

An Overview of Sensory Quality of Apple Fruit

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Abstract

Sensory analysis performed by trained assessors or consumers is the only direct approach to measure perceptible properties of food products and to interpret consumer's responses. Over the last 30 years different sensory techniques, alone or in combination with instrumental characterization of related physical and chemical parameters, have been proposed to study the eating quality of apple fruit (*Malus × domestica* Borkh.) as affected by breeding activities, crop management and post-harvest practices. Cultivar has been defined as the most important source of variability. The study of post-harvest apple sensory quality demonstrated that different sensory patterns were developed by different cultivars during storage. Breeding programs, in general, adopt sensory evaluation as a fundamental tool to study the acceptability of new apple cultivars and their performance in real market conditions, even if not always by application of rigorous sensory science criteria. Texture and taste properties were found to be the most important characteristics driving consumer preferences, even if they appeared to be strongly influenced by external factors. In this review particular attention is also given to correlation studies between sensory properties and instrumental parameters, since sensory analysis requirements, in terms of facilities, commitment by panelists and time, have made the relationships between sensory and instrumental data of considerable interest to researchers wishing to find more convenient ways to describing the sensory profiles of apples.

The perception of quality in apples

Freshness is considered the key factor that determines consumer preferences in fruit and vegetable purchases (Ragaert et al., 2004). A fresh product is defined by ISO (International Standard Organization) 7563:1998 (ISO, 1998) as "a turgescient product with no signs of withering or ageing, the cells of which have not deteriorated", even if the concept of "fresh" can be interpreted by consumers in different ways depending on demographic characteristics and consumption habits (Péneau et al., 2007). Since "texture" is defined by ISO 5492:1992 (ISO, 1992) as "all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile and, where appropriate, visual and auditory receptors", textural properties can be considered as the main factors responsible for freshness and for related consumer choice (Harker et al., 2008; Péneau et al., 2006; 2007). Texture consists of a number of different properties perceived

by means of human senses and its definition implies a sensory evaluation (Bourne, 2002). Texture analysis is used by the food industry, in fact, to define and check physical properties of food products, through the use of mechanical and rheological measurements. If such measures are to accurately predict sensory perception of texture parameters, human assessment should be the standard against which instrument readings should be calibrated. In this way, it would be possible to have a product which falls within the range of textural parameters that experience has shown to be acceptable to the consumer (Bourne, 2002; Harker et al., 2003).

Fruit appearance (shape, size, color, and surface defects), soluble solids concentration, acidity and firmness are usually used to define apple quality, while appearance defects effectively make the fruit unsalable. Compression measurements by penetrometry are the most widely used technique for firmness evaluation (Harker et al., 1997; Qing et

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al., 2008). Sensory analyses, in contrast, are not usually considered for general quality assessment of fruit. However, in the case of a fruit like apple, texture properties are not dissociated from other properties, such as olfactory and gustatory ones, and consumer preferences are generally based on a combination of texture and flavor (Daillant-Spinnler et al., 1996; Gatti et al., 2011; Harker et al., 2003). These relationships justify a sensory-based approach as the starting point for implementing measurement tools that are effective in predicting human perception of apple quality.

Methodological aspects

Sensory Profiling

Sensory analysis is the only approach able to provide a direct evaluation of sensory properties and an overall product profile, rather than studying just one attribute at a time. In addition, it is also suitable for providing an objective meaning to sensory perception, in qualitative and quantitative terms. Sensory analyses, in fact, have the aim of describing products in an objective way, characterizing them by scientific criteria, and defining perceivable differences (Murray et al., 2001). For these reasons, sensory analyses require scientific competency and appropriate facilities, such as laboratories specifically equipped for performing sensory tests (ISO, 2007). Although sensory analyses use a scientific approach, they are able to explain perceivable quality of food by using a language which is close to that of the consumer (Seppä et al., 2012; Swahn et al., 2010).

Descriptive analysis is the most sophisticated of the sensory methodologies available. It requires a panel of trained judges to score the intensity of a series of specific attributes of a product on a linear or numerical scale. The result of such analysis consists of a complete description of sensory properties of one or more products that are related to appearance, odor, flavor and texture. Moreover, it provides the basis to map similarities and differences and to highlight which sensory attributes are important to consumer accep-

tance (Stone and Sidel, 2004). The sensory quality of apples has long been studied, even if sensory science criteria and sensory protocols were not initially very advanced. One of the first contributions came from Fisher et al. (1943) who studied texture and flavor features in 'Delicious' apples in relation to orchard location, maturity level at harvest and storage condition. Mealiness levels and flavor characteristics were associated with instrumental parameters. However, no information about sensory evaluation procedures was provided.

Up until 1996, studies demonstrating that the sensory properties evaluated through instrumental tests could actually represent the attributes which are really important for consumer choice were not available (Daillant-Spinnler et al., 1996). Some previous studies applying sensory analysis do not sufficiently describe and discuss methodologies such as vocabulary development, panel selection and judge performance to allow complete interpretation. In many studies, the attributes to be assessed were chosen from a brainstorming session amongst the judges (Allan-Wojtas et al., 2003; Daillant-Spinnler et al., 1996). In other cases, the sensory vocabulary was directly proposed by the panel leader (Karlsen et al., 1999), or the panel was oriented to the evaluation of some specific attributes (Harker et al., 2002a, 2002b, 2006). In particular, studies focused on the relationship between sensory and instrumental data often propose a specific set of sensory descriptors that might fit with the sensory meaning given to the instrumental measures. Hence texture sensory properties might have been defined for physical measurements or flavor attributes for volatile compounds analysis (Chauvin et al., 2010; Ioannides et al., 2007; Karlsen et al., 1999). Many studies referred to ISO standards for general sensory analysis methodologies and panel selection (Echeverría et al., 2008; Karlsen et al., 1999), whereas Daillant-Spinnler et al. (1996) provided a detailed description of panel training, specific for apple profiling.

Hampson et al. (2000) proposed a detailed tool to analyze judge consistency and performance over several years. Corollaro et al. (2013) also provided a detailed procedure for panel performance evaluation. Moreover, they precisely described attribute definitions, evaluation procedures, and references, and also discussed the advantages of using an innovative way to prepare samples, so that each judge could taste pieces from more fruit and each fruit could be evaluated by more than one judge. Accuracy and precision of sensory data is of fundamental importance: if sensory data are not reliable, i.e., consistent and discriminant, with a good agreement among the judges, any prediction models based on sensory profiles can not be effective.

An important consideration comes from the work by Brookfield et al. (2011), who focused on explaining the wide range of different correlations between sensory and instrumental data that can be observed in the literature. The authors concluded that such variability probably depends on the different cultivars tested in each study – different cultivars tend to respond in a different way to the various models that are used. Their conclusion suggests that a very large set of apple cultivars should be considered in such studies in order to cover the range of variability that can occur within different apple properties.

The link to the consumer

After defining a product sensory profile, it is necessary to identify which attributes are important to the consumer. With regard to the sensory definition of freshness, the main attributes used by the consumer to judge apple freshness are crunchiness, juiciness and mealiness. The first two of these are considered to be positive factors, while the last one is negative (Oraguzie et al., 2009; Péneau et al., 2006).

Crunchiness is an acoustic attribute, evaluated as the intensity and frequency of the sound produced by biting or chewing (Duizer, 2001; Fillion and Kilcast, 2002). Juiciness is associated with a tactile sensation; it

represents the amount of juice released by the product during chewing (Harker et al., 2002a; Ioannides et al., 2009). Mealiness, which is a qualitative defect, is perceived as dry and grainy flesh which breaks down into fine particles as a consequence of the weakening of intercellular bonding. In mealy apples, fractures occur as a result of cell-to-cell debonding, and individual cells do not break to release their contents (Echeverría et al., 2008; Harker et al., 2006).

Harker et al. (2003) highlighted an important feature that needs to be considered when studying apple preferences - that acceptability defines different consumer clusters that are characterized by preferences towards different sensory profiles. For example, it is possible to distinguish people who like crisp and sweet apples from others who like juicy and sour fruit. Often, specific groupings of preferred attributes are the result of expectations related to experience. Since clusters of genes associated with fruit quality usually change together, consumer preferences tend to link specific taste and texture properties because they are generally associated within different cultivars (Harker et al., 2003). Differences in preferences can also be related to consumer age (the elderly tend to like softer and more sour apples; whereas children tend to prefer the reverse), or to nationality or ethnic group, determining a higher or lower familiarity towards different products (Prescott and Bell, 1995). Cliff et al. (2002) performed a consumer survey using digitally modified photos of apples in three different locations, in Canada and in New Zealand, demonstrating that preferences were affected by color, shape, type (striped/blush), and background color. Interestingly, many factors were location-dependent, with different preferences expressed for different apple characteristics by the participants in the three locations.

One of the first examples of studies relating liking of apples to their sensory description was by Wills et al. (1980), even if in this work assessment of fruit performances, in terms of texture and flavor, and of overall

acceptability was done by the same judges. This is not a recommended practice in sensory analysis, because of psychological errors related to the halo effect (Meilgaard et al., 1999). Later, Dailliant-Spinnler et al. (1996) studied the relationship between sensory properties perceived by a trained panel and consumer preferences for different apple cultivars. Texture and taste properties were considered by the consumers to be more important than flavor and appearance. Nevertheless, the relationship between preferences and sensory profiles was not the same for all the cultivars that were examined: some of the cultivars appeared to be quite different based on sensory properties but very similar in terms of consumer preferences. The authors concluded that it is not possible to define a sensory property-based methodology that is useful for predicting acceptance in absolute terms (Dailliant-Spinnler et al., 1996). Jaeger et al. (1998) tested the hypothesis that consumers perceive apple mealiness as a negative attribute and show a higher preference for fresh apples than for stale ones. Fresh apples were evaluated as harder, juicier and crisper by a trained panel, while stored apples were described as old, stale and floury. The consumer test, in contrast with the results by Dailliant-Spinnler et al. (1996), showed that the first dimension on the preference map was strongly related to flavor properties while the second dimension was related to texture differences. However, the conclusion was the same: although the trained panel highlighted perceivable differences related to storage treatment within each cultivar, acceptance appeared to be more strongly linked to the cultivar factor, irrespective of the mealiness level (Jaeger et al., 1998). Recently, Bonany et al. (2014) performed a consumer preference test on several apple cultivars in seven different European countries. They defined an external preference map relating consumer preferences to the sensory profile described by a trained panel and to instrumental characterization, suggesting that such a tool is useful for the positioning of a culti-

var in the market and for leading breeding activities. However, even if sensory description and instrumental characterization seemed to be well related, the authors stressed that it is not a simple task to interpret the results coming from preference tests in order to define practical standards of quality. Moreover, Seppä et al. (2013b) found that the initial liking or disliking expressed by consumers toward an apple cultivar did not always reflect their final choice, since that choice was often influenced by other options the consumers had during the selection process. This result demonstrated that expressed preferences are not to be considered as a constant, but they are strongly dependent on context. Denver and Jensen (2014) studied the preferences expressed by consumers towards a hypothetical combination of different apple characteristics, by considering type of production (organic/conventional), origin (local or not), color and sensory properties (taste and texture). Interestingly, preferences were shown to be mainly driven by apple taste, but consumers having a positive opinion about organic apples usually had the same for locally produced fruit, while consumers showing an attitude towards local products did not have strong preferences for organic apples. The authors suggest that such asymmetry could be useful for studying new market potentials. Costanigro et al. (2014) also studied consumer attitudes towards local and organic apple products. Consumer responses were studied before and after providing them information on the weakness of evidence about positive effects of local and organic production on environment and human health, as well as before and after tasting the fruit. The authors found that information and fruit sensory properties affected consumer preferences differently, dividing the consumers into two macro-categories: people who have a preference for local and organic produce, and people who are against conventional production. The management of marketing strategies should take into account such important differences.

Relationship between sensory and instrumental data

Although the importance of sensory analysis is unquestionable, these methods are expensive and time consuming and therefore such analyses are not always suited to practical use when many samples need to be analyzed. It is, therefore, desirable to replace sensory evaluation by faster, simpler, or cheaper instrumental analysis. For these reasons several studies have examined correlations between sensory and instrumental data.

Texture parameters. Firmness is the most considered and studied texture parameter. In the study by Harker et al. (2002a), instrumentation tests showed that a minimum difference of 6-8 N in instrumental firmness (with an 11 mm probe puncture test) was necessary for a trained sensory panel to detect a difference. Below a minimum value of 50 N measured by the firmness test, the fruit were evaluated as being mealy by the trained panel. So, it is possible to define a critical puncture threshold, below which apples are described as being mealy, and apple producers could define a threshold in their practical measures to ensure that mealy apples are excluded from a pack-out (Harker et al., 2002a). Chauvin et al. (2010) found a logarithmic relationship between physical properties of apples and the sensory scores determined from descriptive analysis, and reported that when apples are soft, humans are more sensitive to textural differences than instruments are. When apples are hard, the ability of panelists to perceive differences may decrease because of fatigue; thus, in this case, instrumental determination would be more reliable than that of panelists (Chauvin et al., 2010). Nevertheless, Ioannides et al. (2007) proposed *in vivo* measurements of texture properties by means of electromyography (EMG), that records facial muscle activity during apple chewing when compared with pressure test analyses. They showed that the penetrometer reading was only able to replicate the first bite, without providing information on the tissue modifications that take place in the mouth as

a result of the chewing process. That factor was considered by the authors to be a limitation of penetrometry in providing effective data for predicting texture sensory properties (Ioannides et al., 2007). However, a limitation of psychological origin in the EMG tracing does exist: the volunteers tended to chew in a different way when they were asked to evaluate some sensory attributes, rather than responding normally when there would be less stress and less need to concentrate (Ioannides et al., 2009).

Several authors have focused on acoustic parameters. Apples, like all fresh vegetables, are composed of living cells, with cell walls fastened to each other by means of the middle lamella and subjected to turgor pressure, which is higher than the external atmospheric pressure. The breaking of the cell wall provokes a rapid expansion of the liquid content which is responsible for the sound emission. Acoustic emission amplitude and frequency are strictly related to the perception of crispness and crunchiness, which are very complex concepts, combining a wide range of perceptions such as sounds, fracture characteristics, density and geometry (Fillion and Kilcast, 2002). Study of consumer responses demonstrated that crispness is characterized by a sudden, clean fracture occurring when a crisp food is bitten. The noise emitted is perceived to be higher pitched and louder than the sound produced during biting crunchy foods, showing low pitch sounds and characterized by a certain degree of bone conduction. That is why the combination of acoustic and mechanical techniques more adequately describes the perception of food acoustic properties than either technique alone (Duizer, 2001). The distinction between the two terms of crunchiness and crispness is actually quite complex. Different definitions of these two factors are used by different authors in sensory studies on apples. Even if not all of them are very precise, it is mainly accepted that crispness is related to the sound emission at the first bite by front teeth, while crunchiness is related to the sound emission

during chewing by lateral teeth (Harker et al., 2002a; Zdunek et al., 2010b).

De Belie et al. (2002) studied the acoustic parameter of crispness that had been separately scored by a trained sensory panel by combining measurements taken by a microphone of the sound emitted during chewing of a sample coming from the same fruit. A fundamental limitation was the use of different subjects and different samples from the same fruit for sensory and instrumental measures: subjects involved in sensory analysis were not the same subjects involved in chewing recordings. The authors proposed that a better relationship between chewing sound and sensory data might be expected if the recordings were taken from each panelist as he/she was scoring for texture attributes (De Belie et al., 2002). Crispness and crunchiness have important cognitive implications: Demattè et al. (2014) demonstrated that artificial modifications of specific frequencies of the sound perceived in real time during biting or chewing of apples significantly affects crispness perception, demonstrating that crispness is an attribute strongly related to the acoustic information coming from the food. Hardness perception was also found to be affected by sound modifications, although it is defined as a mechanical attribute, showing a multisensory interaction in hardness perception. Zdunek et al. (2010a) developed a contact acoustic emission detector, based on the simultaneous use of a puncture test and an acoustic emission detector in contact with the sample during the test. They found that total acoustic emission counts were a better predictor of texture sensory attributes evaluated by a trained panel than penetrometry firmness measurements alone, particularly with respect to crispness, crunchiness and hardness. Costa et al. (2011) related mechanical and acoustic data recorded on apple samples during compression by a texture analyzer to the texture sensory evaluation by a restricted panel of experts. They found that the instrumental acoustic parameters were correlated to sensory crispness, confirming

the important role of acoustic parameters in the perception of crispness. They also found that high crispness required high firmness, while the opposite was not true. Hence, high crispness and high firmness were not dependent on each other and it should not be expected that they would be present together in any case. Corollaro et al. (2014) compared sensory data and texture analyzer data recorded on samples coming from the same fruit, finding that both mechanical and acoustic responses were important in developing effective predictive models for most sensory attributes that defined texture. These results showed that acoustic information was important not only to define crunchiness perception, but also for other texture attributes usually not related to sound or hearing, such as hardness. This confirms the results from Demattè et al. (2014), who found that acoustic information was able to modulate not only crispness, but also hardness evaluation. For juiciness alone, Corollaro et al. (2014) found that other chemical and physical information was needed to achieve good prediction, suggesting that juiciness perception does not depend only on physical properties, but also on cell chemical composition.

The relationship between apple tissue anatomical features and texture properties has also been studied. Allan-Wojtas et al. (2003) compared the sensory description of apples by a trained panel with a micro-structural analysis of the flesh matrix by microscopy. By defining groups of apple cultivars with common sensory profiles and studying the structural properties representative of each group, they were able to describe the structural components responsible for specific sensory responses. Mann et al. (2005) correlated apple anatomical features and texture sensory properties. They found that cell number was important to the prediction of crispness and mealiness, suggesting that fruit with a fewer number of cells per unit area were crisper than fruit with a higher number of cells per unit area, while cell size predicted juiciness, suggesting that bigger cells release more juice. Useful interpretations

come from Ting et al. (2013), who used X-ray tomography to study the anatomical features of different apple cultivars and their relation to instrumental firmness. They found that different microstructural organization and the distribution, number, and size of intercellular spaces were responsible for different texture properties that were characteristic of different apple cultivars. The work by Billy et al. (2008) found a relationship between texture sensory profile and water-soluble pectin (WSP) extraction analysis: mealiness and “fondant” attributes were positively and negatively correlated, respectively, to the concentration of galacturonic acid in the WSP extract.

Flavor parameters. Several authors have found difficulty in developing effective predictive models for taste in apples based on predicting flavor sensory perception from instrumental measures of compositional data. The main reason seems to be the multisensory nature of flavor perception, characterized by interference from taste, olfaction and other sensory properties.

Harker et al. (2002b) found a good prediction for acid taste by using titratable acidity, while soluble solids concentration showed a poor relationship with perceived sweetness. These authors asserted that assessment of fruit by sensory analysis should remain a critical part of fruit quality assessment, since sweetness represents one of the most important factors affecting consumer liking (Harker et al., 2002b). Additional studies highlighted that influences between different sensory properties exist that are able to affect sweetness perception. Harker et al. (2006) demonstrated that sweetness perception depends on the degree of breakdown of apple flesh during chewing – i.e., it depends on textural properties – rather than on differences in sugar and acid content. Echeverría et al. (2008) found a relation between sweetness and mealiness perception scored by a trained panel, with high mealiness values being related to low sweetness values, even if no real correlation between the two sensory attributes was found. Another interest-

ing conclusion from this work was that a low consensus in the panel was observed for those attributes having high interactions with others, e.g., sweetness (Echeverría et al., 2008). In the study by Corollaro et al. (2014) sweet taste perception was effectively predicted by combining chemical data (soluble solids and titratable acidity concentrations) and colorimetric measurements taken on the apple flesh. The authors suggest that a multisensory interaction of sweetness perception can exist, since the flesh appearance seemed to affect the sweetness scoring provided by their trained panel.

The influence of other sensory properties can also be observed with flavor attributes related to retronasal odor perception. Karlsen et al. (1999) looked for a correlation between sensory data and instrumental data coming from texture and volatile compounds (VOCs) analysis on several apple cultivars. The highest correlations were obtained when sensory odor and flavor attributes were correlated at the same time to texture and VOCs instrumental data – the prediction of flavor perception seems to require information about apple texture properties. Differences in flavor release could be due to structural differences as every compound responsible for flavor has to be released from the apple matrix to come in contact with taste and olfactory receptors. Release kinetics are therefore influenced by the chewing process, interaction with saliva, and mouth temperature, which depend both on apple and on subject characteristics (Chen and Engelen, 2012; Foster et al., 2011). Moreover, Aprea et al. (2012) found that the interaction of the same volatile compounds when present at different concentrations can be responsible for the perception of different perceived odors or flavors. Ting et al. (2012) showed that nose-space proton-transfer reaction mass spectrometry analysis of volatiles released during apple consumption provides significant information about real flavor perception. They found that very different volatile profiles came from apple fruit during chewing, as compared to *in vitro* VOC

measurements on the same apple cultivars, confirming that nose-space analysis provides data that better explain real consumer perception. The general conclusion is that it is possible to obtain a better sensory attribute prediction if a larger number of instrumental and/or chemical measurements are taken into account when elaborating a model (Karlsen et al., 1999).

Overall profile. Non-destructive techniques have also been developed and applied to study overall apple quality, since resulting spectra developed from chemometric techniques can give a general overview of a product profile which can be used to predict sensory properties. Mehinagic et al. (2003) tested the effectiveness of vis/NIR spectroscopy in predicting sensory properties. They found that mealiness was negatively and crispness positively correlated with spectroscopic data in the wavelength range corresponding to chlorophyll and starch absorbance bands. Chlorophyll and starch are subjected to changes in their concentrations during ripening. As ripening is a process that also involves structural modifications, it is possible to suppose the existence of a relationship between chlorophyll and starch vis/NIR measures and some textural attributes. Sweetness was negatively correlated and sourness positively correlated with absorbance at wavelengths corresponding to starch. Starch degradation during ripening is the basic mechanism for sugar production, responsible for sweet taste, while, concurrently, acid concentration tends to decrease. Despite these interesting results, the relationships were not strong enough in comparison with better correlations observed between sensory data and penetrometry measures (Mehinagic et al., 2003). Rizzolo et al. (2010) used time-resolved reflectance spectroscopy (TRS), a technique that measures concurrently the absorption coefficient and the scattering coefficient at different wavelengths. The absorption coefficient is a measure related to the absorption of photons by pigments (chlorophyll, carotenoids) and by main chemical components of the flesh (wa-

ter, sugars), while the scattering coefficient is a measure related to photon refractive mismatch caused by cellular structures, such as membranes, cell walls, intercellular spaces, and starch granules. Good correlation between texture sensory attributes and the scattering coefficient was found, and sweet taste was correlated with the absorbance coefficient. The authors were optimistic about the ability to predict texture sensory attributes, mealiness in particular, by TRS. However, the best correlations were found between sensory scores and other more common destructive measurements used as the control. In conclusion, non-destructive techniques (vis/NIR, TRS) seem to be promising in the prediction of some sensory attributes, but are not yet as reliable as commonly used destructive analytical methods.

Consumer preferences. Some authors have studied the relationship between consumer preference and instrumental characterization as a direct way to interpret preferences in terms of chemical and physical properties. Hoehn et al. (2003) compared consumer preference with chemical and mechanical measures on apples. The authors found that not only soft apples, but also very hard ones, were not preferred by consumers, even by the youngest. Such observations confirm the theory that liking falls within a range of intensity for each sensory characteristic (Bourne, 2002). Similar to other studies, they found a good correlation between instrumental measures and liking for one apple cultivar, but not for others. According to the author, this finding should be taken into account when defining the minimum tolerance standards for the instrumental parameters used for quality assurance applied to apples – an instrument is not able to measure the same combination of properties that human senses can, and several sensory attributes together can influence preference judgment (Hoehn et al., 2003). In this context, Harker et al. (2008) tested the instrumental measurements currently available for quality control in order to verify whether they provide appropriate quality pa-

rameters to define consumer acceptability. In their work, an increase in liking was found when firmness measured by penetrometry was above a specific threshold common to all the cultivars examined and equal to 62 N. The authors observed that the market success or failure for an apple cultivar can depend on the ratio between the cultivar's natural firmness distribution and the firmness threshold below which consumers reject apples. When the proportion of fruit below that limit is high, the cultivar tends to be less appreciated and purchased (Harker et al., 2008).

Application of sensory analysis in apple studies

The study of apple quality includes a series of factors that need to be considered, such as the impact of growing conditions; properties and peculiarities of new cultivars being released from breeding activities; post-harvest storage conditions and physiological changes during storage; and post-storage shelf conditions. In the light of the established important role of sensory science in the evaluation of apple quality, it is important to consider the application of descriptive sensory analysis and preference tests in determining the significance of such factors.

Pre-harvest factors: some examples

Crop management practices and pre-harvest treatments can influence product quality both at harvest and during storage, mainly in terms of cell anatomy, structure and turgor (Johnston et al., 2002; Sams, 1999). Many studies are available about the influence of factors such as rootstocks, irrigation and fertilization management, weather conditions, and canopy structure on apple fruit yield and quality, measured in terms of instrumental parameters (e.g. fruit weight, firmness, soluble solids concentration, disease and pest damage, and the incidence of physiological disorders; see, for example, Brackmann et al., 2010; Campi et al., 2009; Casero et al., 2010; Lachapelle et al., 2013; Racsko et al., 2008).

However, few studies relating pre-harvest factors with quality determined by sensory analysis are available. In terms of growing practices, Vanzo et al. (2013) compared apples produced by organic and integrated systems. A consumer panel performed triangle tests and hedonic evaluation of specific sensory attributes. The results showed that consumers were able to discriminate between fruit coming from the different growing systems and that the preferences between organic and integrated fruit for sweetness, tartness, firmness, juiciness, overall flavor and appearance were cultivar dependent. Altitude is also a factor determining differences in ripening stage and fruit chemical composition (Aslantas and Karakurt, 2007; Comai et al., 2005; Singh et al., 2006). Paprštein et al. (2006) studied fruit chosen from orchards in four climatically different locations (about 200, 300, 400 and 500 m above sea level) by asking panels of consumers to score their liking for several sensory attributes related to appearance, flavor and texture. The authors reported a total score, representing the sum of scores for each attribute, and a general "taste score", but they did not perform any statistical analysis to study the differences in sensory properties of each cultivar at the different locations and no evidence of significant differences related to altitude was provided.

Crop load is also known as a factor affecting fruit quality and sensory properties. Baugher and Schupp (2010), for example, demonstrated better quality, in terms of sensory profile and consumer liking, in fruit coming from low crop load treatments compared to high crop load treatments in 'Honeycrisp' apple. Thinning is therefore a key factor to improve crop yield and quality in apple (Link, 2000). The most used way to reduce crop load in apple is the application of phytochemicals which cause fruit abscission (Zibordi et al., 2009). An innovative method consists in shading apple trees by appropriate nets (Byers et al., 1990) – competition for reduced photosynthates is responsible for fruit

abscission (Corelli Grappadelli et al., 1990). Recently, photosensitive colored shading nets have been proposed to promote specific physiological responses by differential spectral transmission of solar radiation (Shahak et al., 2004; Bastías et al., 2012). The only work studying the sensory quality of fruit coming from such new thinning practices is by Corollaro et al. (manuscript submitted), who applied sensory analysis by a trained panel to compare apples from traditional chemical thinning and fruit from thinning via shading. No perceivable differences between treatments were detected. Also, studies on the effect of different photo-selective colored nets, indicated that some sensory differences due to differences in fruit growth and cell proliferation under different light spectra can be found.

Post-harvest changes of apple sensory properties

One of the first studies applying sensory analysis to study post-harvest changes in apples was proposed by Watada et al. (1980), who found strong differences in the sensory patterns for five apple cultivars over a five-month storage period, and suggested that these might be due to differences in physiological age at harvest. Some cultivars, for example, showed high astringency at harvest, typical of fruit picked before reaching maturity. For such cultivars, there was a strong change in their sensory profile during storage, more than in other cultivars, which could be indicative of that fruit being more mature at harvest. However, the authors did not ignore potential differences in chemical composition and cellular structure, suggesting the usefulness of studies on anatomy or metabolic and catabolic processes, determining the relationship between these factors and sensory quality. Several authors have found that different apple cultivars exhibit different patterns in both sensory texture and flavor profiles during storage (Billy et al., 2008; Corollaro et al., 2013; Seppä et al., 2013a). Corollaro et al. (2013) found a

general trend in change of sensory profile for 12 apple cultivars, mainly in terms of texture properties, even if specific patterns were described, helping to identify cultivars which best maintain their sensory profile during storage. Seppä et al. (2013a) defined clusters of cultivars, depending on their sensory profile, and found that most of them moved from one cluster to another during storage as their sensory properties changed. Hence, different cultivars can show similar sensory profiles at a specific moment during storage, but very different profiles at another. Billy et al. (2008) explained the different patterns exhibited by different cultivars during storage as related to different genetic profiles and to the different enzymatic metabolism of pectins.

Modifications in sensory properties during storage of apples do not seem to be related only to textural properties; it has been demonstrated that volatile compounds change markedly during post-harvest storage, and that different patterns can be shown by different apple cultivars (Soukoulis et al., 2013). Aaby et al. (2002) found that differences in sensory properties between fresh and stored apples were mainly related to odor and flavor, while texture and taste attributes did not differ, even if instrumental firmness and titratable acidity decreased during storage. Varela et al. (2005; 2008) studied the relationships between changes of sensory profile of apples during storage, that were evaluated by a trained panel, and consumer acceptability. Rejection of fruit was associated with increased mealiness, ripeness and alcoholic flavor, even if other attributes (such as juiciness, sweetness, and acidity) remained unchanged. Thus, attributes that are most often considered important did not influence the decision by consumers to reject the fruit (Varela et al., 2005). They also highlighted the fact that fruit recently harvested and fruit stored in either cold or controlled atmosphere conditions showed different patterns in how their sensory properties changed subsequently during storage at room temperature (simulating real market conditions) irrespective of

similar instrumental parameters measured at harvest or soon after storage.

Other studies proposed instrumental measure analysis as a way to predict changes in apple sensory quality during post-harvest storage. Mehinagic et al. (2004) employed both descriptive sensory analysis and instrumental measures (penetrometry, compression test, vis/NIR spectroscopy, soluble solid and titratable acidity concentrations) to predict sensory properties at harvest and during storage. Flesh firmness by penetrometer appeared to predict sensory properties well at harvest, while the compression test helped to better explain changes in mealiness and juiciness after storage (Mehinagic et al., 2004).

An important conclusion from such studies is that different cultivars show different sensory patterns during post-harvest storage. That suggests the need to develop and validate sensory tools on wide sets of cultivars, in order to define the different patterns that can be shown within this genus. Moreover, cultivars could be studied under different storage conditions to enhance differences in their responses. Instrumental analyses could also provide information about the chemical and structural changes responsible for the different trends, as highlighted by Costa et al. (2012), who observed a considerable textural variation in texture analyzer performance of different apple cultivars over two months of storage. The authors proposed the calculation of a storage index, based on the ratio between the values of each texture parameter measured at harvest and after storage. Since the main source of variation in the texture performances was genetically based, they concluded that proper evaluation of storage performance by the application of the index they proposed should be considered in breeding programs, in order to select cultivars which can best maintain quality features during storage.

Breeding studies

The most advanced method of breeding is marker-assisted selection, based on the iden-

tification of individuals carrying gene alleles responsible for the phenotype of interest (Costa et al., 2010; Myles, 2013; Sansavini and Tartarini, 2011). Preliminary screenings made on the initial wide set of breeding progeny are necessary, before any sensory characterization, to reduce the samples to a number which can be managed in sensory evaluations. However, such preliminary instrumental screenings can exclude interesting selections, because of an improper transposition of instrumental readings in sensory interpretation. Thus, the implementation of reliable prediction models for apple sensory quality by instrumental measures is required if they are to be applied in breeding studies. Even though disease resistance and facilitating of efficient growing practices are among the most important goals for many breeding programs, that new apple selections must also have a high appeal to consumers is a given. Thus, new selection sensory characteristics and acceptability by consumers are also studied by many authors. Within this context, Granger et al. (1992) studied new scab-resistant apple cultivars for their sensory acceptability through hedonic evaluation of different quality attributes using a flavor profile technique (Caul et al., 1958). The overall acceptability of each apple cultivar was calculated as the difference between the average score for positive quality attributes (flavor, sweetness, acidity, firmness, juiciness and crispness) and the average score for negative quality attributes (astringency, bitterness and mealiness). A five-year study by Paprštejn et al. (2006) on the acceptability of more than a hundred cultivars cultivated in the Czech and Slovak Republics, harvested in four climatically different locations, aimed at identifying which climatic condition could be proposed as being the best for achieving the best sensory quality score for each cultivar.

The first work that applied concurrently descriptive panel analyses, mainly flavor characteristics and appearance, and consumer surveys was performed by Redalen (1988).

The author reported results on 14 apple selections from a five-year study involving about 35 new selections. The results showed agreement between the highest scores for the intensity of flavor properties and consumer preferences, but no regression analyses were provided. Hampson et al. (2000) developed a more detailed protocol for the definition of liking drivers in new apple cultivars. A trained panel was involved in both hedonic and descriptive evaluation of seven sensory attributes related to appearance, texture and flavor of both new and standard cultivars over a period of four years. In the first two years of activity, the hedonic and descriptive evaluations were both performed during the same session, and because of this combined evaluation the results can be affected by halo effects, even if these are more frequently observed as involving consumers rather than trained judges (Meilgaard et al., 1999). During the following two years, the two different evaluations were performed in different sessions. A consumer preference test was then performed on a sub-set of samples. Crispness accounted for 90% of variation in texture liking and sweetness, sourness and aromatics explained about 50% of the variation in flavor liking, and sensory data were better predictors of liking than the instrumental methods were. They concluded that analytical measurements are not adequate to substitute for sensory evaluation in screening new breeding products. Miller et al. (2005) studied 20 new apple cultivars both in the eastern US and in British Columbia, Canada. Hedonic scales were used to score the liking for appearance, texture and flavor, while intensity scales were used to score the intensity of texture and taste attributes. In Canada, a sensory panel expressed the liking scores, while a different panel of trained judges provided the intensity scores. In the eastern US, instead, the same panel evaluated the samples for both liking and intensity of some descriptors. In this case, as well, this is a not recommended practice (Meilgaard et al., 1999). Differences in apple sensory quality were

found for cultivar and site. The authors suggested that widespread sensory tests of new apple cultivars across several sites should always be considered when evaluating new apple cultivar performance under different soil and climatic conditions. Bonany et al. (2013) tested products grown in a specific site and then tested by different consumers at different locations around Europe. The results showed significant interactions between apple cultivar and country, age and gender, indicating that differences in eating quality acceptance among cultivars were influenced by these factors. A sensory profile developed on the same fruit by a trained panel provided a definition of those sensory characteristics that were appreciated in different countries and by different consumer classes (Bonany et al., 2013).

Kühn and Thybo (2001), instead, applied descriptive sensory analysis only, studying 22 scab-resistant apple cultivars for their sensory properties by a trained sensory panel which assessed 13 different attributes. The cultivars, which were evaluated at different storage times, showed differences that were related both to cultivar and to storage time (Kühn and Thybo, 2001).

Conclusions

The study of apple eating quality has been of interest for a long time, both in relation to sensory properties and to consumer acceptability. However, only some papers have reported stringent criteria for the use of sensory evaluation protocols. A wide series of studies also applied instrumental analyses to confirm sensory data and to interpret them, and also to identify correlations between sensory and instrumental variables to predict the sensory profile. Many studies report different and sometimes innovative sensory and instrumental methodologies to evaluate apple eating quality. The application of sensory analysis in specific studies on apple quality in relation to pre- and post-harvest factors, as well as the study of sensory characteristics of new cultivars is less common in the literature,

mainly because of the limitations of sensory methodologies, which require more time and specialized resources than instrumental characterizations. As much of the literature reviewed here lacks a rigorous application of the proper scientific criteria for sensory analysis, the main recommendation should be to consider sensory analysis as a science of its own, needing proper approaches and criteria to be applied. Appropriate references should be the various ISO standards for sensory analysis, which clearly lie at the foundations for these analyses that can easily be followed by those involved in apple cultivar testing and also in evaluating quality of fruit from different production systems (training, pruning, crop load control approaches, irrigation management, etc.). We have also observed that the main source of variability in the conflicting results available in the literature is the apple cultivar. Thus, the application of sensory analysis on very large sets of apple samples is recommended. However, since sensory analysis is expensive and time-consuming, further studies to improve the prediction of sensory properties based on instrumental characterization should be undertaken. The reduction and optimization of the analyses to be performed will ensure the application of prediction models as a standard procedure for those involved in apple production and apple quality evaluation. Moreover, since the context has been found to be an important factor influencing consumer choice, further research is needed to investigate it, not only as affected by product intrinsic properties, but also by considering motivational/emotional factors contributing to the choice (Arvola et al., 2008). When resources are limited and make descriptive sensory analysis not applicable, quicker and less expensive innovative methods could be applied, such as flash profile, Napping[®], check-all-that-apply or sorting methods (Varela and Ares, 2012; Valentin et al., 2012), involving semi-trained assessors or even consumers. These methods are useful to quickly define key descriptors driving consumer liking. Innovative dynamic

methods are also available, such as Temporal Dominance of Sensations (TDS; Thomas et al., 2014), to study key sensory attributes and their change during tasting.

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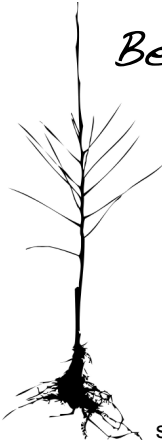
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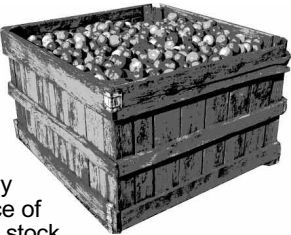
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