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

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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

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

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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 acceptable 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 component 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 even 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 components 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.

Test name	Test type (objective)	Number of panellists required	Statistical analysis	Notes
Triangle test	Overall difference	20–40 (difference) 50–100 (similarity)	Tables [a,b]	Not for fruits and vegetables
Duo-trio	Overall difference	>20	Tables [b]	Easy to understand
Two-out-of-five	Overall difference	10–20	Tables [b]	Not for samples with carry-over; good for texture differences
Simple difference test	Overall difference	100–200	χ^2-test	For samples with strong carry-over
Difference-from-control	Attribute difference	20–50	ANOVA	Panellists must be familiar with scale
Ranking	Attribute difference, or sample preference	16–30	Friedman	Does not indicate degree of difference Not more than five samples
Quantitative Descriptive Analysis	Descriptive profiling	10–12, trained	ANOVA, MANOVA, PCA	
Spectrum	Descriptive profiling	10–12, trained	ANOVA, MANOVA, PCA	
Free Choice Profiling	Descriptive profiling	10–12, semi-trained	GPA	
Affective test	Sample preference	> 80	ANOVA χ^2-test	Nine-point hedonic scale, just-right scale

[a] [139]
[b] [48]
Abbreviations: ANAOVA, 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 consumer 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 cor-

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 panellists 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 panellists 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 O_2 and CO_2 ranging 1–5 kPa each (in air, O_2/CO_2 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-derived esters [19, 100, 109]. Low O_2 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 O_2 and elevated CO_2 levels, similar to that of CA. Lowering O_2 and raising CO_2 levels can maintain the quality of many fresh fruits and vegetables for extended periods. However, exposure of fresh produce to O_2 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 (CO_2, 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 ethanol 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

1 Prior RL and Cao G. Antioxidant phytochemicals in fruits and vegetables: diet and health implications. HortScience 2000: 35:588–592.

2 Dillard CJ and German JB. Phytochemicals: nutraceuticals and human health. Journal Science and Food Agriculture 2000: 80:1744–1756.

3 Dai Q, Borenstein A, Wu Y, Jackson JC and Larson EB. Fruit and vegetable juices and Alzheimer's disease: the Kame project. The American Journal of Medicine 2006: 119:751–759.

4 Kader AA, Stevens MA, Albright-Holton M, Morris LL and Algazi M. Effect of fruit ripeness when picked on flavour and composition in fresh market tomatoes. Journal of the American Society for Horticultural Science 1977: 102:724–731.

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

5 Kader AA, Morris LL, Stevens MA and Albright-Holton M. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. Journal of the American Society for Horticultural Science 1978: 103:6–13.

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

6 Kader AA. A perspective on postharvest horticulture (1978–2003). HortScience 2003: 38(5):1004–1008.

**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.

7 Plotto A and Chandler CK. Taste panels evaluate quality of five University of Florida strawberry selections. Proceedings of the Florida State Horticultural Society 2006: (in press).

8 Podoski BW, Sims CA, Sargent SA, Price JF, Chandler CK and Okeefe SF. Effects of cultivar, modified atmosphere, and pre-harvest conditions on strawberry quality. Proceedings of the Florida State Horticultural Society 1997:110:246–252.

9 Baldwin EA, Nisperos MO and Moshonas MG. Quantitative analysis of flavor and other volatiles and for other constituents of two tomato varieties during ripening. Journal of the American Society for Horticultural Science 1991:116:265–269.

10 Baldwin EA, Nisperos-Carriedo MO and Moshonas MG. Quantitative analysis of flavor parameters in six Florida tomato varieties (*Lycopersicon esculentum* Mill). Journal of Agricultural and Food Chemistry 1991:39:1135–1140.

11 Stebbins RL, Duncan AA, Compton OC and Duncan D. Taste rating of new apple cultivars. Fruit Variety Journal 1991: 45:37–44.

12 Baldwin EA, Scott JW and Shewfelt RL. Quality of ripened mutant and transgenic tomato cultigens. Proceedings of the Tomato Quality Workshop 1995: 503:47–57.

13 Wright DH and Harris ND. Effect of nitrogen and potassium fertilization on tomato flavor. Journal of Agricultural and Food Chemistry 1985:33:355–358.

14 Romani R, Labavitch J, Yamashita T, Hess B and Rae H. Preharvest AVG treatment of 'Bartlett' pear fruits: Effects on ripening, color change, and volatiles. Journal for the American Society for Horticultural Science 1983: 108:1046–1049.

15 Plotto A, Azarenko AN, McDaniel MR, Crocket PW and Mattheis JP. Eating quality of 'Gala' and 'Fuji' apples from multiple harvests and storage durations. HortScience 1997: 32(5):903–908.

16 Maul F, Sargent SA, Balaban MO, Baldwin EA, Huber DJ and Sims CA. Aroma volatile profiles from ripe tomatoes are influenced by physiological maturity at harvest: an application for electronic nose technology. Journal for the American Society for Horticultural Science 1998: 123:1094–1101.

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

17 Maul F, Sargent SA, Sims CA, Baldwin EA, Balaban MO and Huber DJ. Recommended storage temperatures affect tomato flavor and aroma quality. Journal of Food Science 2000: 65:1228–1237.

18 Buttery RG, Teranishi R and Ling LC. Fresh tomato volatiles: a quantitative study. Journal of Agricultural and Food Chemistry 1987: 35:540–544.

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

19 Mattheis JP, Buchanan DA, and Fellman JK. Volatile compounds production by Bisbee Delicious apples after sequential atmosphere storage. Journal of Agricultural and Food Chemistry 1995: 43:194–199.

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

20 Plotto A, McDaniel MR and Mattheis JP. Characterization of 'Gala' apple aroma and flavor: differences between controlled atmosphere and air storage. Journal for the American Society for Horticultural Science 1999: 124:416–423.

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

21 Dan K, Todoriki S, Nagata M and Yamashita I. Formation of volatile sulfur compounds in broccoli stored under anaerobic condition. Journal of the Japanese Society for Horticultural Science 1997: 65:867–875.

22 Shamaila M, Powrie WD and Skura BJ. Analysis of volatile compounds from strawberry fruit stored under modified atmosphere packaging (MAP). Journal of Food Science 1992:57:1173–1176.

23 Baldwin EA, Nisperos-Carriedo MO, Shaw PE and Burns JK. Effect of coatings and prolonged storage conditions on fresh orange flavor volatiles, degrees Brix, and ascorbic acid levels. Journal of Agricultural and Food Chemistry 1995: 43:1321–1331.

24 Cohen E, Shalom Y and Rosenberger I. Postharvest ethanol buildup and off-flavor in Murcott tangerine fruits. Journal of the American Society for Horticultural Science 1990: 115:775–778.

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

25 Saftner RA, Conway WS and Sams CE. Postharvest calcium infiltration alone and combined with surface coating treatments influence volatile levels, respiration, ethylene production, and internal atmospheres of 'Golden Delicious' apples. Journal of the American Society for Horticultural Science 1999:124:553–558.

26 Saftner RA. The potential of fruit coating and film treatments for improving the storage and shelf-life qualities of 'Gala' and 'Golden Delicious' apples. Journal of the American Society for Horticultural Science 1999:124:682–689.

27 Baldwin EA, Burns JK, Kazokas W, Brecht JK, Hagenmaier RD, Bender RJ and Pesis E. Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. Postharvest Biology and Technology 1999: 17:215–226.

28 Mitcham EJ and McDonald RE. Respiration rate, internal atmosphere, and ethanol and acetaldehyde accumulation in heat-treated mango fruit. Postharvest Biology and Technology 1993: 3:77–86.

29 Koehler PE and Kays SJ. Sweet potato flavor: Quantitative and qualitative assessment of optimum sweetness. Journal of Food Quality 1991: 14:241–249.

30 Baldwin EA, Scott JW, Einstein MA, Malundo TMM, Carr BT, Shewfelt RL and Tandon KS. Relationship between sensory and instrumental analysis for tomato flavor. Journal of the American Society for Horticultural Science 1998: 23:906–915.

31 Baldwin EA, Malundo TMM, Bender R and Brecht JK. Interactive effects of harvest maturity, controlled atmosphere and surface coatings on mango (*Mangifera indica* L.) flavor quality. HortScience 1999: 34:514.

32 Malundo TMM, Shewfelt RL, Ware GO and Baldwin EA. Sugars and acids influence flavor properties of mango. Journal of the American Society for Horticultural Science 2001: 126:115–121.

33 Hartwig P and McDaniel M. Flavor characteristics or lactic, malic, citric, and acetic acids at various pH levels. Journal of Food Science 1995: 60:384–388.

34 Jones RA and Scott SJ. Genetic potential to improve tomato flavor in commercial F_1 hybrids. Journal of the American Society for Horticultural Science 1984: 109:318–321.

35 Knee M. Apple. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 325–346.

36 Baldwin EA. Citrus fruit. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 107–149.

37 Hobson G and Grierson D. Tomato. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 405–442.

38 Manning K. Soft Fruit. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 347–377.

39 Eck P. Blueberry. In: CRC Handbook of Fruit Set and Development. Monselise, SP. Boca Raton, FL, CRC Press; 1986: pp. 75–85.

40 Brady CJ. Stone Fruit. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 379–404.

41 Kanellis, AK and KA Roubelakis-Angelakis. Grape. In: The Biochemistry of Fruit Ripening. Seymour GB, Taylor JE and Tucker GA (editors). New York: Chapman and Hall; 1993: pp. 190–234.

42 Shaw PE and Wilson CW. Carambola and bilimbi. In: Tropical and Subtropical Fruits. Shaw PE, Chan HT and Nagy S (editors). Auburndale, FL: AgScience; 1998: pp. 521–556.

43 Wyllie SG, Leach DN, Wang Y and Shewfelt RL. Key aroma compounds in melons: Their development and cultivar dependence. In: American Chemical Society Symposium series 1995:596:248–257.

44 Patton S and Josephson DV. A method for determining significance of volatile flavor compounds in foods. Food Research 1957: 22:316–318.

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

46 Teranishi R, Buttery RG, Stern DJ and Takeoka G. Use of odor thresholds in aroma research. Lebensmittel-Wissenschaft und-Technologie 1991:24:1–5.

47 ASTM. Standard Practice Designation E 679–91. Determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits. American Society for Testing and Materials, Philadelphia; 1997.

48 Meilgaard M, Civille GV and Carr BT. Sensory evaluation techniques. 3rd edition. Boca Raton: CRC Press; 1999: 387pp.

**This book is the bible of sensory evaluation. It gives the principles of sensory evaluation and many practical examples that can be readily applied. Each newer edition has the most recent updates of this fast-advancing field.

49 Schieberle P and Hofmann T. Evaluation of the character impact odorants in fresh strawberry juice by quantitative measurements and sensory studies on model mixtures. Journal of Agricultural and Food Chemistry 1997: 45:227–232.

50 Buettner A and Schieberle P. Evaluation of aroma differences between hand-squeezed juices from Valencia Late and Navel oranges by quantitation of key odorants and flavor reconstitution experiments. Journal of Agricultural and Food Chemistry 2001: 49:2387–2394.

51 Buttery RG, Teranishi R, Flath RA and Ling LC. Fresh tomato volatiles. Composition and sensory studies. In: Flavor Chemistry: Trends and Developments. Teranishi, R, Buttery, RG and Shahidi, F (editors). Washington, DC: ACS Symposium Series; 1989 pp. 213–222.

**Comprehensive review of tomato aroma volatiles.

52 Buttery RG, Teranishi R, Ling LC and Turnbaugh JG. Quantitative and sensory studies on tomato paste volatiles. Journal of Agricultural and Food Chemistry 1990:38:336–340.

53 Buttery RG. Quantitative and sensory aspects of flavor of tomato and other vegetable and fruits. In: Flavor Science: Sensible Principles and Techniques. Acree TE and Teranishi R (editors). Washington, DC: American Chemical Society 1993 pp. 259–286.

54 Tandon KS, Baldwin EA and Shewfelt RL. Aroma perception of individual volatile compounds in fresh tomatoes (*Lycopersicon esculentum*, Mill.) as affected by the medium of evaluation. Postharvest Biology and Technology 2000:20:261–268.

**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 Plotto A, Margaría CA, Goodner KL, Goodrich R and Baldwin EA. Odour and flavour thresholds for key aroma components in an orange juice matrix: terpenes and aldehydes. Flavour and Fragrance Journal 2004: 19:491–498.

56 Teranishi R and Kint S. Sample preparation. In: Flavor science: sensible principles and techniques. Acree T and Teranishi R (editors). Washington DC: ACS Books; 1993: pp. 137–167.

57 Schamps N and Dirinck P. The use of headspace concentration of Tenax for objective evaluation of fresh fruits. In: Chemistry of foods and beverages. Charalambous G (editor). New York, NY: Academic Press; 1982: pp. 25–47.

58 Pawliszyn J. Solid phase microextraction, theory and practice. New York, NY:Wiley-VHC, Inc.; 1997: pp 247.

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

59 Baltussen E, Sandra P, David F and Cramers C. Stir bar sorptive extraction (SBSE), a novel extraction technique for aqueous samples: theory and principles. Journal of Microcolumn Separations 1999: 11:737–747.

60 Skoog DA, Holler FJ and Nieman TA. Principles of Instrumental Analysis, 5th edition. Brooks Cole; 1997: pp 832.

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

61 Brichford N and Parry R. Fast GC/MS characterization of flavor mixtures. Food Testing and Analysis 1997: 3:18–21.

62 Deans DR. A new technique for heart cutting in gas chromatography. Chromatographia 1968: 1:18.

63 Schomburg G, Kötter H and Stoffels W. Automated Instrumentation for Multidimensional Preparative Scale GC (PSGC), Reissign 15th International Symposium on Chromatography, Nürnberg; 1984.

64 Amirav A and Hongwu J. Pulsed flame photometer detector for gas chromatography. Analytical Chemistry 1995: 67:3305–3318.

65 Springett M. Current trends in flavor analysis. Food Manufacture 1991: 66:32–34.

66 Shaw PE, Rouseff RL, Goodner KL, Bazemore R, Nordby HE, Widmer WW. Comparison of headspace GC and electronic sensor techniques for classification of processed orange juices. Lebensmittel-Wissenschaft und Technologie 2000: 33: 331–334.

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

67 Goodner KL, Baldwin EA, Jordán MJ and Shaw PE. The use of an electronic nose to differentiate NFC orange juices. Proceedings of the Florida State Horticultural Society 2000: 113:304–306.

68 Tan T, Schmitt V and Isz S. Electronic tongue: a new dimension in sensory analysis. Food Technology 2001: 55:44–50.

69 Dittman B, Nitz S and Homer G. A new chemical sensor on a mass spectrometric basis. Advances in Food Science 1998: 20:115–121.

70 Goodner KL and Rouseff RL. Using an ion-trap MS sensor to differentiate and identify individual components in grapefruit juice headspace volatiles. Journal of Agricultural and Food Chemistry 2001: 49:250–253.

71 McDaniel MR, Miranda-Lopez R, Watson BT, Micheals NJ and Libbey LM. Pinot noir aroma: a sensory/gas chromatographic approach. In: Flavors and Off-Flavors; Charalambous G. (Editor). Amsterdam: Elsevier; 1990 pp 23–36.

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

72 Acree TE, Barnard J and Cunningham DG. A procedure for the sensory analysis of gas chromatographic effluents. Food Chemistry 1984: 14:273–286.

73 Grosch W. Detection of potent odorants in foods by aroma extract dilution analysis. Trends in Food Science Technology 1993: 4:68–73.

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

74 Pollien P, Ott A, Montignon F, Baumgartner M, Muñoz-Box R and Chaintreau A. Hyphenated headspace-gas chromatography-sniffing technique: Screening of impact odorants and quantitative aromagram comparisons. Journal of Agricultural and Food Chemistry 1997: 45:2630–2637.

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

75 Da Silva MAAP, Elder V, Lederer CL, Lundahl DS and McDaniel MR. Flavor properties and stability of a corn-based snack: relating sensory, gas-chromatography, and mass-spectrometry data. In: ShelfLife Studies of Foods and Beverages; Charalambous G. (Editor). Amsterdam:Elsevier; 1993: pp. 707–738.

76 Plotto A, Mattheis JP and McDaniel MR. Characterization of changes in 'Gala' apple aroma during storage using Osme analysis, a gas chromatography-olfactometry technique. Journal American Society Horticultural Science 2000: 125:714–722.

77 Ferreira V, Pet'Ka J and Aznar M. Aroma extract dilution analysis. Precision and optimal experimental design. Journal of Agricultural and Food Chemistry 2002: 50:1508–1514.

78 Abbott NP, Etiévant P, Issanchou S and Langlois D. Critical evaluation of two commonly used techniques for the treatment of data from extract dilution sniffing analysis. Journal of Agricultural and Food Chemistry 1993: 41:1698–1703.

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

*Widely-used GCO technique based on odour thresholds.

80 Marin AB, Acree TE and Barnard J. Variation in odor detection thresholds determined by charm analysis. Chemical Senses 1988: 13:435–444.

81 Carpenter, RP, Lyon DH and Hasdell, TA. Guidelines for Sensory Analysis. In: Food Product Development and Quality Control. 2nd Ed. Githersburg, MD: Aspen Publishers, Inc.; 2000: 210 pp.

82 Lawless, HT and Heymann, H. Sensory Evaluation of Food. Principles and Practices. Gaithersburg, MD: Aspen Publishers, Inc.; 1999 827 pp.

83 Aust LB, Gacula Jr MC, Beard SA and Washam II, RW. Degree of difference test method in sensory evaluation of heterogeneous product types. Journal of Food Science 1985: 50:511–513.

84 O'Mahony M. Understanding discrimination tests: a user-friendly treatment of response bias, rating and ranking R-index tests and their relationship with signal detection. Journal of Sensory Studies 1991: 7:1–47.

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

85 Cliff MA, King MC, Scaman C and Edwards BJ. Evaluation of R-indices for preference testing of apple juices. Food Quality and Preference 1997: 8 (3):241–246.

86 Harker FR, Norquay C, Amos R, Jackman R, Gunson A and Williams M. The use and misuse of discrimination tests for assessing the sensory properties of fruit and vegetables. Postharvest Biology and Technology 2005: 38: 195–201.

87 Baldwin EA, Goodner KL, Plotto A, Pritchett K and Einstein M. Effect of volatiles and their concentration on perception of tomato descriptors. Journal of Food Science 2004: 69(8):S310–318.

88 Abbott JA, Affeldt HA and Liljedahl LA. Firmness measurement of stored 'Delicious' apples by sensory methods, Magness-Taylor, and sonic transmission. Journal of the American Society for Horticultural Science 1992: 117:590–595.

*Good example of combining sensory and instrumental firmness data.

89 Abbott JA, Massie DR, Upchurch BL and Hruchka WR. Nondestructive sonic firmness measurements of apples. Transactions of the American Society of Agricultural Engineers. 1995: 38(5):1461–1466.

90 Karlsen AM, Aaby K, Sivertsen H, Baardseth P and Ellekjær MR. Instrumental and sensory analysis of fresh Norwegian and imported apples. Food Quality and Preference 1999: 10:305–314.

91 Watada AE and Abbott JA. Apple quality: influences of pre- and postharvest factors and estimation by objective methods. In: Evaluation of Quality of Fruits and Vegetables. Pattee HE (editor). Westport, CN: AVI Publisher; 1985 pp. 63–81.

92 Daillant-Spinnler B, MacFie HJH, Beyts PK and Hedderley D. Relationships between perceived sensory properties and major preference directions of 12 varieties of apples from the Southern hemisphere. Food Quality and Preference 1996: 7:113–126.

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

93 Jaeger SR, Andani Z, Wakeling IN and MacFie HJH. Consumer preferences for fresh and aged apples: a cross-cultural comparison. Food Quality and Preference 1998: 9:355–366.

94 Hampson CR, Quamme HA, Hall JW, MacDonald RA, King MC and Cliff MA. Sensory evaluation as a selection tool in apple breeding. Euphytica 2000: 111: 79–90.

95 Rodrigue N, Guillet M, Fortin J and Martin JF. Comparing information obtained from ranking and descriptive tests of four sweet corn products. Food Quality and Preference 2000:11: 47–54.

96 Lea P, Næs T and Rødbotten M. Analysis of Variance for Sensory Data. Wiley, New York, 1998 102 pp.

**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.

97 Martens M and Martens H. Partial leas square regression. In: Statistical Procedures in Food Research. Piggott JR (editor) England: Elsevier Applied Science Publishers Ltd.; 1986: pp. 293–359.

98 Fellman JK, Mattinson DS, Bostick BC, Mattheis JP and Patterson ME. Ester biosynthesis in 'Rome' apples subjected to low-oxygen atmospheres. Postharvest Biology and Technology 1993: 3:201–214.

99 Fellman JK, Miller TW, Mattinson DS and Mattheis JP. Factors that influence biosynthesis of volatile flavor compounds in apple fruits. HortScience 2000: 35(6):1026–1033.

100 Fellman JK, Rudell DR, Mattinson ES and Mattheis, JP. Harvest maturity relationship to flavor regeneration after CA-storage of 'Delicious' apples. Acta Horticulturae 2003: 600:541–554.

101 Cliff MA, Lau OL and King MC. Sensory characteristics of controlled atmosphere- and air-stored 'Gala' apples. Journal of Food Quality 1998:21:239–249.

102 Watada AE and Aulenbach BB. Chemical and sensory qualities of fresh market tomatoes. Journal of Food Science 1979: 44:1013–1016.

103 Malundo TMM, Shewfelt RL, Ware GO and Baldwin EA. An alternative method for relating consumer and descriptive data used to identify critical flavor properties of mango (*Mangifera indica* L.). Journal of Sensory Studies 2001: 16(2):199–214.

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

104 Fallik E, Archbold DD, Hamilton-Kemp TR, Loughrin JH and Collins RW. Heat treatment temporarily inhibits aroma volatile compound emission from Golden Delicious apples. Journal Agriculture and Food Chemistry 1997: 45:4038–4041.

105 Cohen RA and Hicks JR. Effect of storage on quality and sugars in muskmelon. Journal of the American Society for Horticultural Science 1996: 111:553–557.

106 Moretti CL, Baldwin EA, Sargent SA and Huber DJ. Internal bruising alters aroma volatile profiles in tomato fruit tissues. HortScience 2002: 37(2):378–382.

107 McDonald RE, McCollum TJ and Baldwin EA. Prestorage heat treatments influence free sterols and flavor volatiles of tomatoes stored at chilling temperature. Journal of the American Society for Horticultural Science 1996:12:531–536.

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

Handbook Number 66, The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. Gross K (editor). http://www.ba.ars.usda.gov/hb66/index.html, revised April 2004, accessed December 2006.

109 Bai J, Baldwin EA, Goodner KL, Mattheis JP and Brecht JK. Response of four apple cultivars to 1-methylcyclopropene treatment and controlled atmosphere storage. HortScience 2005: 40(5):1534–1538.

110 Patterson BD, Hatfield SGS and Knee M. Residual effects of controlled atmosphere storage on production of volatile compounds by two varieties of apples. Journal of the Science of Food and Agriculture 1974: 25:843–849.

111 Willaert GA, Dirinck PJ, De Pooter HL and Schamp NN. Objective measurements of aroma quality of Golden Delicious apples as a function of controlled-atmosphere storage time. Journal of Agricultural and Food Chemistry 1983: 31:809–813.

112 Streiff J and Bangert F. Production of volatile aroma substances by 'Golden Delicious' apple fruits after storage for various times in different CO_2 and O_2 concentrations. HortScience 1988: 63:193–199.

113 Lidster PD, Lightfoot HJ and McRae KB. Fruit quality and respiration of 'McIntosh' apples in response to ethylene, very low oxygen and carbon dioxide storage atmospheres. Sciencia Horticulturae 1983: 20:71–83.

114 Yahia E, Liu FW and Acree TE. Changes of some odor active volatiles in controlled atmosphere stored apples. Journal of Food Quality 1990:13:185–202.

115 Brackmann AJ, Streif J and Bagerth F. Relationship between a reduced aroma production and lipid metabolism of apples after long-term controlled-atmosphere storage. Journal of the American Society for Horticultural Science 1993: 118:243–247.

116 Saftner RA, Abbott JA, Conway WS, Barden CL and Vinyard BT. Instrumental and sensory quality characteristics of 'Gala' apples in response to prestorage heat, controlled atmosphere, and air storage. Journal of the American Society for Horticultural Science 2002: 127:1006–1012.

*The study combines instrumental and sensory studies to evaluate apple flavour quality as affected by postharvest treatment.

117 Yahia EM. Production of some odor-active volatiles by 'McIntosh' apples following low-ethylene controlled atmosphere storage. HortScience 1991: 26:1183–1185.

118 Mattheis JP, Buchanan DA and Fellman JK. Change in apple fruit volatiles after storage in atmospheres inducing anaerobic metabolism. Journal of Agricultural and Food Chemistry 1991:39:1602–1605.

119 Crouzet J, Signoret A, Coulibaly J and Roudsari MH. Influence of controlled atmosphere storage on tomato volatile components. In: The Shelf Life of Foods and Beverages. Charalambous G (editor). Amsterdam, The Netherlands: Elsevier Science Publishers; 1986: pp. 355–367.

120 Kader AA. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Technology 1986: 40 (5):99–104.

121 Dourtoglou V, Gally A, Tychopoulos V, Yannovits N, Bois F, Alexandri M, Malliou S, Rissakis M and Bony M. Effects of storage under CO_2 atmosphere on the volatiles, phenylalanine ammonia-lyase activity and water soluble constituents of strawberry fruits. In: Food Flavors: Generation, Analysis, and Process Influence. Charalambous, G (editor). New York, NY: Elsevier Science; 1995: pp. 1379–1394.

122 Bai J, Baldwin EA and Hagenmaier RH. Alternative to shellac coatings provide comparable gloss, internal gas modification and quality for 'Delicious' apple fruit. HortScience 2002: 37(3):599–563.

123 Hagenmaier RD. The flavor of mandarin hybrids with different coatings. Postharvest Biology and. Technology 2002: 24(1):79–87.

124 Watkins CB. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnology Advances 2006: 24:389–409.

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

125 Fan XT and Mattheis JP. Impact of 1-methylcyclopropene and methyl jasmonate on apple volatile production. Journal of Agricultural and Food Chemistry 1999: 47:2847–2853.

126 Mattheis JP, Fan XT and Argenta LC. Interactive response of Gala apple fruit volatile production to controlled atmosphere storage and chemical inhibition of ethylene action. Journal of Agricultural and Food Chemistry 2005: 53:4510–4516.

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

127 Saftner RA, Abbott JA, Barden CL and Conway WS. Effect of 1-Methylcyclopropene and heat treatments on ripening and pathogen-induced decay development in 'Golden Delicious' apples. Journal of the American Society for Horticultural Science 2003: 128:120–127.

128 Watkins CB, Nock JF and Whitaker BD. Response of early, mid and late season apple cultivars to postharvest application of 1-methylcyclopropene (1-MCP) under air and controlled atmosphere storage conditions. Postharvest Biology and Technology 2000:19:17–32.

129 Defilippi BG, Dandekar AM and Kader AA. Impact of suppression of ethylene action or biosynthesis on flavor metabolites in apple (*Malus domestica* Borkh) fruits. Journal of Agricultural and Food Chemistry 2004: 52:5694–5701.

130 Defilippi BG, Kader AA and Dandekar AM. Apple aroma: alcohol acyltransferase, a rate limiting step for ester biosynthesis, is regulated by ethylene. Plant Science 2005: 168:1199–1210.

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

131 Golding JB, Shearer D, McGlasson WB and Wyllie SG. Relationships between respiration, ethylene, and aroma production in ripening banana. Journal of Agricultural and Food Chemistry 1999: 47:1646–1651.

132 Mir N, Canoles M, Beaudry R, Baldwin E and Mehia CP. Inhibiting tomato ripening with 1-MCP. Journal of the American Society for Horticultural Science 2004: 129(1):112–120.

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.

134 Ritenour MA, Mangrich ME, Beaulieu JC, Rab A and Saltveit ME. Ethanol effects on the ripening of climacteric fruit. Postharvest Biology and Technology 1997: 12:35–42.

135 Paz O, Janes HW, Prevost BA and Frenkel C. Enhancement of fruit sensory quality by post-harvest applications of acetaldehyde and ethanol. Journal of Food Science 1981: 47:270–276.

136 Bai J, Baldwin EA, Soliva-Fortuny R, Mattheis JP, Stanley R, Perera C and Brecht JK. Effect of pretreatment of intact 'Gala' apple with ethanol vapor, heat or 1-methylcyclopropene on quality and shelf life of fresh-cut slices. Journal of the American Society for Horticultural Science 2004: 129(4):583–593.

137 Plotto A, Bai J, Narciso JA, Brecht JK and Baldwin EA. Ethanol vapor prior to processing extends fresh-cut mango storage by decreasing spoilage, but does not always delay ripening. Postharvest Biology and Technology 2006: 39:134–145.

138 Perez AG, Olias R, Sanz C and Olias JM. Furanones in strawberries: Evolution during ripening and postharvest shelf life. Journal of Agricultural and Food Chemistry 1996:44:3620–3624.

Additionally, fruits and vegetables may have a beneficial effect on the naturally occurring bacteria in our gut. Aune also notes that itâ€™s unlikely all of the beneficial compounds in fruits and veggies could be replicated in pill form. How does your diet stack up to new USDA guidelines?Â Flavor with fruits and vegetables rather than dressings and dips,â€ she said. â€œFreezing fruit is also a great way to enjoy natureâ€™s candy in the evenings, and cauliflower rice is a newer and tastier way to reduce carb intake by replacing with a vegetable source.â€Â He also wants to see more study done on how fruit and vegetable intake may affect causes of death other than cancer and cardiovascular disease.