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Challenges and opportunities for sensory and consumer science in new cultivar development and fresh produce marketing

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Traditionally, sensory quality was not prioritized in fruit and vegetable breeding programs as they focused on introducing high yielding, disease resistant products. In recent years, the sector has been shifting away from a commodity market to more value-added and branded options. To stay competitive, new cultivar introductions increasingly require excellent sensory properties resulting in the integration of sensory and consumer research into many fruit and vegetable breeding programs. This shift is not without its challenges for sensory scientists who, when evaluating produce need to manage high natural variability, maturity, ripeness and postharvest handling considerations. Heightened focus on value-added marketing has also led to increased interest in meeting consumer demands to reduce food waste by marketing imperfect produce. This trend is just one example of new opportunities for sensory and consumer science in the produce sector, an area of research that is expected to continue to grow in the coming years.

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Introduction

For most of the last century, the fresh produce industry has primarily been a commoditized market. Fruits and vegetable pricing was dictated by supply and demand with no differentiation in the commodity itself. Each fruit and vegetable was sold under a single banner (i.e. 'peaches') without noting when there were differences in cultivar at retail. In recent years this has been changing, with an increasing array of named or branded cultivars available in the produce section.

Plant breeding is the main tool used to develop new cultivars of fruits and vegetables. A cultivar refers to a cultivated variety, meaning it was selected and cultivated by humans for a specific characteristic or trait (genetic variation). Cultivars generally have to be vegetatively propagated which differs from a variety which is found in nature and generally propagated from seed [1]. Traditionally, breeding involves cross-pollination of a diverse set of cultivars of a fruit or vegetable so as to produce a subsequent generation of plants that randomly combines qualities from the original plants [2]. Thus, an apple with unique flavor qualities but poor texture may be crossed with an apple that has bland flavor but crisp and juicy texture with the hope of obtaining an apple that has both the unique flavor properties of the one cultivar and desirable texture qualities of the other. In a typical breeding program, thousands of cross-pollinations are completed annually. It is a labour-intensive process and often out of 2000–10 000 plants evaluated in a year, only 15–50 crosses are selected for more rigorous evaluation [3].

Up until recently, decisions regarding which cultivars (i.e. crosses) to advance to the next stage of evaluation were made by a small group of individuals from a breeding team [4]. Generally, the selections were made through informal tastings based on personal preferences and did not incorporate proper sensory evaluation methods, account for bias or market segments. Decisions were largely industry-driven and based on factors such as yield, disease-resistance, fruit size, storability and ability to withstand transport. Sensory properties were not a major focus and the result was fruits and vegetables that were efficient to produce and ship all around the world, however with unremarkable, sometimes even undesirable, sensory qualities [5].

Knowledge of sensory and consumer science has increased within the field of horticulture along with the additional costs associated with these methods. As plant breeding advanced and most fruits and vegetables on the market developed a foundation of high quality agronomic traits, new targets needed to be sought to differentiate new introductions of fruit and vegetable cultivars. Thus, in recent years, sensory quality has become a key focus in an increasing number of breeding programs [5,6], and with that target, sensory and consumer science is quickly gaining traction in the horticulture sector.

Apples, one of the most widely consumed produce items in the world, are unsurprisingly one of the most commonly studied produce items in the sensory literature, both historically and presently [7–9,10•]. Fortunately the application of sensory and consumer science in horticulture is diversifying to smaller crops with recent publications contributing to the limited knowledge of sensory drivers of liking for pomegranate [11], strawberries [12], papaya [13], edamame [14], sweet potatoes [15] and leafy vegetables including kale [16••] to name a few. Sensory drivers of liking refer to the intrinsic properties of the fruit such as aroma, flavour, taste, texture and appearance. It may differ based on the type of produce, hence the importance of sensory and consumer methods to identify and describe what characteristics increase liking within a given cultivar.

Sensory science in the living world of horticulture is not without its challenges. As sensory and consumer research is applied to an expanding range of crops, many recent publications [13,14,16••,17•] make reference to the unique challenges of completing sensory studies on fresh produce and make attempts to address the intrinsic limitations and control for the high natural variability. This review will focus on research conducted over the past two years with an emphasis on the integration of sensory and consumer research to new cultivar development, considerations of how to address natural variability and the impact of produce imperfections on consumer acceptance and decisions to purchase. The topics addressed in this review are relevant to a diverse audience across the produce value chain including horticulturalists, sensory scientists, market researchers and business commercialization.

Overcoming the challenges

Fresh produce is highly variable both within and across batches. Sensory properties are impacted by many factors including (but not limited to):

- The growing environment: production method [18], geographic location [11], year-to-year weather differences [19]
- Postharvest treatment: chemical treatments [20], storage [21]
- The maturity or ripeness level of the fruit: maturity at harvest [22] and ripeness at the time of evaluation [23]

Product variability

To help control these factors, most sensory studies that attempt to compare the sensory properties of different cultivars of a fruit or vegetable source product that is grown and stored in comparable conditions in an effort to minimize the number of factors contributing to this variability. Products used in studies that compare the sensory properties of different cultivars typically use product grown on a research farm associated with the sensory researcher's institution, from a single commercial farm or from a single produce packer [15,16••,17•].

In some cases, which of these factors and how much they influence sensory properties of a fruit or vegetable are still under investigation. For example, a study on spinach found that growing the same cultivar of spinach in a high tunnel production style resulted in significantly higher consumer liking scores for flavor, texture and overall compared to the same spinach grown on the same farm but in an open field [17•]. Another study compared consumer acceptance of pomegranate that was grown in two regions in California, one on the coast and one inland. It was found that the growing region only impacted consumer liking of certain cultivars. Of note was that the cultivar that comprises 90–95% of commercial pomegranate production was liked significantly more when grown inland compared with on the coast [11]. The same broccoli cultivar grown under standardized conditions (pot size, irrigation and nutrient supply) in four different regions under natural conditions differed in sensory properties [19]. Broccoli plants grown in a climate with high temperatures and shorter days were found to be perceived as having higher bitter taste, cabbage flavor and color hue compared to plants grown under cooler temperature and longer days. Considering the impact of production style and region differs depending on the crop, this factor should be controlled for when making cultivar comparisons in cases where prior research regarding the impact of production style or location on sensory properties is unknown.

Maturity and ripeness

Product maturity or ripeness is another key factor that must be controlled for in sensory studies of fresh produce. For example, in melons under ripe products tend to be too acidic, too low in sweetness, have lower levels of flavor volatiles and have textures that are too firm, whereas over ripe products tend to develop off-flavors and have textures that are too soft [17•,22]. Industry standards for when to harvest cantaloupe melons are based on non-destructive maturity indices such as ground color, degree of netting and maturity of the slip (development of an abscission layer between the vine and the fruit). However these features unfortunately do not always correlate with maturity [22]. Thus identifying the optimal ripeness at which to evaluate a crop is not only important to ensure a cultivar is given a fair chance with consumers but also so conclusions and comparisons on sensory differences can be made across cultivars.

Determining the optimal ripeness can be a challenge. In apples, ripeness is typically determined using the starch-iodine index [24] which provides an objective tool to assess maturity based on the ratio of sugars to starches in a cultivar. This approach ensures that all cultivars are at a similar physiological maturity stage for sensory and consumer evaluations. Citrus fruit measures the Maturity Index (MI) defined as the ratio between total soluble solids and acidity [25]. In other crops, the process is more nuanced. Similar to melons described above, tomatoes are picked based on appearance, typically at red ripe stage [18] or light red stage [26]. A visual indicator that may differ between tomato cultivars and has no correlation to sugars, acids or flavors.

In many cases, different cultivars of the same crop reach maturity and are ready for harvest at different points in the growing season. This adds an additional challenge of timing of evaluation and management of postharvest shelf life to sensory studies. When the produce under evaluation is highly perishable and does not store well, it may not be possible to include all cultivars of interest in the study since some cultivars may mature outside the timeframe of the research [17•,25]. Alternatively, the research timeline can be extended to ensure all cultivars of interest are evaluated at their optimal maturity, however, this adds extra costs and extends the timelines. In other cases, if the goal is to make side-by-side comparisons, this may not be possible if the cultivars ripen at different times. In crops that can be stored for longer, one work-around has been to complete sensory profiling of each cultivar as it reaches its optimal ripeness level. Then when the products are taken for consumer testing, any products that were profiled significantly earlier and whose sensory properties may have changed since their original profiling (at peak ripeness) are re-profiled. These strategies were employed by Bowen [10•] with apples profiled over a four month period from August to November and with some apples appearing twice on the preference map to provide context for apples that were tasted by consumers after some time in storage but also allow for prediction of liking scores for those apples when they were freshly harvested and within their optimal ripeness window.

Generally, before deciding on the best approach forward it is helpful to know what degree of impact the harvest time has on sensory properties within a crop. For example, a recent study by Menezes Ayres [17•] examined sensory properties of different melon cultivars and evaluated the cultivars at different harvest times. The authors concluded that in the case of melons, cultivar had a larger influence over sensory properties than harvest time and thus future studies could compare melons harvested at different points in their harvest window and still make adequate cultivar-to-cultivar assessments of sensory quality among them.

Postharvest management

Once the fruit or vegetable has been harvested, how they are stored is another important consideration. Storage conditions must be carefully controlled to maintain produce quality and avoid chilling injury, desiccation, wilt or rot, and to allow flavor volatiles to fully develop upon removal from storage [27–29]. Apples placed in storage and removed were left to acclimate for 24 hours before completing sensory or physicochemical measurements [30]. Whereas, tomatoes should not be refrigerated before sensory evaluation because it reduces volatile perception and can have negative impacts on consumer liking. Ponce-Valadez *et al.* [26] found that tomatoes refrigerated at 10°C had lower consumer liking scores and were perceived as less fresh with off odors compared to tomatoes stored at 12.5°C and 20°C. Similarly, improperly stored peaches and nectarines can become discolored and mealy when evaluated days after removal from storage [21]

Use of 1-methylcyclopropene (MCP), an ethylene inhibitor to delay ripening of some climacteric fruits in storage is common practice for apples, pears, avocado and other fruits and vegetables [31]. Its ability to maintain fruit quality is cultivar dependent and can have both positive and negative impacts of the sensory perception and resultant liking of the produce. Implementing sensory and consumer testing is an effective way to elucidate impact of 1-MCP application to product quality. Salazar [20] found 1-MCP application could extend the postharvest storage of the kiwi cultivar 'Soreli' by three weeks at 20°C and 8 weeks in cold storage at 0°C. Sensory evaluation found no differences between control and 1-MCP treated kiwis, with medium to high scores of consumer acceptability.

Applications in new cultivar development

Breeding for new cultivar introductions is a multi-year process [3]. When is the right time to integrate sensory and consumer science into the pipeline? Traditionally, defining a cultivar's sensory characteristics and consumer acceptance is done when a cultivar is ready to be commercialized. Unfortunately, this may be too late in the process especially if the cultivar is not well liked by consumers or you are trying to integrate consumer traits into the breeding program [10•,16••,32•]. There are challenges, however, in trying to integrate sensory research early in the pipeline. These challenges include narrowing down which of the hundreds/thousands of crosses should be evaluated, having sufficient numbers of product for sensory or consumer evaluations and defining the production practices for initial evaluations.

It is not uncommon to use instrumental measures to help narrow down the number of products that will be brought forward to a sensory panel or consumer test. Researchers are continuously looking for the best approaches to correlate sensory perception with instrumental methods. A penetrometer is a standard instrument for measuring texture in many fruits and vegetables, but it often does not correlate to the multi-dimensional aspects of texture perception in mouth [23]. A study on apples found that tribology correlates better to texture perception, having strong correlations to juicy, crisp and mealy perceptions [30]. Moving to genetic mapping to reduce the pool of candidates for sensory screening by developing markers to identify consumer traits of interest has been implemented into breeding programs in apples [33], tomatoes [34], and potatoes [32•]. Regardless of the role of instrumental methods in breeding programs, validation of the top selections using sensory/consumer tests is recommended.

It is also important to balance agronomic traits (yield, disease resistance, storability, shelf-life) with sensory characteristics driving liking as they can be inversely related [17•]. An in-depth study into the sensory properties and consumer liking drivers of leafy *Brassicas* was undertaken to develop a standard lexicon and better understanding of the texture and bitterness levels accepted by consumers for integration into cultivar improvement since these are related to their nutrient profiles [16••]. Tomatoes have been bred for agronomic traits at the expense of sensory quality, many breeding programs are now trying to bring flavor back into the breeding pipeline by understand drivers of consumer liking and integrating preferred perceptions back into breeding lines through biochemical and molecular biology approaches [18]. Similar approaches have been employed in new cultivar development for apples [33] and edamame [14] and potatoes [32•].

Different actors along the produce value chain all exert influence over characteristics desired in the development and introduction of new cultivars. A study of the apple value chain by Djekic [35•] highlighted these differences in the assessment of fruit quality between industry (grower, packer, retailer) and consumers. Quality indicators for the grower related to yield, size, price; for packers it related to postharvest storage, ease of transport and absence of defects; for the retailer it related to advertising, packaging, price; whereas for the consumers it related to appearance, taste, texture.

Despite the challenges of conducting sensory evaluation on horticultural products, sensory scientists are finding creative ways to overcome these barriers and research in this sector is proliferating rapidly. As the fruit and vegetable sector emerges from the commodity market and moves into a more value-based category with brand differentiation, other consumer-relevant features outside of sensory properties are also entering the spotlight. For nearly two decades, the impact of labels such as local, organic and genetic engineering status have been and continue to be a hot topic in consumer studies on fresh produce [36–39]. In the past 2–3 years a new area of interest has emerged: waste reduction.

Imperfect produce

It is estimated that approximately one-third of the food produced globally is wasted and in the produce sector, this figure increases to around 40% [40]. In households, food waste from fruits and vegetables makes up almost 50% in the EU [41]. One way in which the produce sector is aiming to reduce food waste is by marketing imperfect produce in grocery stores at a discounted price. However, the successful introduction of imperfect produce to a clientele accustomed to perfectly shaped, pristine-colored and blemish-free product requires some strategy. Sensory and consumer scientists have addressed this knowledge gap with studies that provide guidance on what level of imperfection is marketable and how to present it to consumers.

Unsurprisingly, it has been found that consumers perceive produce with internal or external defects as having lower quality and these items are infrequently selected both at the point of purchase and at the point of consumption [42••,43•]. When consumed, products with visual damage are perceived as having lower quality sensory properties and are rated lower for liking [44,45].

A study that examined the level of damage that led to rejection found that small amounts of browning did not lead to disposal. However, when the relative area of browning on an apple was greater than 8%, then half of consumers indicated they would cut away and throw out that portion of the apple. When browning was more severe (over 35% of the relative apple area), then half of consumers indicated they would throw away the whole apple [43•]. Different types of imperfections also impact quality perception differentially. Imperfections that impacted the integrity of an apple (rot, cuts, bruising) were most likely to lead to rejection. Apples with rot or mold were most likely to be rejected (rejected by 67–84% of consumers) followed by those with cuts or bruising (rejected by 41–67%). Finally, consumer rejection of apples with imperfections such as color blemishes or odd-shaped apples varied widely between consumers depending on the blemish appearance or shape, with rejection ranging from 4 to 40%. Although this was a wide range, the percentage of apples that were rejected was overall lower than for apples presenting with rot, mold, cuts or bruises [42••]. Clearly, within these types of imperfections there appears to be a range of acceptability. This was further supported by a study by Louis and Lombart [46•] which indicated that there is an optimal level of shape-related imperfection that achieves the most positive consumer response: moderately misshapen fruits and vegetables were most positively viewed whereas those that were only slightly misshapen or heavily misshapen were perceived as being lower quality. Thus, these criteria can be used to guide specification criteria for which products are suitable to be sold in the fresh market as imperfect produce in grocery stores.

As was previously mentioned, produce with rot, cuts or bruises were most likely to be rejected [43•]. It has been found that consumers generally perceive imperfect produce as having a higher food safety risk [42••,47]. This likely explains why consumers who have children are less likely to purchase imperfect produce, out of concern for their safety. Consumers who are more likely to purchase imperfect produce tend to have more pro-environmental views [47] and tend to more regularly engage in grocery shopping and home cooking [44]. It was also found that consumers are more willing to accept imperfect produce when shopping in the context of a farmer's market [47].

Considering the increased acceptance of imperfect produce by consumers who engage in more food skill related activities, it may not be surprising to note that familiarity with imperfect produce also impacts acceptance. Lack of familiarity has been identified as a barrier to consumer acceptance of imperfect produce [46•] and it has been suggested that images of imperfect produce should be gradually introduced into grocery retail advertisements to increase exposure along with claims regarding health benefits of produce consumption and desirable taste [46•].

It has been proposed that messaging to educate consumers regarding the waste reduction benefits of purchasing imperfect produce or suggesting the use of these products as ingredients in cooking or baking could be used to increase interest in imperfect produce [43•]. A psychology-based study indicated that simply imagining themselves eating defective produce can negatively impact how consumers view themselves. In an attempt to counteract this effect, the researchers conducted a study wherein imperfect produce sales were tracked in a grocery store with signage either simply encouraging customers to purchase imperfect produce ('Pick ugly produce!') or it contained the same message prefaced with a self-esteem boosting message ('You are fantastic! Pick ugly produce!'). It was found that the self-esteem boosting messages significantly increased consumer purchasing of imperfect produce (50% of customers versus 26% of customers exposed to the control advertisement) [48].

Discount pricing has also been shown to be an effective strategy to motivate purchasing of imperfect product [49,50]. However, one should use caution with focusing on cost savings as the main benefit for consumers. It has been found that focusing on cost savings of purchasing imperfect produce positively impacted consumer trust in the retailer in the case of a conventional grocery outlet however it negatively impacted consumer trust in the retailer in the case of an organic grocery outlet where customers are accustomed to a premium offering [46•].

Conclusions

Development of new fruits and vegetables is a labor intensive and long-term proposition. Adding sensory and consumer science to the breeding toolbox enriches the pipeline with consumer targets linked to sensory characteristics and acceptance. This approach is not without its challenges due to product variability, difficulty of assessing maturity and ripeness, postharvest handling and quality assessment. Fortunately, there are many different methods that can be applied to address these challenges and through increased collaboration with breeding programs, postharvest scientists and actors along the produce value chain. The opportunity is ripe to contribute to food sustainability and waste reductions by understanding how to position produce to increase consumer acceptance as was highlighted through the growing body of research into marketing imperfect fruits and vegetables.

Continued experimentation on the best methods to correlated sensory perception and consumer acceptance with physicochemical quality measures, instrumental techniques and genomic and metabolomics approaches will increase the multi-disciplinary collaboration and create efficiencies in new cultivar development. This will hopefully accelerate breeding timelines, enrich breeding populations with desirable traits and reduce costs in new cultivar development.

Conflict of interest statement

Nothing declared.

CRediT authorship contribution statement

Amy J Bowen: Conceptualization, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Alexandra Grygorczyk:** Conceptualization, Investigation, Methodology, Writing - original draft.

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