Influence of initial gas modification on physicochemical quality attributes and molecular changes in fresh and fresh-cut fruit during modified atmosphere packaging

**初始气体改性对气调包装期间新鲜水果和鲜切水果的理化质量属性和分子变化的影响**

**Keywords:** **关键词:**

Active gas flushing 活性气体冲洗

Bioactive compounds 生物活性化合物

Volatile organic compounds 挥发性有机化合物

Gene expression 基因表达

**ABSTRACT**

The quality of fresh and fresh-cut (FC) fruit can be preserved by creating an optimal atmospheric condition around the product. Extensive research has been reported on the application and effects of initial gas modification on fruit quality.

Active modified atmosphere packaging (MAP) is a commonly applied postharvest technology to maintain quality and extend shelf life of fresh fruit; however, the response of individual fruit types to the exposed atmosphere widely varies depending on gas composition and storage condition. Hence, as the demand for active MAP application increases, identifying and understanding the role of gases used for activeMAP, their mechanism and effects on the quality of fresh and FC fruit becomes more relevant.

This review examined the effects and mechanisms by which initially modified atmosphere affects the quality of fresh and FC fruit with respect to physicochemical quality, and composition of organic acids, bio-active compounds, and secondary metabolites.

The review further highlighted on the application of genomic tools towards better understanding molecular changes in fruit subjected to MAP during postharvest handling.

**摘要:**

通过在产品周围创造最佳的大气条件，可以保持新鲜水果和鲜切水果的品质。关于初始气体改性对水果品质的应用及其影响的广泛研究已有报道。

活性气调包装（MAP）是一种常用的采后技术，可保持新鲜水果的质量并延长保质期。然而，根据气体成分和储存条件的不同，单个水果对暴露于大气中的反应差异很大。因此，随着对主动MAP应用的需求的增加，识别和了解用于主动MAP的气体的作用，其作用机理以及对新鲜水果和FC水果质量的影响变得越来越重要。

这篇综述从理化质量，有机酸，生物活性化合物和次生代谢物的组成等方面，研究了最初的改良气氛影响新鲜水果和FC水果的质量的影响和机制。

这篇综述进一步强调了基因组工具在采后处理期间更好地了解MAP水果中分子变化的应用。

**1.Introduction**

Fruit are living and respiring products that maintain active metabolism even after harvest. They are easily perishable after harvest due to their soft texture, high physiological activity, high sensitivity to microbial spoilage as well as mechanical injury, which limit the market potential and consumer access (Lu et al., 2018; Opara & Pathare, 2014;Opara, 2007; Zhang, Meng, Bhandari, Fang, & Chen, 2015). Therefore,it is necessary to seek methods to prolong the shelf life and maintain quality of fruit during postharvest handling.

**1.前言**

水果是可以呼吸和活动的产品，即使在收获后也能保持活跃的新陈代谢。 它们柔软的质地，高的生理活性，对微生物变质的高敏感性以及机械损伤会在收获后容易腐烂，这限制了市场潜力和消费者进入渠道（Lu等人，2018; Opara＆Pathare，2014; Opara ，2007；张萌，班达里，方和陈，2015）。 因此，有必要寻求延长贮藏后处理过程中货架期和保持果实品质的方法。

Changing the atmosphere around fresh and fresh-cut (FC) fruit through modified atmosphere packaging (MAP) has been reported as one innovative postharvest approach, which has positive impact on fruit quality and safety (Jo, An, &Lee, 2014; Caleb, Mahajan, Manley, & Opara, 2013; Caleb, Mahajan, AlSaid, & Opara, 2013a; Caleb, Mahajan, Al-Said, & Opara, 2013b; Caleb,Opara et al., 2013; Caleb, Opara, & Witthuhn, 2012). In this approach,fresh and FC fruit are packed in a plastic polymeric film and the atmosphere inside the package is modified to accelerate the establishment of in-package optimum gas composition and avoids high concentration of unsuitable gases (Banda, Caleb, Jacobs, & Opara,2015; Belay, Caleb, Mahajan, & Opara, 2018; Jouki & Khazaei, 2014).During respiration process, fresh and FC fruit consumes O2 and produces CO2, therefore, the concentration of O2 and CO2 inside the package is reduced and increased, respectively.

据报道，通过改良气调包装（MAP）改变新鲜水果和新鲜切割水果的气氛是一项创新的收获后方法，这对水果质量和安全性具有积极影响（Jo，An，＆Lee，2014; Caleb ，Mahajan，Manley，＆Opara，2013; Caleb，Mahajan，Al Said，＆Opara，2013a; Caleb，Mahajan，Al-Said，＆Opara，2013b; Caleb，Opara等人，2013; Caleb，Opara，＆ Witthuhn，2012年）。 在这种方法中，将新鲜水果和FC水果包装在塑料聚合物薄膜中，并对包装内部的气氛进行修改，以加快建立包装内最佳气体成分，并避免高浓度的不合适气体（Banda，Caleb， Jacobs和Opara，2015年; Belay，Caleb，Mahajan和Opara，2018年; Jouki和Khazaei，2014年）。在呼吸过程中，新鲜水果和FC水果会消耗O2并产生CO2，因此内部的O2和CO2浓度较高 包装分别减少和增加。

Therefore, it is important to establish optimum gas composition at equilibrium, which is determined by the product weight and physiology (respiration rate(RR), maturity stage), environmental conditions (temperature, relativehumidity), and properties of the packaging material (film thickness,permeability, perforation density, and surface area) (Caleb, Mahajan,Manley et al., 2013; Hussein, Caleb, & Opara, 2015; Hussein, Caleb,Jacobs, Manley, & Opara, 2015; Opara, Hussein, Caleb, & Mahajan,2015; Opara, Hussein, & Caleb, 2017).

因此，重要的是要在平衡状态下确定最佳的气体成分，该成分由产品的重量和生理特性（呼吸速率（RR），成熟阶段），环境条件（温度，相对湿度）以及包装材料的性能（薄膜厚度）决定。 （渗透率，射孔密度和表面积）（Caleb，Mahajan，Manley等人，2013; Hussein，Caleb，＆Opara，2015; Hussein，Caleb，Jacobs，Manley，＆Opara，2015; Opara，Hussein，Caleb， ＆Mahajan，2015; Opara，Hussein，＆Caleb，2017）。

Modified atmosphere packaging, which utilizes only the natural component of the atmosphere (O2, CO2 and N2), has achieved public acceptance due to the advantage that synthetic chemicals are not used and no toxic residue is left on produce. Initial modification of gas has the favourable effect to reduce the respiratory activity and prolonging the shelf life of fresh and FC fruit (Belay, Caleb, & Opara, 2017).

气调包装，仅利用天然大气（O2，CO2和N2）的组成部分已经公开,由于不使用合成化学品且产品上没有残留毒物的优势而被接受。 气体的初始改性具有减少呼吸活动并延长新鲜和FC水果的货架期的有利作用（Belay，Caleb和Opara，2017年）。

Removal or exclusion of O2 by displacing air with desired gas composition inhibits rate of oxidation, reduce respiration rate (RR), delay fruit ripening and slows the rate of degradation of valuable flavour and colour components (Fante, Carolina, & Boas, 2014; Li & Zhang, 2015;Teixeira, Júnior, Ferraudo, & Durigan, 2016). Similarly, super-atmospheric O2 concentration has been shown to be effective to prevent anaerobic respiration, inhibiting microbial growth and effective at reducing decay of fresh produce (Belay et al., 2017; Maghoumi et al.,2014). Elevated O2 could enhance the production of reactive oxygen species (ROS), such as superoxide, hydrogen peroxide, and hydroxyl radicals, that damage the cytoplasm and inhibit various metabolic activities, leading to deterioration of produce quality (Choudhury, Rivero,Blumwald, & Mittler, 2017).

通过用所需的气体组成置换空气来去除或排除O2会抑制氧化速率，降低呼吸速率（RR），延迟果实成熟并减慢有价值的香精和色素成分的降解速率（Fante，Carolina，＆Boas，2014; Li ＆Zhang，2015; Teixeira，Júnior，Ferraudo，＆Durigan，2016）。 同样，超大气中的氧气浓度已被证明可有效防止厌氧呼吸，抑制微生物生长并有效减少新鲜农产品的腐烂（Belay等人，2017年; Maghoumi等人，2014年）。 升高的O2可以增强活性氧（ROS）的产生，例如超氧化物，过氧化氢和羟基自由基，从而破坏细胞质并抑制各种代谢活性，从而导致生产质量下降（Choudhury，Rivero，Blumwald， ＆Mittler，2017）。

Despite the enormous advantages of modifying these gases, the use

of extremely low or high concentrations causes imminent risks as severe damage to fresh produce tissue could occur. For instance, if O2 concentration declines below the critical limit required for sustaining anaerobic respiration and fermentation would set in, resulting in the development of off-flavour (Li, Jiang, Li, Tang, & Yun, 2014). Similarly,the presence or the accumulation of high CO2 concentration could also have a negative effect on fruit quality by accelerating changes in colour(h°) and firmness, and increasing the solubilisation of pectic compounds(Teixeira et al., 2016). However, responses differ for each fresh produce when packaged under MAP conditions. Thus, it is necessary to quantify the effects of the applied atmosphere on specific produce (Lu et al.,2018).

尽管改性这些气体具有巨大的优势，但使用浓度过低或过高都会导致即将发生的风险，因为可能会对新鲜农产品组织造成严重损害。 例如，如果O2浓度降至低于维持厌氧呼吸所需的临界极限，则会发酵，从而导致异味的产生（Li，Jiang，Li，Tang和Yun，2014年）。 同样，高浓度CO2的存在或积累也可能通过加速颜色（h°）和硬度的变化以及增加果胶化合物的增溶作用而对果实品质产生负面影响（Teixeira et al。，2016）。 但是，在MAP条件下包装时，每种新鲜产品的响应都不同。 因此，有必要量化所施加的气氛对特定产品的影响（Lu等人，2018）。

The changes in quality attributed of fruit are linked to the over utilization of various substrates, as the activation and/or reduction of different metabolic pathways in response to the storage condition. Inrecent studies, these changes in quality parameters under MAP have been presented by determining the genomic interpretation and their transcriptional abundance as affected by the packaging condition (Blanch, Rosales, Mateos et al., 2015; Rosales et al., 2016).

水果品质的变化与过度各种基材的利用，如活化和/或还原响应于储存条件的不同代谢途径有关.在最近的研究中，通过确定受包装条件影响的基因组解释及其转录丰度，已经提出了MAP下质量参数的这些变化（Blanch，Rosales，Mateos等人，2015; Rosales等人，2016）.

The importance of this approach includes identifying different genes, which acted as markers of fruit senescence, ripening or stress response to the storage atmosphere. The genomic interpretation of the results thus can be used to identify candidate gene for breading new resistance cultivar for the packaging conditions (Liu et al., 2015). In this regard, individual fruit responded differently to the initially modified atmosphere conditions and controversial results were reported in the literature on how storage atmosphere impacts product quality and shelf life.

这种方法的重要性包括鉴定不同的基因，这些基因可作为果实衰老，成熟或对贮藏气氛的胁迫反应的标记。 因此，结果的基因组解释可用于鉴定候选基因，以在包装条件下为新的抗性品种添面包（Liu等人，2015）。 在这方面，单个水果对最初改变的大气条件的反应不同，有关存储气氛如何影响产品质量和保质期的文献报道了有争议的结果。

These findings show the usefulness of detailed analysis of recent literature to understand how initial gas modification under MAP affects the quality of fresh and FC fruit. Therefore, the aim of this review was to assess the mechanisms and effects of initial gas modification on the quality attributes of different fresh and FC fruit during MAP, and elucidate the response at molecular level.

这些发现表明，对最新文献进行详细分析对于了解MAP下的初始气体改性如何影响新鲜水果和FC水果的质量很有用。 因此，本综述的目的是评估MAP期间初始气体改性对不同新鲜水果和FC水果的质量属性的作用机制和效果，并阐明分子水平上的响应。

1. **Effect of initial gas modification on physical quality attributes**

**2.初始气体改性对物理质量属性的影响**

2.1. Effects on weight loss 对失重的影响

2.2. Effects on loss of colour attributes 对失去颜色属性的影响

Fruit colour is the first perception for consumer acceptability and it can be influenced by maturity, genotype and cultivar (Giuggioli et al.,2015; Pathare, Opara, & Al-Said, 2013). Fruit colour commonly associated with breakdown of cellular chloroplasts, chromoplasts and change in natural pigments (chlorophylls, anthocyanins, carotenoids,flavonoids) (Yin et al., 2016). Almost

叶绿素, 花青素, 类胡萝卜素,类黄酮

all of these pigments can be affected by packaging and storage conditions. Furthermore, change in colour is the potential indicator of change in shelf life and maturity of fresh and FC fruit (Fagundes et al., 2015). For instance, FC papaya (Waghmare & Annapure, 2013), “Eva” apple (Fante et al., 2014) and strawberry (Giuggioli et al., 2015) were shown to be affected by active MAP. High CO2 concentrations was shown to protect shredded vegetables from browning, because they limit the action of polyphenol oxidase (PPO) and the concentration in phenolic substances(Manolopoulou & Varzakas, 2013).

水果色是消费者接受度的第一个感知，它可能会受到成熟度，基因型和品种的影响（Giuggioli等，2015; Pathare，Opara和Al-Said，2013年）。 水果的颜色通常与细胞叶绿体，染色体的降解和天然色素（叶绿素，花青素，类胡萝卜素，类黄酮）的变化有关（Yin等人，2016）。 几乎所有这些色素都可能受到包装和储存条件的影响。 此外，颜色的变化是新鲜水果和FC水果货架期和成熟度变化的潜在指标（Fagundes等，2015）。 例如，FC木瓜（Waghmare和Annapure，2013），“ Eva”苹果（Fante等，2014）和草莓（Giuggioli等，2015）均受活性MAP的影响。 高的CO2浓度可保护切碎的蔬菜免于褐变，因为它们限制了多酚氧化酶（PPO）的作用和酚类物质的浓度（Manolopoulou＆Varzakas，2013）。

Colour change related to the effect of an enzymatic browning under high O2 MAP has been associated with the substrate inhibition(底物抑制) of enzyme polyphenol oxidase (PPO) (Li et al., 2014). Molinu et al. (2016)linked the increase in h° with PPO activity during storage of 'Sanguinello Comune' blood orange. Packaging material with high barrier properties significantly affected the evolution of PPO activity in FC apples, whereas, those packed in plastic bags with low O2 permeability exhibited steadier inhibition (Li, Li, Fan, Tang, & Yun, 2012). In this study, storage atmosphere significantly affected the PPO depilation(消耗),where apple cubes packed in MAP were efficiently preserved from browning when O2 is initially absent. Enzymatic browning(酶促褐变) is resulted from reactions between phenolic compounds and oxidative enzymes (氧化酶)owning to cellular (Li et al., 2014).

颜色变化与酶促褐变的影响有关,高O2 MAP与酶多酚氧化酶（PPO）的底物抑制有关（Li等，2014）。 Molinu等。（2016）将'Sanguinello Comune'血橙储存期间h°的增加与PPO活性联系起来。 具有高阻隔性的包装材料显着影响了FC苹果中PPO活性的演变，而那些包装的具有低O2渗透性的塑料袋则表现出更稳定的抑制作用（Li，Li，Fan，Tang和Yun，2012年）。 在这项研究中，存储气氛显着影响了PPO的消耗，当最初没有O2时，有效地保护了用MAP包装的苹果块免于褐变。 酶促褐变是酚类化合物与细胞内氧化酶之间的反应导致的（Li等，2014）。

Extensive literatures reported the advantage of low, high or supe-ratmospheric(高于大气压) O2 concentrations for maintaining the different colour attributes of fresh and FC fruit. Belay et al. (2017) reported that different MAP, storage time and their interaction(相互作用) had significant effect(p < 0.05) on the colour intensity(颜色强度) (C\*) of pomegranate (cv. Wonderful) arils(假种皮) stored at 5 °C. In this study, highest C\* (30.14 ± 7.1) and slight increase in hue angle (h°, 36.51 ± 8.6) were observed in arils under low O2 atmosphere (5%), whereas, super-atmospheric O2 (70%)maintained the initial values of C\* (14.91 ± 2.9) and h° (30.21 ± 5.3)throughout the storage. Martínez-Romero et al. (2013) observed a reduction in hue angle of pomegranate (cv. Mollar de Elche) arils treated with A. Vera gel, citric(柠檬酸) and ascorbic acid(抗坏血酸), while h° increased in control non-treated arils. Teixeira et al. (2016) presented the significant effect of atmospheres on h°for guava fruit kept in 5% O2 and (5% O2 + 1%CO2 and 5% O2 + 5% CO2). The results showed a significant(p < 0.05) reduction of h° under low O2 atmosphere than those that were stored in higher CO2 concentration. On the other hand, Maghoumi et al. (2014) observed no significant effect of active MAP on C\* value during storage of pomegranate (cv. Malese-Saveh) arils. However, loss of colour may not be exclusively attributed to chemical reaction, but rather to a summation of many appearance defects(外观缺陷), some of which may result from excessive loss of water (Paniagua, East, Hindmarsh, &Heyes, 2013). The tendency of a slight decreasing of C\* and increasing of h° reflect a loss of colour intensity occurring during storage (Palma,Continella, La Malfa, Gentile, & D’Aquino, 2015). According to Bessemans, Verboven, Verlinden, and Nicolaï (2016), higher h° value indicates fresh green colour, while lower h° indicate more yellowish background colour of the fruit.

大量文献报道了低，高或高于大气压的O2浓度可以保持新鲜水果和FC水果的不同色泽。 Belay等。 （2017）报告说，不同的MAP，储存时间及其相互作用对5°C储存的石榴（cv。Won derful）假种皮的颜色强度（C \*）有显着影响（p <0.05）。在这项研究中，在低氧气含量（5％）的假种皮中观察到最高C \*（30.14±7.1）和色相角（h°，36.51±8.6）略有增加，而超大气氧含量（70％）整个存储过程中C \*（14.91±2.9）和h°（30.21±5.3）的保持初始值不变。 Martínez-Romero等。 （2013年）观察到用A. Vera凝胶，柠檬酸和抗坏血酸处理过的石榴（cv。Mollar de Elche）假种的色相角减小，而未处理的对照假种皮的h°增加。 Teixeira等。 （2016年）提出了大气对5％O2和（5％O2 + 1％CO2和5％O2 + 5％CO2）中保存的番石榴果实hh的显着影响。结果表明，与在较高CO2浓度下存储的氧气相比，在低O2气氛下的h°显着降低（p <0.05）。另一方面，Maghoumi等。 （2014年）观察到在存储石榴（cv。Malese-Saveh）假种皮期间，活性MAP对C \*值无显着影响。然而，颜色损失可能不仅仅归因于化学反应，而是许多外观缺陷的总和，其中一些缺陷可能是由于水分过多流失造成的（Paniagua，East，Hindmarsh，＆Heyes，2013）。 C \*略微降低和h°升高的趋势反映了存储过程中颜色强度的损失（Palma，Continella，La Malfa，Gentile和D'Aquino，2015年）。根据Bessemans，Verboven，Verlinden和Nicolaï（2016）的说法，较高的h°值表示新鲜的绿色，而较低的h°表示该水果的背景颜色更淡。

The study conducted by Cortellino, Gobbi, Bianchi, and Rizzolo(2015) on‘Golden Delicious’ apple slices under (1% O2, 99% N2, and5% O2, 90% N2, 5% CO2) and Ar and CO2 combination (80% Ar, 20%CO2) successfully maintained the initial value of browning index (BI)(褐变指数)for 11 days of cold storage. In this study, the slices packed under Ar,N2O mix (65% N2O, 25% Ar, 5% CO2, 5% O2) showed the same behaviour as those stored in air. An atmosphere with 2.2% O2 + 5.7%CO2, under MAP induced significant BI development during cold storage of Bartlett’pears (Wang & Sugar, 2013). The effectiveness(有效性) of superatmospheric O2 in preserving colour characteristics also reported by Li,Li et al. (2012).The study stated that storage under super-atmospheric greatly contributed to slow down changes in red colour of FC pears.Similar to a\* value, the increasing rate of b\* value in samples stored in high O2 conditions was smaller than that of other packaging (low O2 and passive atmosphere) systems. The study further illustrated that super-atmospheric O2 especially 80% O2 was much effective on inhibiting discoloration(抑制变色). The loss of colour during active MAP can be maintained by monitoring(检测) and controlling both enzymatic and nonenzymatic activities. The enzymatic activities can be controlled by reducing the O2 concentration(浓度), whereas, loss of colour related to water loss can be controlled by appropriately selecting packaging film, which can regulate(调节) the in-package RH (相对湿度)(Belay et al., 2018).

由Cortellino，Gobbi，Bianchi和Rizzolo进行的研究（2015）在“黄金美味”苹果片上（氧气含量1％，氮气含量99％和5％的氧气，90％的氮气，5％的二氧化碳）以及氩气和二氧化碳的组合（80％的氩气，20％CO2）成功保持了褐化指数（BI）的初始值冷藏11天。在这项研究中，切片在Ar下填充，N2O混合物（65％N2O，25％Ar，5％CO2、5％O2）表现出与储存在空气中相同的性能。在巴特利特豌豆冷藏期间，MAP下含2.2％O2 + 5.7％CO2的大气诱导了显着的BI生成（Wang＆Sugar，2013）。 Li，Li等人也报道了超大气压O2保持颜色特性的有效性。 （2012）。研究表明，在超大气压下储存可大大减轻FC梨的红色变化。与a \*值相似，在高O2条件下存储的样品中b \*值的增加速率小于其他包装（低氧气和被动气氛）系统。研究进一步表明，超大气氧（尤其是80％的氧）在抑制变色方面非常有效。可以通过监测和控制酶和非酶活性来维持活性MAP期间的颜色损失。可以通过降低O2浓度来控制酶的活性，而可以通过适当选择包装膜来控制与水分损失有关的颜色损失，该包装膜可以调节包装内的相对湿度（Belay等人，2018）。