Shelf-life versus flavour-life for fruits and vegetables: how to evaluate this complex trait

Elizabeth A Baldwin*, Anne Plotto and Kevin Goodner
USDA/ARS Citrus & Subtropical Products Laboratory, 600 Ave S N.W., Winter Haven, FL, USA

Abstract

Purpose of review: This review highlights progress made in the recent past in understanding the flavour quality of fruits and vegetables, how it is perceived, how to evaluate this trait, and how it is affected by harvest maturity and postharvest handling.

Recent findings: The field of flavour chemistry and sensory science is rapidly evolving in terms of new detection technology, refinement of sensory techniques and understanding human perception of flavour, as well as relating sensory to instrumental data. This is especially true for fruit and vegetable flavour and needs to be taken into consideration when determining shelf-life and evaluating quality of fresh produce.

Limitations: Flavour is a complex trait comprised of many variables including sugars, acids, volatiles and other compounds and, thus, is difficult to evaluate both chemically and in terms of sensory perception. The relationship between chemical and sensory data is also sometimes difficult to interpret.

Directions of future research: The individual contributions of flavour compounds and their interactions in terms of the overall flavour quality of fresh produce needs to be determined for many important horticultural crops. The effect of harvest maturity, handling, storage temperature and shelf-life duration needs to be evaluated for flavour quality shelf-life, which may be shorter than appearance shelf-life for many commodities.

Keywords: fruit; vegetable; flavour; sugars; acids; volatiles; sensory

Abbreviations

ABBREVIATIONS

1-MCP 1-Methylcyclopropene
AEDA Aroma Extract Dilution Analysis
ANOVA Analysis of Variance
CA Controlled Atmosphere
GC Gas Chromatography
GCO Gas Chromatography–Olfactometry
HPLC High Performance Liquid Chromatography
MA Modified Atmosphere
MAP Modified Atmosphere Packaging
MS Mass Spectrometry
PCA Principle Components Analysis
SBSE Stirbar Sorbtive Extraction
SPME Solid Phase Microextraction
SS Soluble Solids
TA Titratable Acidity

*Correspondence to: Elizabeth Baldwin, USDA/ARS Citrus & Subtropical Products Laboratory, 600 Ave S N.W., Winter Haven, FL, USA. Tel./Fax: 863-293-4133; 863-299-8678; email: ebaldwin@citrus.usda.gov

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Introduction

Fruits and vegetables are important nutritional components of the human diet. Much medical and nutritional research in recent literature suggests that consuming as much fresh fruits and vegetables or their products as possible will boost the immune response, help maintain eyesight, reduce risk of cancer and heart disease and even stave off Alzheimer’s [1–3]. Unfortunately in many cases, commercially available fresh produce, while generally having excellent appearance, has mediocre to poor flavour. This can result in “turning off” consumers and subsequently decreasing the amount of fruits and vegetables in their diet. There are three main reasons for the general decline in flavour of fresh produce: genetics, harvest maturity and postharvest handling. The latter two will be discussed in terms of how they affect flavour-life in relation to appearance shelf-life, a concept recognised early on by Adel Kader in tomatoes [4*, 5*] and summarised in a recent review along with nutritional and textural shelf-life [6**].

Common sense would indicate that the starting genetic material has the inherent flavour potential and, therefore, flavour analysis should be part of breeding selection. Data has shown that there are differences in quality and quantity of flavour components among varieties of fruits and vegetables [7–11]. Then there are preharvest factors, including environmental influences during the production season that can affect flavour quality [12–14]. Adel Kader was first to draw attention to the effect of harvest maturity and postharvest handling on flavour quality in tomatoes [4*, 5*]. Harvest maturity affects flavour, especially for climacteric fruits that ripen after harvest [15]. Too often fruits and vegetables are harvested immature to access early markets, or to withstand long distance shipping due to the gain in shelf-life. Less mature fruits tend to be firmer than riper fruit and have time to ripen during transit and storage, but not always with good quality [15, 16*]. Finally, by extending shelf-life using postharvest handling techniques such as low temperature, CA or modified atmosphere (MA) storage as well as edible coatings (fruit waxes), eating quality may be decreased at some point during storage. Little attention is paid to the flavour quality of fruits and vegetables as it is affected by storage temperature [5*, 17, 18**], controlled atmosphere (CA) storage [19*, 20*], modified atmosphere packaging (MAP) [21, 22], edible coatings [23, 24*–27], or quarantine treatments [28], as long as achievable appearance is maintained and shelf-life is adequate.

One reason flavour is not evaluated for effect of harvest maturity or postharvest handling is that it is a very complex trait that is difficult to analyse. Flavour analysis is complex in that the number of components, especially volatile components, which comprise its character can number in the hundreds. The volatile components are often present in very small amounts, requiring expensive and complex analytical equipment. Determining which volatile components actually impact the flavour of a fruit or vegetable requires some sensory input. Sensory science is also complicated as well as labor intensive. The relation of sensory to chemical data requires elaborate multivariate statistics and expensive statistical software. Finally, there is much we do not understand in terms of fruit flavour components, their biosynthetic pathways in fresh produce, and how they are perceived by the gustatory and olfactory systems.

Flavour components

Flavour in fruits and vegetables is made up of sugars, acids, salts, bitter compounds such as alkaloids or flavonoids and aroma volatiles. Sugars that contribute to flavour include glucose, fructose, sucrose and in rare cases, sorbitol. Of these sugars, fructose is perceived as most sweet, followed by sucrose and then glucose. Often sucrose equivalents are used to indicate sweetness in relation to sucrose [29]. The amount of these three sugars varies among commodities. Sugars are commonly thought to be synonymous with soluble solids (SS) and simple, inexpensive refractometry can easily measure SS. However, the quantification of individual sugars requires complicated laboratory analysis for example by high performance liquid chromatography (HPLC). Although SS are often thought to be related to sweetness, this is not always the case. In some fruits, such as orange, SS relates to sweetness, while in others, like tomato and mango, the relationship is not linear [15, 30–32]. Major organic acids in fruits and vegetables include citric, malic, tartaric and occasionally oxalic acid. Different acids can affect sourness perception depending on their chemical structure. An increase in molecular weight increased sourness perception while increasing carboxyl groups decreased acidity [33]. Acids can be measured individually by HPLC [9, 10], by titration to get titratable acidity (TA) with sodium hydroxide [34], or by pH [30]. Sometimes SS, the ratio of SS/TA, or pH relate better to sourness perception than TA itself [30, 32].

Relative sugar concentrations differ for different fruits and vegetables. For example, sucrose is the major sugar in apple [35] and orange [36], while tomato has glucose and fructose in near equal amounts and only trace levels of sucrose when ripe [9, 10, 37]. In most berry fruits, sucrose, glucose and fructose are present in roughly equivalent concentrations [38, 39]. The main sugar in peaches is sucrose, but cultivars differ greatly in glucose, fructose and sorbitol ratios, which may contribute to differences in flavour [40]. Likewise, acid concentrations and ratios differ in different commodities. For example, major fruit acids are citric for citrus [36], malic for apple [35], tartaric and malic for grape [41], and oxalic and tartaric for carambola fruits [42]. Some fruits, like melon and banana, have very little acid [43].

Volatiles with odour-activity usually contribute to food flavour. It is generally accepted that when a compound is present in a food at a concentration higher than its odour threshold, that compound contributes to the food flavour [44–46]. Odour (or taste) thresholds can be measured in air, water, or a food matrix (juice) by presenting increasing concentrations of the measured compound to trained panellists against a blank,
and the threshold is the level at which panellists can perceive the compound [47, 48**]. Odour units [46] or odour activity values (OAVs) [45] are commonly used in flavour research to determine which compounds contribute to a food flavour [49, 50]. Another method includes calculation of log odour units, calculated from the ratio of the concentration of a compound in a food to its odour threshold. Compounds with positive odour units contribute to food flavour [51**]. Buttery and co-workers [18**, 52, 53], for example, determined concentrations, odour thresholds and log odour units for tomato volatiles and found 11 compounds out of 15 in fresh tomatoes, and 16 out of 40 in tomato paste to have positive log odour units. However, the aroma perception of volatile compounds is affected by the medium of evaluation. For example, both the thresholds and descriptors of some volatile compounds in tomato were different if the background media contained levels of methanol and ethanol similar to that found in fresh tomato homogenate or in the deodorised homogenate itself, compared with water [54**]. Threshold of orange volatile compounds were higher in deodorised orange juice than in water (in which few of the compounds are soluble, explaining low thresholds in water) [55]. Therefore, thresholds of aroma compounds reported for water or air may not be accurate for perception of the same aroma in a fruit or fruit juice.

Flavour chemical measurements

Although flavour is a complex trait to deal with analytically, there have been rapid increases in technology over the last two decades. Instrumentation, although ever more expensive, is orders of magnitude more sensitive, with better controls, increased automation and improved data management. There have been significant advances in sample preparation, analysis and detection.

Gas chromatography

Initially steam distillation and solvent extraction were commonly used to extract, isolate and quantify aroma compounds [56]. Unfortunately these techniques can modify the flavour profile of a sample both qualitatively and quantitatively [57]. The resulting sample concentration, however, allows identification of compounds by gas chromatography–mass spectrometry (GC/MS). More recently, purge and trap headspace sampling methods became popular. These methods involve trapping and concentrating volatile compounds on a solid support or cryotrap. Volatiles are later released from the trap using heat and analysed on GC or GC/MS [56, 57]. Static headspace methods better reflect the true flavour profile, but compounds present at low levels may not be detected or easily quantified.

Currently, there are new technologies such as solid phase microextraction (SPME) [58**] and stir bar sorptive extraction (SBSE) [59] that allow rapid and sensitive sample preparation. Both SPME and SBSE work in a similar manner in that analytes of interest are absorbed onto a coating and then released by heating. SPME has many different types of coatings with varying polarities and affinities, while SBSE is currently limited to a single non-polar coating, albeit a considerably larger amount of coating that allows for more trapping. Automation and computer control have advanced to allow high-throughput analysis along with automated data analysis and reporting [60**].

For flavour chemists, one of the main instruments is the GC. Some advances have been in inlet technology [60]. “Fast GC” [61] allows for an analysis to be completed in shorter times without loss in resolution. 2-Dimensional GC (GC-GC) [62, 63] is a technique that allows “cuts” from the first GC to be injected into a second GC for further separation by a different column type (eg, a non-polar and polar). The flame photometric detector (FPD) increases the sensitivity over the flame ionisation detector (FID) by approximately two orders of magnitude and allows for selectivity for both sulphur and phosphorus containing compounds in the same analysis [64]. Improvements in MS, both quadrupole and time of flight (TOF) [60], have lowered limits of detection by several orders of magnitude over the last 20 years. Current mass spectrometers offer approximately picogram detection limits in full scan mode and femtogram detection limits for single ion monitoring (SIM). Gas chromatography–olfactometry (GCO) is widely used in aroma research to determine contribution of individual compounds to food aroma (discussed below).

In addition, whole new types of instrumentation have been developed, such as the electronic nose (e-nose) which discriminates samples based on pattern responses of an array of sensors that respond to volatile compounds [66] and has proven to be a powerful tool in quality control and research [66*, 67]. The electronic tongue discriminates samples based on pattern responses of an array of sensors modelled after true taste receptors such as sweet, salty, sour, bitter and umami [68]. The chemsensor utilises a mass spectrometer with no chemical separation and uses each ion as a “sensor” for discrimination [69]. This allows the chemsensor to have many more sensors than an e-nose and has the added feature of having the sensors being related to specific ions [70].

Gas chromatography–olfactometry

GCO is widely used in aroma research to determine contribution of individual compounds to food aroma and represent a unique case where instrumental and sensory data come together. A GC column is split so that some of the flow goes to a sniff port where a person can determine whether or not the peaks coming off the column have odour activity. GCO has evolved into three basic techniques: determination of compound intensity such as in the Osme method [71*], determination of compound potency such as in CharmAnalysis™ [72] or aroma extract dilution analysis (AEDA) [73*] and frequency analysis of perceived compounds [74*]. In the Osme method, samples are evaluated in three or four replicates by three or four trained panellists, who rate odour-active compounds on a 15-point scale. Using this method, continuous variables are created and can be analysed by
Table 1. Different tests used in sensory analysis, test types, number of panellists required for each type of test, statistical techniques used to analyse test data and notes relating to each test.

<table>
<thead>
<tr>
<th>Test name</th>
<th>Test type (objective)</th>
<th>Number of panellists required</th>
<th>Statistical analysis</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangle test</td>
<td>Overall difference</td>
<td>20–40 (difference)</td>
<td>ANOVA, MANOVA, PCA</td>
<td>Not for fruits and vegetables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50–100 (similarity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duo-trio</td>
<td>Overall difference</td>
<td>&gt;20</td>
<td>ANOVA</td>
<td>Easy to understand</td>
</tr>
<tr>
<td>Two-out-of-five</td>
<td>Overall difference</td>
<td>10–20</td>
<td>ANOVA</td>
<td>Not for samples with carry-over;</td>
</tr>
<tr>
<td>Simple difference test</td>
<td>Overall difference</td>
<td>100–200</td>
<td>χ²-test</td>
<td>good for texture differences</td>
</tr>
<tr>
<td>Difference-from-control</td>
<td>Attribute difference</td>
<td>20–50</td>
<td>Friedman</td>
<td>For samples with strong carry-over</td>
</tr>
<tr>
<td>Ranking</td>
<td>Attribute difference, or sample preference</td>
<td>16–30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantitative Descriptive Analysis Spectrum</td>
<td>Descriptive profiling</td>
<td>10–12, trained</td>
<td>ANOVA, MANOVA, PCA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Descriptive profiling</td>
<td>10–12, trained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Choice Profiling</td>
<td>Descriptive profiling</td>
<td>10–12, semi-trained</td>
<td>GPA</td>
<td></td>
</tr>
<tr>
<td>Affective test</td>
<td>Sample preference</td>
<td>&gt; 80</td>
<td>ANOVA, MANOVA, PCA</td>
<td>Nine-point hedonic scale, just-right scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>χ²-test</td>
<td></td>
</tr>
</tbody>
</table>

*a* [139]  
*b* [48]  

**Abbreviations:** ANOVA, Analysis of Variance; MANOVA, Multivariate Analysis of Variance; PCA, Principle Components Analysis; GPA, Generalised Procrustes Analysis

Analysis of variance (ANOVA) and multivariate statistics; it has been used to quantify changes of odour-active volatiles in storage [75, 76]. In CharmAnalysis™ or AEDA, one or two panellists evaluate samples in successive dilutions until no odorant is perceived. Each compound threshold in air is therefore determined. This method represents an easy and simple screening technique, widely used in aroma research [77]. In the frequency methods, six to nine panellists indicate when an odour-active compound is present during the sniffing run. The use of a larger panel has the advantage of taking into account differences between panellists that may bias results in the former methods [78, 79*, 80]. However, information about compound potency is lost using this method and it is therefore less precise.

**Sensory evaluation**

Chemical analysis of flavour compounds generates lots of data, however, it does not shed much light on flavour quality without relationship to sensory input. Sensory tests, traditionally relying on a few experts in quality control, have become increasingly sophisticated as they are used in research to understand perception, in consumer studies and in industry for quality assurance. Sensory tests are classified into types depending on which question is to be answered. 1. “Is there any difference between two products?”; or 2. “The products are different, but how large is the difference and how can the difference be qualified or quantified?”; and finally 3. “Would a consumer prefer one product over the other?”. The first two questions do not address quality on an emotional level (preference, liking), while the third question does [48, 81, 82]. Table 1 gives a summary of the most commonly used sensory techniques.

Overall difference tests, such as the triangle and duo-trio tests, are to determine whether a general difference is perceived between two samples. The triangle test is widely used, but it is not appropriate for heterogeneous samples such as fruit and vegetables [83]. Thus the R-index [84**] was proposed as a viable alternative for fruits [85, 86]. The duo-trio test is easier to perform than the triangle test because a reference sample is provided with two of the coded samples, one of which matches the reference sample. This test is easily understood and the reference provides an anchor when looking for a difference.

In descriptive tests, panellists are trained to identify specific attributes describing a sample and then to rate these attributes using a determined scale. Descriptive profiling has been used in horticultural research to understand texture, flavour and aroma of specific fruits and then data are correlated with instrumental measurements [15, 30, 87, 88*, 91]. Descriptive profiling is also used to understand the drivers of sensory preference. Consumers can express an opinion and tell that they prefer one product over another, but they do not necessarily know why they prefer a product. Descriptive sensory analysis, on the other hand, will explain a difference between products using specific words and grading. Results from consumer panels and a descriptive profile can, therefore, be co-
related [92*, 93]. Both descriptive and consumer panels were used to evaluate and screen apple selections [94].

Simpler tests include the difference-from-control test, which is used when the size of the difference in one attribute is to be measured. This test assumes that panelists are at least familiar with the scale and the attribute of interest. Ranking tests are used to determine the difference between samples for one attribute (eg, flavour, sweetness, off flavour, preference), but the difference is not quantified. The simple ranking test is well adapted for three to six samples. It was shown to be comparable to a conventional descriptive test for a corn product [95], or give similar results to preference of apple juice in a consumer panel [85].

**Statistical analyses and relating sensory perception to chemical data**

It is important to establish a relationship between chemical and sensory data for flavour compounds and perception, respectively. Sensory techniques using a scale generate data that can be analysed with parametric statistics. Descriptive analysis, the difference-from-control test, and consumer panels are such techniques, and data are usually analysed using ANOVA to measure mean differences between samples [96**]. The use of multivariate analysis such as Principle Components Analysis (PCA) is now a common practice to present descriptive profile results in a perceptual map, with each Principal Component representing a linear combination of attributes explaining most of the variation in each dimension. Other multivariate statistical techniques that are used to map descriptive sensory data include multiple factor analysis and discriminant analysis. With a well-trained descriptive panel, the panelists are calibrated like instruments, and as such, data can be correlated with instrumental data of flavour components using the Partial Least Square statistical method [97]. More simple methods to relate sensory data to instrumental measurements (or to consumer liking) include simple linear regressions and multiple regression modelling.

**Effect of harvest maturity and postharvest handling on flavour**

Using both chemical and sensory analyses, studies have been conducted to determine the effects of harvest maturity and postharvest handling practices on the flavour of fruits and vegetables. Both harvest maturity and postharvest handling techniques are often geared toward extending the shelf-life of fresh produce after harvest. The limit on shelf-life is generally based on appearance and lack of decay, but while fruits and vegetables exhibit good visual quality, their internal quality characteristics, including flavour and texture, may have deteriorated.

**Harvest maturity**

Horticultural crops should be harvested at optimal eating quality, but practical considerations often dictate that they are harvested at a stage that minimises physical damage during shipping and handling, and maximises shelf-life. Apple, tomato and mango are good examples where harvest maturity affects the postharvest flavour quality. The climacteric stage at harvest reportedly affected ester formation in apples [98, 99, 100], while acid levels decreased with later harvest maturities and affected consumer responses for tartness [15]. Late harvested apples, however, were fruitier and sweeter than apples harvested 2 weeks earlier [101]. Harvest maturity affected both the sensory and chemical analysis of ripened tomato fruit [16]. Tomatoes harvested at the immature green stage resulted in ripened fruit with lower aroma volatile levels than mature green-harvested tomatoes. Ripened tomatoes harvested at the table ripe stage had higher intensities for sweetness, saltiness and fruity floral aroma (due to levels of both volatile and non-volatile components) than green or breaker-harvested fruit [102]. Similarly, tomato fruit harvested at the turning-red stage were sweeter, less sour and more tomato-like, with less off-flavour than earlier-harvested fruit [4]. Mango fruit harvested later were sweeter, less sour and generally had more intense aroma characteristics [31]. Harvest maturity also affected consumer acceptability ratings for mango, and trained descriptive panel ratings for sweetness, sourness and various aroma descriptors [103*].

**Postharvest factors**

Various techniques are used to extend the shelf-life of fruits and vegetables after harvest, to control postharvest decay and to eliminate pests (quarantine treatments). These storage techniques and treatments involve cold, heat, irradiation, chemical applications and different storage atmospheres. Apples, melons and tomatoes provide good examples of the effect of temperature on flavour quality. Heat treatment of apples to reduce physiological and pathological disorders inhibited emission of volatile esters important to apple flavour [104]. Levels of fructose and glucose, but not sucrose, decreased with increased storage time and storage temperature for muskmelon. However, sensory analysis did not find differences in flavour or sweetness between stored and freshly harvested melons [105]. Chilling tomato fruit to 5°C for 1 week with subsequent ripening at 20°C reduced flavour quality [5*], while tomato fruit stored at 2, 5, 10, and 13°C had reduced levels of important volatiles [17, 18]. These tomatoes had less ripe aroma and flavour as well as more off-flavour compared with fruit stored at 20°C, as judged by a trained descriptive panel [17]. Even bruising tomato fruit [106] and subjection of fruit to heat treatments for preconditioning and decay control [107] resulted in altered aroma volatile profiles.

CA can prolong the appearance shelf-life of fresh produce, especially for apples, which can be stored in cold and CA for up to 1 year [108]. Generally CA, with O2 and CO2 ranging 1–5 kPa each (in air, O2:CO2 is 21:0.03 kPa) and low temperature storage retards firmness and acidity loss, but promotes volatile loss in apples compared with air storage [109, 110, 111]. The longer the fruit remains in storage, the more...
pronounced the decrease in volatile production [112–114]. The atmosphere composition affects the total quantity of volatiles [112], as well as the type of esters produced [98, 115]. ‘Gala’ apples lost sensory quality after 2–4 months in storage [116*]. CA altered the flavour of apples [117] and if prolonged, reduced the volatile emission compared with air-stored fruit, especially lipid-derivesters [19, 100, 109]. Low O₂ CA storage decreased not only ester content, but also enzymatic activity responsible for ester biosynthesis in apples [98]. However, when atmospheres induced anaerobic metabolism, large concentrations of ethanol and acetaldehyde accumulated. The altered synthesis of fruit volatiles, resulted in increased amounts of ethyl acetate and certain ethyl esters at the expense of others [118]. Sensory analysis of CA-stored apples revealed that intensity of fruity and floral descriptors decreased after 10 weeks in CA, while sourness and astringency were higher compared with apples stored in air. Some recovery of aroma was noted after removal from CA to air [20*]. On the other hand, compared with air-stored fruit, CA storage also increased certain volatiles in tomato [119].

Use of packaging and edible coatings can create a MA with reduced O₂ and elevated CO₂ levels, similar to that of CA. Lowering O₂ and raising CO₂ levels can maintain the quality of many fresh fruits and vegetables for extended periods. However, exposure of fresh produce to O₂ levels below their tolerance level can increase anaerobic respiration and lead to the development of off-flavour [120]. In broccoli, sulphur-containing volatiles, including methanethiol and dimethyl disulfide, were produced in response to anaerobic conditions that can be created by MAP [21]. Storing strawberries in MAP altered volatile profiles depending on the MAP conditions (CO₂, mixed gases or air), enabling separation of the samples using multivariate statistics [22, 121]. Use of edible coatings affected flavour and the level of volatile flavour compounds in apple [25, 26, 122] citrus [23, 24, 123] and mango fruit [31]. The coating barrier probably induced anaerobic respiration and the synthesis of ethanol and acetaldehyde, and entrapped volatiles including ethanol and acetaldehyde [23, 31].

Gaseous treatments of fruits and vegetables are also used commercially and can affect flavour. Use of ethylene to synchronise ripening has been practiced for years on banana and tomato, and for degreening of citrus. Ethylene gassing of tomato fruit altered volatile levels [107]. The ethylene action inhibitor, 1-methylcyclopropene (1-MCP) has been widely adopted by the apple industry to extend the storage life of apples (Mattheis, personal communication) [124**]. Treatment of apple fruit with 1-MCP and methyl jasmonate inhibited both ethylene production and production of many volatile alcohols and esters, including the formation of esters from alcohols [125]. Use of 1-MCP also reduced volatile levels of several apple cultivars but maintained acidity and firmness alone or in combination with CA [109, 126*, 128]. Response to 1-MCP and storage atmosphere varies between cultivars [124**, 128] and maturity at harvest (Mattheis, personal communication). While all volatile compounds contributing to ‘Gala’ aroma decreased with 1-MCP treatment [126*], aldehydes were not affected in ‘Greensleeve’ apples [129]. Also, when 1-MCP treated apples were stored in air, volatile production recovered sooner than for untreated apples stored in CA [126*]. In fact, the effect of 1-MCP decreased over time if treated apples were stored in air, while it was the opposite for CA-stored apples. The combination of 1-MCP treatments with different storage temperatures and storage atmospheres requires storage management by cultivar and maturity, and hence allows the apple industry to target specific markets (Mattheis, personal communication). The mechanism of action of 1-MCP is not fully understood; however, research with 1-MCP and transgenic lines of apples [130*] has shown that ester production is under the control of ethylene at the level of esterification through alcohol acyl transferase. Treatment of bananas with 1-MCP also suppressed volatile production and composition, resulting in an increase in alcohols and a decrease in related esters [131]. Effect on flavour volatiles levels in tomato by 1-MCP is slight but evident [132].

Other gas treatments such as ethanol or acetaldehyde vapours were shown to delay senescence in tomato and other fruit [133*, 134]. Application of acetaldehyde and ethanol vapours to blueberries, tomatoes and pears increased their sugar content, sugar-acid ratio and hedonic sensory rating [135]. Use of ethyl vapour treatment on intact apple [136] or mango [137] to inhibit ethylene production and reduce decay in fresh-cut slices resulted in off- or altered flavour while extending appearance shelf-life. Other chemical treatments of fresh produce may also affect flavour. For example, pressure infiltration of apples with calcium chloride transiently reduced levels of important flavour volatiles [25]. Ozone treatment of strawberry fruit for decay control resulted in a 40% reduction in volatile esters [138].

Conclusions
While flavour of fruits and vegetables may be a difficult trait to analyse, both chemically and in terms of perception, it is an important part of quality. External quality (appearance) of fresh produce may influence initial sales, but internal quality characteristics such as flavour and texture drive repeat purchases. Fresh fruit and vegetable losses due to discarded “plate waste” or food not consumed is often due to consumer dissatisfaction with product quality [6*].

Repeated purchase and consumption of fruits and vegetables affect the health and well-being of the population by boosting the immune system and reducing disease and age-related disorders. Research is needed to identify instances where flavour (textural or nutritional) shelf-life falls short of shelf-life established based on appearance. This would need to be done to optimise harvest maturity and postharvest handling practices for individual commodities or even cultivars so that consumption of these healthy foods is increased.
References

Papers of interest have been highlighted as:

**Marginal importance

**Essential reading


**This paper is one of the first to recognise the effect of harvest maturity on flavour.


**This paper is one of the first to recognise the effect of postharvest handling on flavour.


**This is an excellent summary of the effects of postharvest biology and technology, as well as addressing the issue of shelf-life based on appearance versus flavour, nutrition and texture.


**This is a good example of electronic nose technology used to evaluate flavour quality as influenced by harvest maturity.


**One of the first papers to address aroma volatiles as an aspect of flavour quality.


**This comprehensive study illustrates the effect of CA on apple volatile production.


A good example of relating sensory to flavour chemistry to understand postharvest storage effect on flavour.


**This research demonstrates that coatings can cause anaerobic conditions that result in off-flavour.


45 Grosch W. Determination of potent odorants in foods by aroma extraction dilution analysis (AEDA) and calculation of odour activity values (OAVs). Flavour and Fragrance Journal 1994: 9:147–158.


50 This study illustrates best the effect of interactions between volatile compounds and the food matrix. In this case, aroma volatiles were spiked in water, an ethanol/methanol mixture and deodorised tomato homogenate. Perception thresholds were very different according to the medium of evaluation.


55 This book provides a comprehensive overview of SPME. There are ample amounts of practical as well as theoretical information.


58 This analytical textbook covers a vast range of instrumental techniques. It includes theory, basics, applications and examples.

59 Goodner KL and Rouseff RL. Using an ion-trap MS sensor to differentiate Multidimensional Preparative Scale GC (PSGC), Reissign 15th International Symposium on Chromatography, Nürnberg; 1984.


63 *Details the volatiles present in grapefruit and illustrates genetic differences.


69 *Use of GCO based on the laws of psychophysics in which the sensory response to the stimulus follows a logarithmic function.


*The basis of the AEDA technique. This is a method of determining relative aroma intensities using GCO.


*The basis of the frequency technique. This is a method of determining relative aroma intensities using GCO.


79 Acree TE and Barnard J. Gas chromatography-olfactometry and CharmAnalysis.** In: Trends in Flavour Research; Muarse H and Van Der Heij DG. (Editors); Amsterdam:Elsevier; 1994: pp. 211–220.

**Widely-used GCO technique based on odour thresholds.


**Good description of discrimination tests for determination of differences between samples.


*Good example of combining sensory and instrumental firmness data.


**A very complete study linking apple specific characteristics measured with a sensory descriptive panel and consumer panels.


**This is a highly specialised book on ANOVA applied to sensory evaluation. It may be used for ANOVA for other experimental set-ups, Very practical, it gives examples and how to perform ANOVA with SAS, SYSTAT, STATISTIX and MINITAB.


**Innovative use of logistic regression and consumer purchase response in descriptive sensory analysis and flavour composition.


108 Watkins CB, Kaperferman E and Rosenberger DA. Apple. In: Agriculture


*This is a very comprehensive review of the most recent research done with 1-MCP on fruits and vegetables.


*This study illustrates the effect of CA and 1-MCP on stored ‘Gala’ apples.


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* A very clean study of action of 1-MCP on apple esters using transgenic apples, ethylene treatments and 1-MCP.


133 Beaulieu JC and Saltveit ME. Inhibition or promotion of tomato fruit ripening by acetaldehyde and ethanol is concentration dependent and varies with initial fruit maturity. Journal of the American Society for Horticultural Science 1997: 122:392–398.

*Study shows the effect of ethanol/acetaldehyde on tomato ripening via ethylene.


