2	52.05 ± 2.29^{aA}	47.53 ± 0.81^{aB}	44.79 ± 1.21^{bB}	40.07 ± 2.25^{bC}	9.04 ± 1.36^{bC}	10.29 ± 1.95^{bB}	11.16 ± 1.33^{bB}	14.36 ± 1.27^{bA}
4	53.56 ± 4.00^{aA}	49.47 ± 1.26^{aB}	46.81 ± 0.86^{abB}	43.59 ± 2.15^{abC}	8.74 ± 1.32^{cC}	9.56 ± 1.79^{aA}	10.22 ± 1.39^{cA}	12.41 ± 1.12^{cB}
6	55.39 ± 0.02^{abA}	53.20 ± 1.14^{abB}	49.88 ± 3.81^{aB}	46.14 ± 1.71^{aC}	7.11 ± 1.25^{bB}	8.39 ± 1.27^{bA}	9.31 ± 1.38^{bA}	11.23 ± 1.52^{bC}
8	60.45 ± 0.76^{abA}	57.47 ± 2.69^{abB}	55.46 ± 4.67^{aB}	53.68 ± 2.52^{aC}	6.31 ± 1.47^{aC}	8.06 ± 1.21^{cA}	9.28 ± 1.14^{aA}	10.57 ± 1.51^{aB}
10	67.88 ± 2.43^{bA}	59.13 ± 2.02^{bB}	57.91 ± 4.85^{cB}	55.59 ± 1.82^{aC}	5.22 ± 1.06^{cC}	7.31 ± 1.22^{aB}	7.47 ± 1.25^{cB}	9.42 ± 1.03^{cA}
12	70.29 ± 5.62^{bA}	61.72 ± 1.22^{bB}	61.41 ± 2.29^{aB}	59.48 ± 2.31^{aB}	5.04 ± 1.43^{aC}	6.25 ± 1.61^{cB}	7.28 ± 1.07^{aB}	9.09 ± 1.24^{aA}

Note: (1) Values and standard deviations from three replicates are presented.
(2) Different small letters (a,b,c) in same row are significantly different ($P<0.05$).
(3) Different capital letters (A,B,C) in same column are significantly different ($P<0.05$).

2.3　Total Volatile Base Nitrogen (TVB-N) Value

According to Ref. [15], the fillets in first-grade freshness of TVB-N value is under 18 mg N/100 g, the second-grade freshness is between 18 mg N/100 g and 30 mg N/100 g. As shown in Table 2, TVB-N value of pomfret fillets in CK group has exceeded 30 mg N/100 g from day 4, which was higher than other groups obviously.

The minor differences of initial TVB-N values in all groups may be attributable to fish non-protein nitrogen content for season, size, environmental reasons and initial microbiological quality of fillets. TVB-N values showed an increase trend with the prolonging of storage time. TVB-N content in untreated pomfret fillets increased quickly and reached 30.48 mg N/100g at day 4, then kept increasing rapidly due to autolytic deamination brought about by proteolysis[21]. TVB-N values of fillets with HPP treatment increase slowly and reach 21.20, 19.69 and 17.31 mg N/100 g respectively at day 4. TVB-N values significantly increased during the following storage time and reach 39.45 mg N/100 g at day 8 in control group when compared with HPP-treated fillets, which attained much lower values of 30.47, 28.02, 24.67 mg N/100 g for 200 MPa at 10, 20 and 30 min respectively. All HPP-treated fillets were classified as better than fillets in control group. Based on the results obtained from this research, TVB-N value could be used for evaluating the deterioration degree of the pomfret fillets and describing the changes during storage. The reason for increasing slowly in TVB-N value was explained by general acidification of high glycogen content that is converted to lactic acid.

Among the pressure treatment conditions, 200 MPa for 30 min (HPP30) was found to be the most effective condition for inhibiting the production of TVB-N value.

2.4　Color Difference

ΔE values, as an indicator of total color difference, showed that there was significant difference in this parameter with different treatment. The smaller the value of ΔE, the lesser deviation in color with respect to the reference.

As shown in Table 2, it is found that the lowest score was obtained with a treatment of 200 MPa for 30 min. According to Silva *et al*[23], the values of ΔE between 0～0.2 stand for the imperceptible color difference, 0.2～0.5 for least difference, 0.5～1.5 for less difference, 1.5～3.0 for distinct, 3.0～6.0 for very distinct, 6.0～12.0 for great, and the values more than 12 for very great difference. Based on this, untreated fillets (CK) resulted in very great color differences while with very distinct color differences were obtained by compared with the HPP treatment respectively. ΔE values of HPP treated fillets indicated the progressive color changed in different fillets compared to initial values obtained after HPP. Overall, the color values varied depending on the treatment combination and there was no clear trend as to how the pressure level or hold time was interacted to affect the chromatism values.

Total color difference (ΔE) fluctuated due to both pressure levels and storage period. Fillets with 200 MPa treatments had significantly lower ΔE immediately after pressurization than that of the control. It suggested that these changes in color parameters by HPP are possibly caused by the denaturation of the myofibrillar and sarcoplasmic proteins. However, lipid oxidation is considered as another factor for the color change due to the degradation of highly unsaturated carotenoids[23].

2.5　Water Holding Capacity (WHC)

The unfolding and denaturation of muscle proteins with HPP were also attributed to WHC of fish muscle. As shown in Table 2, W_{WHC} of HPP groups were fluctuated during storage. However, W_{WHC} did not change greatly and treated group still remained in a relatively high level, while the control group had been in a low level. The pressurization may affect the protein structure of fish muscle and the water-binding of muscle protein was unstable during storage[24].

2.6　TPA

Texture attributes like hardness and springiness, which are related to the denaturation of protein, are often used as freshness indicators for fish[25].

As shown in Fig. 2, the hardness and chewiness were all affected by HPP treatment. Generally the hardness and chewiness of pomfret fillets are positive correlation as the increase of holding time and

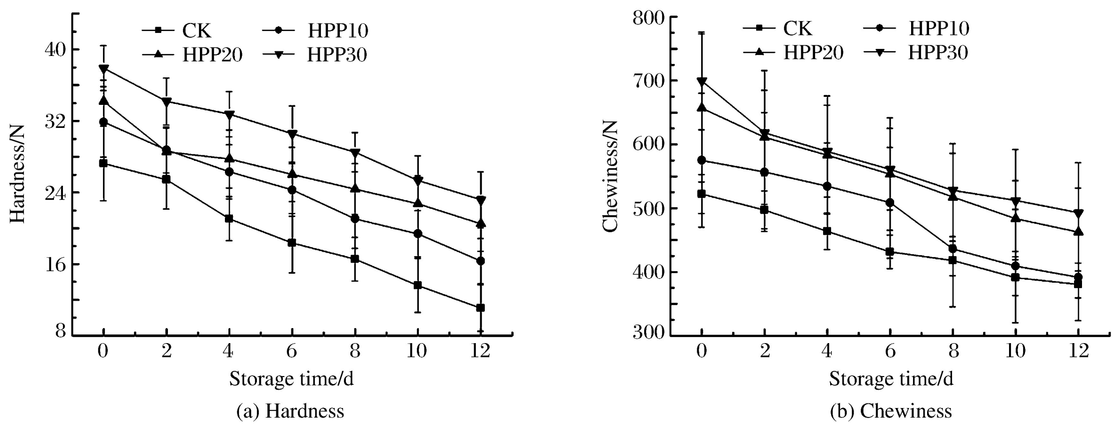

Fig. 2　Variations of TPA in pomfret fillets during refrigerated storage

gradually decreased with the storage time. The hardness of samples was decreased sharply at the initial of storage, but the value were relatively steady later. As for chewiness, a decreasing trend, similar to that of hardness, was observed with storage time.

2.7　Sensory Evaluation

The results of sensory evaluation in pomfret fillets with different treatment are presented in Fig. 3. The results indicated that sensory scores of each parameter showed a significant decline in 4 groups with the increase of storage period. Pomfret fillets with the characteristic of fresh fish had a pleasant taste and odor at day 0. Fillets in CK group at day 6 showed less elasticity and a little dark, whose sensory score was less than 2 and it means not acceptable. Fillets with HPP treatment remained good in firm muscle and elasticity. As it demonstrated that the sensory score declined slower than controlled one with the prolonging of holding time under the same pressure condition, which is in agreement with Luo *et al*[27] who found that according to sensory assessment, the smoked fish remained a shelf life of 6 and 8 weeks for untreated and HPP treated (250 MPa for 5 min and 10 min) fillets stored in cold storage conditions respectively. It was shown that the fillets with HPP treatment got the higher appearance score than the control one significantly. According to the sensory evaluation, the shelf lifes of 8－12 d achieved for HPP treated fillets corresponding to at least a 4 day-extension of the shelf life in comparison with control fillets, it indicated that the shelf life of HPP treated and untreated sample as determined by the all-around acceptability sensory scores are 12 d and 6 d respectively. Sasi *et al*[28] reported the shelf life of seer fish (*Scomberomorus commersonii*) was 11 d, the shelf lifes of gold band goatfish (*Upeneus moluccensis*) and red mullet (*Mullus barbatus*) stored in ice were 8 d and 11 d respectively. When combined with the proper temperature and processing method, it is a useful method to extend the shelf life of aquatic products. Zare[29] performed the research of HPP (200 MPa for 30 min and 220 MPa for 30 min) on microbiological, chemical, and sensory criterion of tuna when kept in cold enviroment. Lakshmanan *et al*[30] also reported the limit of acceptability for pressurized cold smoked salmon (200 MPa, 20℃ for 20 min) in refrigerated storage to be extended to 6 weeks.

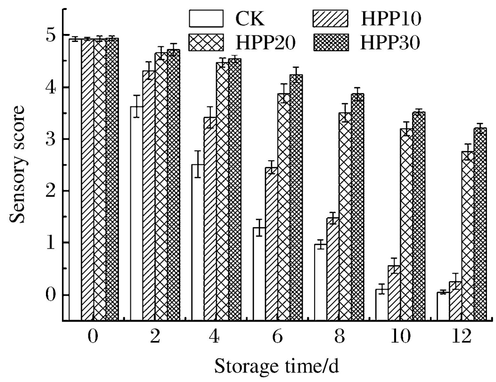

Fig. 3　Variations of sensory evaluation in pomfret fillets during refrigerated storage

2.8　Relationship between Δ*E*, pH Value, TVB-N and TVC

When compared with the correlation values of different groups (Table 3), which suggested that the correlation between Δ*E*, pH value, TVB-N and TVC were significant.

From Table 3, the difference of each group between pH value and TVB-N, TVC and TVB-N were very significant ($P<0.01$). The difference of each treatment group between Δ*E* and TVB-N value was significant ($P<0.05$). With the prolonging of shelf life, the pH value and WHC of each sample were decreased, which was a significant negative correlation. The values of Δ*E*, TVB-N and TVC were all increased, which was a significant positive correlation. It can be seen that TVB-N and TVC value can be used as one of the important indexes for evaluating the quality change of pomfret with HPP treatment after different holding time.

Table 3 Correlation analyses between ΔE, pH value, TVB-N and TVC of different groups

Group	Correlations	WHC	ΔE	pH value	TVB-N
CK	ΔE	0.117			
	pH	0.364	0.132		
	TVB-N	−0.249	−0.555**	−0.565**	
	TVC	−0.133	−0.686**	−0.452*	0.884**
HPP10	ΔE	−0.090			
	pH	0.083	0.799**		
	TVB-N	0.025	−0.534*	−0.663**	
	TVC	−0.097	−0.717**	−0.931**	0.768**
HPP20	ΔE	−0.271			
	pH	0.014	0.765**		
	TVB-N	0.017	−0.555*	−0.928**	
	TVC	0.054	−0.575**	−0.933**	0.980**
HPP30	ΔE	0.521*			
	pH	0.330	0.582**		
	TVB-N	−0.245	−0.494*	−0.891**	
	TVC	−0.038	−0.422	−0.869**	0.839**

Notes: (1) ** means the correlation is significant at the 0.01 level (2-tailed).
(2) * means the correlation is significant at the 0.05 level (2-tailed).

3 Conclusions

HPP with 200 MPa treatments have shown to be effective in inhibiting the microbial growth and the increase of TVB-N, which can remarkably prolong the shelf life of pomfret fillets during refrigerated storage. The effect of sterilization on pomfret fillets has an increasing relationship with the holding time. The shelf life of pomfret fillets can be extended from 4 d to 8−12 d by using the proposed treatment methodology. The optimal HPP condition was 200 MPa and 30 min. Therefore, HPP has shown to have great potential as an alternative technology for extending the quality of pomfret fillets during refrigerated storage.

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保压时间对超高压鲳鱼片冷藏期间品质变化的影响

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摘要:为研究保压时间对超高压鲳鱼片冷藏期间品质变化的影响,以未做任何处理样品作为对照组(CK),研究在 200 MPa 的超高压条件下,通过 10 min(HPP10)、20 min(HPP20)与 30 min(HPP30)的保压时间处理后样品的品质变化,每隔 2 d 分别对各组样品的微生物指标(Total Viable Count, TVC)、理化指标(pH 值、总挥发性盐基氮(Total Volatile Base Nitrogen, TVB-N)、色差、持水力(Water Holding Capacity, WHC)与质构分析(Texture Profile Analysis, TPA)与感官分值进行测定。结果表明,样品经过超高压处理后,其在贮藏期间的微生物生长、蛋白质降解与汁液流失得到明显抑制,其质构特性得以保持。指标间相关性分析结果显示,ΔE、pH 值、TVB-N 和 TVC 等相关性好。经 200 MPa、30 min 超高压处理能使冷藏鲳鱼片的货架期由 4 d 延至 8～12 d。

关键词:超高压处理;鲳鱼;冷藏;品质变化
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