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Sensory characterization of two California-grown avocado varieties (*Persea americana* Mill.) over the harvest season by descriptive analysis and consumer tests

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Abstract: In this work, descriptive analysis (DA) and consumer panels were conducted on “Hass” and “3-29-5” (GEM®) avocados, grown in southern California. Both panels encompassed at least five time points across the 2019 harvest season. The DA panel identified and evaluated overall richness, creamy, smooth, watery, oily, sweet, bitter, umami, salty, astringent, buttery, nutty, and green. The texture attributes received the highest scores in both “Hass” and “3-29-5.” Both varieties increased in richness, creaminess, and oiliness at harvests 5 and 6. The consumer panel found that “3-29-5” showed more changes in its eating experience over the season than “Hass,” which agreed with dry weight data collected in a simultaneous analytical study. Correspondence analysis indicated that “Hass” samples had a consistent sensory profile over the harvest season, whereas “3-29-5” changed substantially, becoming more closely associated with a positive eating experience late in the harvest season. This is the first work to characterize avocado flavor over the harvest season using both trained and consumer sensory panels.

Practical Application: Many aspects of avocado were found to have some impact on flavor, but textural properties were by far the most important in determining how well the fruit was liked. This information will be useful in future taste evaluations of avocado and the ongoing development of new avocado varieties.

KEYWORDS

avocado, consumer test, descriptive analysis, flavor, harvest, sensory

1 | INTRODUCTION

Varietal differences in avocado are linked to the three races they come from, which have unique geographical regions (Bost et al., 2013). Trading promoted mixing of these varieties and selection of desirable avocados from wild trees set the stage for later breeding efforts. The earliest vegetative propagation of avocados occurred in Florida, beginning in 1901 (Bost et al., 2013). The search for a superior avocado variety led to the introduction of “Fuerte” in California from Atlixco, Mexico in 1911. It was the leading California variety between 1920 and the early 1970s, when it was overtaken by “Hass.” The variety “Hass” arose as a chance seedling with excellent flavor, which led its namesake to patent the variety in 1935 (Bost et al., 2013). The variety “Hass” has other desirable properties for commercialization, such as its size and tough skin to protect it from shipping damage (Handwerk, 2017). “Hass” is now ubiquitous in the international avocado industry and has been propagated around the world. The drawback of this is that the diverse avocado varieties grown worldwide are being removed to grow “Hass” and the narrowing of the avocado genetic pool makes “Hass” more susceptible to opportunistic diseases (Bost et al., 2013; Handwerk, 2017). Genetically, the variety “3-29-5” is a great grandchild of “Hass” and was developed by the University of California, Riverside (UCR). The variety “3-29-5” has been patented (Martin & Bergh, 2003) and commercially marketed under the name of GEM®. It is less prone to alternate bearing than “Hass,” meaning that it produces a consistent yield of fruit each year (Lahav & Lavi, 2013).

Development of marketable avocado varieties would be remiss without sensory evaluation of their flavor and texture. A trained sensory panel in New Zealand developed an avocado lexicon, complete with reference materials for each attribute (Yahia & Woolf, 2011). No results were published from the original panel that applied this lexicon to rating avocado samples. Obenland et al. applied the New Zealand avocado lexicon to avocados originating in the United States, Mexico, Chile, and Peru (Obenland et al., 2012). A semi-expert panel (prior experience with avocados, although not trained as a descriptive panel) evaluated the fruit using check-all-that-apply (CATA). After a preliminary study, the attributes creamy, rich, and grassy were selected as the most important to monitor in relationship to hedonic score (Obenland et al., 2012). Creaminess and richness were found to be positively correlated with liking, whereas grassiness was negatively correlated to liking (Obenland et al., 2012). Another study used a semitrained panel to evaluate “Hass” avocados in Spain at three harvest points (Cañete et al., 2018). Training was limited to only two sessions. No statistical differences were found among the fruit for any attribute (Cañete et al., 2018). Very recently, a study was published that evaluated the descriptive profile and drivers of liking of two commercial (“Hass” and “Fuerte”) and five noncommercial cultivars (Marín-Obispo et al., 2021). Panelists were trained in the Spectrum™ method and had over 500 hr of descriptive experience on various foodstuffs. Nineteen attributes, encompassing flavor, texture, basic tastes, and one trigeminal sense, were evaluated. The key attributes to distinguish the avocado varieties were related to the lipid’s flavor impact and texture (Marín-Obispo et al., 2021).

The objective of this work was to establish a sensory lexicon for avocado with a trained sensory panel, similar to the New Zealand work, and apply this lexicon over the harvest season to “Hass” and “3-29-5” avocados to monitor how flavor and texture change over time. Although recent avocado sensory work has characterized the flavor profile of seven avocado cultivars (Marín-Obispo et al., 2021), the current work is the first to our knowledge to characterize the sensory profile across the harvest season and explore the impact of preparation on sensory attributes. Further, a complementary consumer panel was conducted on fruit from the same harvests to measure the overall liking and determine the terms consumers associate with the fruit they tasted. In combination, these data provide information about what characteristics are associated with liking in avocados and how avocado flavor changes over the harvest season. This study is more in depth compared to the previous sensory work of Obenland et al. (2012), although it too uses changing harvest date to observe differences in avocado sensory properties. Further, by using separate panelists for the consumer and descriptive panels, the consumer panel will be more representative of the average consumer’s perceptions. In a companion study by our lab, analytical measures were performed on “Hass” and “3-29-5” avocados over the harvest season to increase the knowledge on avocado flavor and relate aroma-active volatiles to the moisture and oil contents and fatty acid profile (Hausch et al., 2020). The fruit analyzed were from the same lots as those used in this study.

2 | MATERIALS AND METHODS

2.1 | Avocados

Initial panel development and training in the fall of 2018 was done with imported “Hass” avocados bought directly from a produce distribution center (Fresno, CA). The origin of the fruit was Mexico, Chile, and Peru. For the descriptive analysis (DA) and consumer panels, avocados were harvested near Saticoy, California on an approximately monthly basis between February and July 2019 (February 6, March 8, April 3, May 8, June 25, and July 29). The avocado orchard, storage, and ripening were described previously (Hausch et al., 2020). For sensory analysis, the avocados were surface sterilized with bleach, at a concentration of 25 mg sodium hypochlorite/L water (Lawton et al., 2020). A quarter-size segment of peel was cut off the avocado and the firmness was checked with a manual penetrometer (U.C. Firmness Tester) using an 8-mm tip. Penetration into the fruit was approximately 1 cm. Only avocados with a firmness of 2.2–8.9 N were used for sensory analysis.

For the sensory DA panel, the avocado preparation method was also investigated. Only the middle third of avocados without internal defects were used. The preparations for both “Hass” and “3-29-5” were cubed samples, approximately 1–1.5 cm^3, and an avocado puree was made by blending the sample with a hand mixer until lumps were removed. The purpose of the puree was to present a uniform sample to all panelists, as opposed to cubes coming from different fruit, the latter of which would have inherent variability.

2.2 | Sensory DA

2.2.1 | Panel selection and training

Internal Review Board Socio-Behavioral (IRB-SB) Exempt status for the panels was obtained from the UCR (IRB-SB HS-18-180). Panelists were recruited through staff emails at the San Joaquin Valley ARS Research Center (SJVASC) and UC Kearney Agricultural Research and Extension Center (UCKREC) in Parlier, CA, and flyers were also posted at a local college. Interested participants were asked to come for an initial taste evaluation session, in which they identified basic taste solutions, generated descriptors for a chocolate sample, and performed a triangle test on sets of avocado samples. Additionally, participants answered questions about their avocado consumption and availability to participate in the panel. Participants were only removed from the candidate pool if their availability was incompatible with the panel meeting times or would not be able to commit to a 11-month study. During the first panel meeting, the research was described, and panelists agreed to sign an informed consent form. Initially, 13 individuals joined the panel and 11 panelists were still enrolled at the end of the training period and participated in the subsequent DA panel. For this final group, six panelists were male and five were female. Panelists ranged from their 30s to 70s. The median age was early 50s, range 50–54. Avocado consumption for the panelists, outside of panel, was at least once a week for 10 of the 11 panelists, with two panelists eating avocado more than once per day. One panelist consumed avocados less than once a month outside of panel. The panel went through approximately 24 hr of training, in 1-hr increments, meeting twice per week over a period of approximately 3 months. This ranged from basic taste practice, instruction on sensory DA, term generation, reference screening and anchoring, and line scale practice. Panelists were compensated with avocados and snacks.

2.2.2 | Data collection

DA was executed in a combined Spectrum™ and Qualitative Descriptive Analysis (QDA®) format (Meilgaard et al., 2006). For each attribute, except for "richness," the line scale was anchored with a reference material. The attributes and their corresponding references are shown in Table 1. Panelists were provided with each reference during each panel meeting and encouraged to refresh themselves on the reference ratings. Panelists completed their avocado evaluations using Compusense® software (Ontario, CA) on a tablet, in either a sensory booth or around a table in the main room of the sensory building. Panelists evaluated up to three avocado samples per session and rinsed between avocados and references using La Croix® seltzer water, followed by warm water (50 ± 5°C). La Croix® seltzer water was specifically chosen due to its lack of sodium, that is, no saltiness.

2.3 | Consumer test

The consumer test was conducted at UCR, with faculty, staff, and students recruited to participate by emails and flyers with fruit from the six harvests. As with the DA panel, the research had exempt status granted by an IRB-SB board at UCR. Fruit were partially ethylene ripened at UCKREC as described previously (Hausch et al., 2020). They were then transported to the UCR campus (~450 km) in cooled ice chests. Once on campus, the fruit were completely ripened at 20°C and prepared into cubes as described for the descriptive panel. Panelist turnout ranged from 55–80 individuals per panel, with one panel per harvest. The demographic profile of the panelists is shown in Table 2. In general, panels had an even proportion of males and females, although some harvests had more females participating. Panelists tended to be young, with at least 40% of the panel composed of individuals under 30 years of age. Also, across all panels, at least 55% of the panel was composed of individuals consuming avocados one or more times per week. Tasting was done in a conference room at an open table. Panelists tasted four samples, which were presented in two sets of two. Each set contained one sample of "Hass" and one sample of "3-29-5," labeled with three-digit random codes. The second set was a replicate of the first, in order to evaluate the same samples with different questions. A bite of carrot and a drink of distilled water were used to cleanse the palate between samples. Panelists rated the samples on a 9-point hedonic scale, their desire for a repeat consumption on a 7-point scale, and then described the samples by generating their own terms (free response) (set one) and then selecting all the attributes that applied (CATA) from a list (set two). For set two, the panelists were forced to select at least three attributes, although there was the option to enter one's own descriptor(s) if the given attributes did not apply. The fill-in option was provided to limit panelists selecting terms out of necessity that they felt were unimportant. The list of CATA attributes was based on the terms generated by the DA panel during training. After compiling the terms from all harvests, including filled-in terms, any term that was

TABLE 1 Avocado attributes determined by descriptive analysis panel and associated reference materials with intensity on a 15-cm line scale[a]

Attribute (line scale extremes)	Reference material	Preparation steps	Intensity
Overall			
Richness (bland to rich)	None	–	–
Texture			
Creamy (nonfat to creamy)	Kraft® Philadelphia original cream cheese	Cut into generous size cubes	12.5
Smooth (nonhomogenous to smooth)	Fage® Total 5% milkfat yogurt	Mix yogurt to incorporate separated water and place a dollop of yogurt into sample cups	11.5
Watery (watery to oily)	Del Monte® Light sliced peaches—yellow cling peaches in extra light syrup	Rinse peaches with tap water. Cut peaches into cubes, removing the smallest pieces that come from the tips of the wedges. Place peaches in a bowl and add 200 ml distilled water for every 15 oz can. Soak overnight in the refrigerator.	3
Oily (watery to oily)	Jif® Natural peanut butter with Chosen Foods® avocado oil	100 g peanut butter mixed with 5 g Chosen Foods avocado oil	10
Stringy	None	–	–
Flavor			
Buttery (no butter flavor to buttery)	Whipped butter: Tillamook® sweet cream unsalted butter with Sunnyside Farms® ultra-pasteurizedheavy whipping cream	110 g butter beaten with 60 g heavy whipping cream	12.5
Nutty (not nutty to nutty)	Raw almonds	Roasted almonds ground with the Mainstays™ 1.5 cup mini chopper. Pan roast almonds without oil and allow to cool. Grind almonds and place 8 g per Teflon sniff bottle. Store almonds in the freezer (−18°C) for up to 1 week.	12.5
Green	None	–	–
Taste			
Sweet (not sweet to extremely sweet)	Sunny Select® sugar	Present as a 50 mM sucrose	5
Salty (not salty to extremely salty)	Morton® salt (sodium chloride)	Present as 30 mM sodium chloride	3.5
Bitter (not bitter to extremely bitter)	Lipton® black tea	Pour 24 oz boiling water on three tea bags and steep for 5 min	9
Umami (not umami to extremely umami)	Kitchen Basics® Organic vegetable stock	Dilute 1:2 with distilled water	7.5
Trigeminal			
Astringent (not astringent to extremely astringent)	Tones® alum	Present as 0.3 g/L alum	4.5

[a]Stringy was rated on a 1–3 scale while green was either present or absent.
[b]All references presented at room temperature.

TABLE 2 Profile of avocado consumer panel

	Harvest[a]					
	1	**2**	**3**	**4**	**5**	**6**
Number of panelists	73	75	55/30[b]	64	80	73
	Percentage composition of panel (%)					
	Harvest					
Criteria	1	2	3	4	5	6
Female	46.6	73.3	61.8	51.6	58.8	54.8
Male	53.4	24.0	38.2	46.9	40.0	41.1
Gender, prefer not to answer	0.0	2.7	0.0	0.0	1.3	2.7
Age, 18–24	23.3	18.7	27.3	28.1	30.0	26.0
Age, 25–29	20.5	24.0	20.0	15.6	22.5	23.3
Age, 30–34	21.9	17.3	10.9	15.6	21.3	19.2
Age, 35–39	12.3	13.3	7.3	7.8	7.5	5.5
Age, 40–44	2.7	8.0	12.7	7.8	3.8	5.5
Age, 45–49	0.0	2.7	5.5	6.3	3.8	6.8
Age, 50–54	0.0	6.7	7.3	1.6	3.8	0.0
Age, 55–59	8.2	1.3	3.6	4.7	2.5	2.7
Age, 60–64	8.2	4.0	1.8	3.1	1.3	2.7
Age, 65–69	1.4	2.7	3.6	6.3	2.5	5.5
Age, 70–74	0.0	0.0	0.0	0.0	0.0	0.0
Age, 75 or older	0.0	0.0	0.0	0.0	0.0	0.0
Age, prefer not to answer	1.4	1.3	0.0	1.6	1.3	1.4
Consumption, more than once/day	1.4	0.0	0.0	0.0	1.3	0.0
Consumption, once/day	1.4	8.0	10.9	6.3	3.8	2.7
Consumption, 2–3 times/week	30.1	25.3	29.1	34.4	25.0	32.9
Consumption, once/week	24.7	26.7	18.2	21.9	26.3	19.2
Consumption, 2–3 times/month	28.8	26.7	23.6	26.6	25.0	27.4
Consumption, once/month	12.3	6.7	5.5	1.6	10.0	9.6
Consumption, less than once/month	1.4	6.7	12.7	7.8	8.8	6.8
Number participated in past sensory test	34.2	45.3	52.7	67.2	36.3	49.3

[a]2019 harvest dates were February 6, March 8, April 3, May 8, June 25, and July 6.

[b]A limited number of "3-29-5" avocados were at eating firmness at the time of sensory evaluation. Only avocados with a penetrometer reading of 2.2–8.9 N were used.

used by less than 10% of the panelists over the entire harvest season was eliminated. Panelists were compensated with snacks, including guacamole.

2.3.1 | Free response data interpretation

Free response data have the potential advantages of a fuller characterization of the data and making panelists more invested in the data, as opposed to CATA (Mahieu et al., 2020). The challenge of free response data is coding in a way that can be interpreted by the researcher while remaining true to the panelists' description. As discussed by others, processing free response data involves correcting misspellings, removing connecting or unnecessary words, lemmatization, and equating synonyms (Lahne et al., 2013; Symoneaux et al., 2012). In the case of this study, hedonic statements in the descriptions were removed. Examples of the data coding are shown in Table S1.

2.4 | Statistics

For each attribute, comparison of fruit varieties over harvesting time and preparation levels, including interactions between harvesting and varieties, was estimated using mixed effect models including estimation of panelists' random effects. Statistically significant differences were evaluated at the 95% confidence level (p-value < 0.05). The solution to the mixed model equations is a maximum likelihood estimate for normally (or nearly normally) distributed responses where the random effect refers to the portion of variance of the intercept that depends on the panelist. In addition, polynomial regressions were used to interpolate data points in order to provide a visual reference of the trends existing over the plotted data. When the response was dichotomic, a generalized linear mixed effects model was used with binomial link functions that, as above, included a random effect component for the panelist. Mixed effects models were computed using the lmr4 R package (Bates et al., 2015). Correspondence analysis (CA) was implemented as an adaptation of principal component analysis (PCA) tailored to handle nominal variables (Abdi & Williams, 2010). With CA, the contingency tables of attributes (frequencies) were analyzed over harvesting time per fruit variety. These were chi-squared tested in order to provide factor scores for both the rows and the columns of the contingency table (in the PCA tradition, these factors are usually called components). Two principal orthogonal factors were used to project multidimensional variables into bidimensional frames that captured the majority of the variation in the data (Kassambara, 2017). The scatter plots (i.e., biplots) show harvesting times stratified per variety within the context of two cartesian axes (i.e., two principal factors); contextually, dots were used to represent the contribution of each attribute to each factor. CA was computed using the FactoMine R package and the Factoextra R package to produce ggplot2-based visualization of the CA results. All the graphical representations and data preprocessing were performed using the Tidyverse R package (Wickham et al., 2019) of R statistical software.

3 | RESULTS AND DISCUSSION

3.1 | Descriptive analysis

DA panel development and discussion led to the selection of 15 attributes. Avocados were evaluated on one global attribute (richness), six texture attributes (creamy, smooth, watery to oily, firmness, and strings), three flavor attributes (buttery, nutty, and green), four taste attributes (sweet, bitter, umami, and salty), and one trigeminal attribute (astringent). The chemical sensing of astringent compounds with the human body has been carefully studied (Schöbel et al., 2014). The textural aspects attributes agree with many that were identified in New Zealand "Hass" avocados, especially oil release and water release, fibrousness, and particles (Yahia & Woolf, 2011) and also a number that were described by Marín-Obispo et al. (2021). Additionally, the panelists evaluated the texture by compressing it with a spoon in the study of Marín-Obispo et al. (2021). Previous work by Yahia and Woolf (2011) found more flavor attributes than were identified in this study, including hay odor, woody pine, canned pea, floral, banana, and citrus flavors. On the other hand, the current work identified the flavor attribute buttery, which agrees with the findings of Marín-Obispo et al. (2021), who used the term lipidic complex, creamy, and oily to describe aromatic flavors relating to lipid flavor aspects. The current study and Marín-Obispo et al. (2021) examined sweetness and the trigeminal sensation, astringent. Umami/savory was evaluated in the current and Yahia and Woolf (2011) studies but not by Marín-Obispo et al. (2021). Regional variation and possibly cultivar differences in avocados are potential contributing factors to these differences.

At each harvest, the panelists answered multiple choice questions about firmness, strings, and green. The attribute green was only rated as present or not present, as some panelists could not consistently recognize green. Because the avocados were checked for firmness by the penetrometer before selection for sensory evaluation, the firmness question served to confirm with the panelists that the avocados were an appropriate ripe firmness (data not shown). Similarly, stringy was rated as not stringy, one to two strings noticeable, or very stringy. During analysis, the category "very stringy" was eliminated because there was only one instance of this choice being selected across all harvests, preparations, and panelists. As with firmness, a categorical classification of stringiness was important for giving a complete picture of the avocado eating experience, but a precise characterization was deemed unnecessary. All other attributes were evaluated on a continuous line scale from 0 to 15. The panelists did not detect any sourness in the avocados during scale development; thus, it was excluded. In most cases, one reference was used as an anchor for each scale. The references used and their assigned intensity are given in Table 1. There were exceptions to one anchor per scale. In the case of watery and oily, panelists chose to place watery and oily as opposites on a continuum because, in the case of avocado, the two characteristics are inversely correlated. The watery end of the scale was anchored with canned peaches that had been soaked overnight in water at a rating of "3," and peanut butter thinned with oil anchored the oily side of the scale at "10." On the other hand, the attribute richness was defined as overall avocado intensity, not specific to any characteristic. Given this definition, it was not possible to provide any suitable reference for richness.

Figure 1 shows the outcome of the DA panel across all attributes from harvest 2 to 6. Between the time necessary for attribute and reference selection and other events outside of our control, the evaluation of avocados for actual data collection was not possible until harvest 2. However, this did allow the DA panel to practice with California

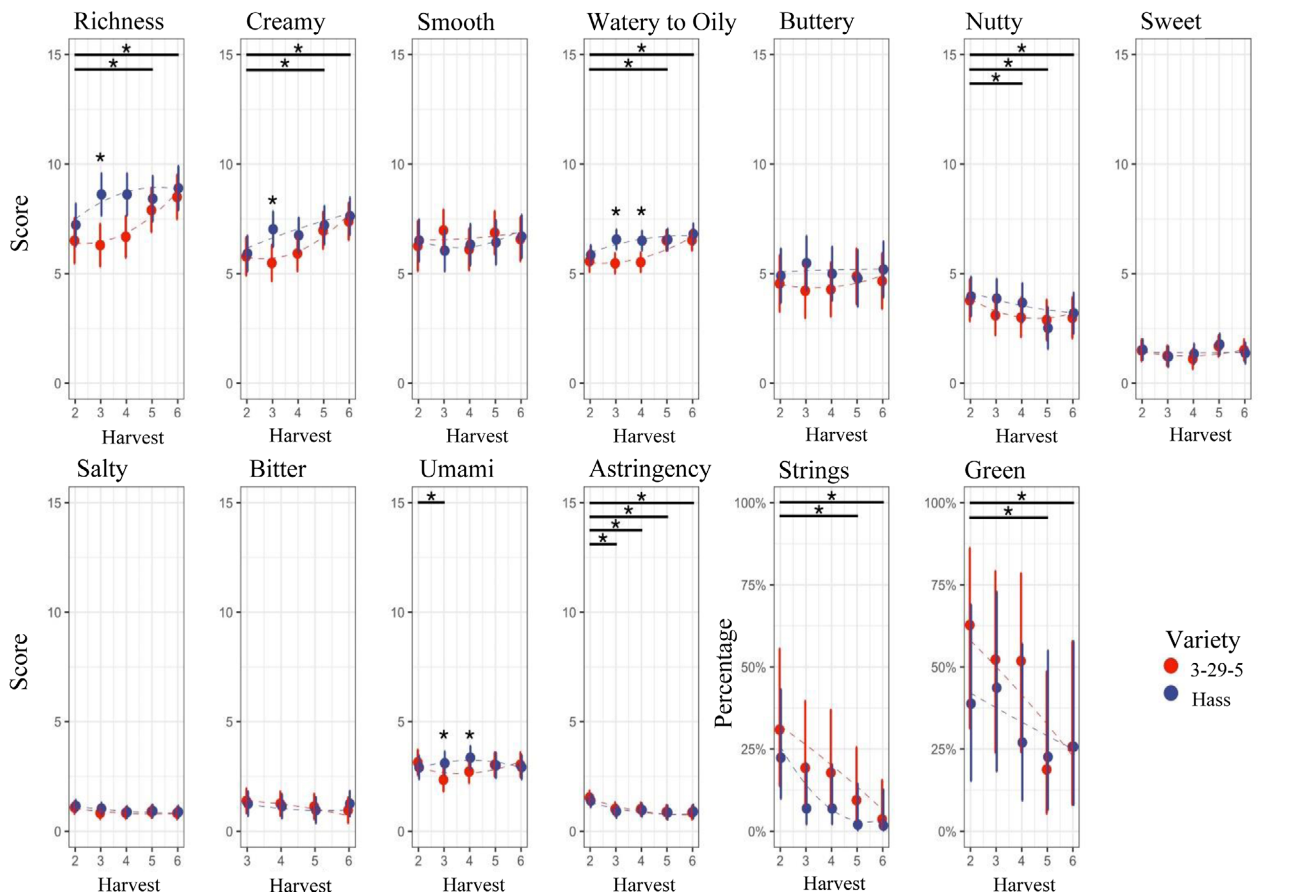

FIGURE 1 Descriptive analysis attributes for combined creamed and pureed "3-29-5" and "Hass" sampled over the harvest season. On the horizontal axis the harvest time (from 2 to 6) and on the vertical axis scores for the sensory attributes (one attribute per figure); fruit were evaluated on a 15-point scale; "strings" and "green" attributes were reported as percentage of panelists reporting the attribute. The points show the observed scores and 95% confidence intervals are indicated with the vertical lines estimated from the mixed effects model (model details available in Table S3). Dashed lines represent quadratic trends. Overall, cubed and pureed samples were associated with similar (i.e., nonsignificantly different) scores, thus data for these treatments were combined. The "smooth" attribute was evaluated on cubed samples only. Black lines with asterisks indicate those harvests statistically different (at least $p < 0.05$) from harvest 2. Black asterisks directly above the points refer to a variety effect per harvest time. Harvest dates were March 8, April 3, May 8, June 25, and July 6

"Hass" and "3-29-5" fruit for 1 month. The plot points are the estimates obtained from the mixed effects model of the data with the 95% confidence intervals indicated by the vertical bars. The dashed lines are the polynomial interpolation of the data points. As observed from the plots, richness, creamy, watery to oily, nutty, umami, and astringency were observed to show statistical differences over harvest. In both varieties, most statistical changes are observed at harvests 5 and 6, where increases in richness, creaminess, and oiliness are observed. Additionally, declines in nuttiness (from harvest 4) and astringency (from harvest 2) are observed. The dry weights of the avocados are shown in Table S2, which were collected in our corresponding analytical study (Hausch et al., 2020). The dry weights for both varieties increase over the harvest season, with statistical changes prominent in "3-29-5," as observed by a significantly higher dry weight at harvest 6 compared to harvest 4. In "Hass," the average dry weight is significantly higher at harvest 6 compared to harvest 1 and the trend for a small, nonstatistical increase in dry weight is observed between harvests 2 and 6. These dry weight results agree with the panelists' perception of decreased wateriness at later harvest dates. An increase in avocado dry weight is highly correlated with an increase in oil content (Lee et al., 1983), and the avocado industry uses dry weight for many avocado varieties as a maturity standard for avocado (Westlaw, 2020). The data indicate that "Hass" at harvest 3 was scored higher on the attributes of richness, creaminess, oiliness, and umami. For both varieties, the basic tastes sweet, salty, and bitter and trigeminal sense astringent are all present at a low level at all the harvests. Umami is the most important basic taste, with an average rating around 3. Buttery and nutty receive higher ratings than the taste attributes, scoring around 4.6 and 3.8, respectively. The texture attributes dominate the avocado eating experience, as would be expected, with creamy and smooth both receiving ratings averaging around 6.25. The magnitude of richness ratings is comparable to creamy and smooth. In past avocado sensory panels, composed of consumers or panelists with limited training, creamy was also recognized as one of the key attributes. Specifically, in "Hass" avocados evaluated from the United States, Mexico, Chile, and Peru, the attributes creamy, smooth, nutty, and buttery were most frequently associated with avocados with high hedonic scores, out of the 25 sensory attributes available for selection (Obenland et al., 2012). Likewise, in a study evaluating new cultivars for suitability under Florida growing conditions, creamy was a highly selected attribute from a list of possible attributes, along with firm and mushy, in some cases (Pisani et al., 2017).

From Figure 1, the incidence of strings and green in avocados was observed to decline across the harvest season. These changes were only statistically significant at the last two harvest points. In our accompanying study, examining the chemical composition of avocado, aroma extract dilution analysis (AEDA) was used to determine the odor potency of each volatile aroma compound (Hausch et al., 2020). In AEDA, serial dilutions of the avocado extract are evaluated by gas chromatography olfactometry. The compound's threshold and concentration in the sample determine the highest dilution at which it can be detected, which is measured as the flavor dilution (FD) factor. The odor intensity of hexanal (green, grassy aroma) declined in "Hass" from harvest 3 to 6, as observed from the FD value decreasing from 4096 to 256, whereas it remained constant for "3-29-5" (FD of 512 or 256 at each harvest) (Hausch et al., 2020). The responses here for green do not reflect this trend for "3-29-5." Increased oil content reduces flavor release with lipophilic compounds. For example, it was shown with nonanal that the concentration released decreased approximately 10-fold when the oil content of the emulsion was increased from 1% to 20% (Tamaru et al., 2018). Because the "3-29-5" avocados showed a statistical increase in oil content (Hausch et al., 2020) (increase of about 9% oil), there is likely a lower partitioning of hexanal into the headspace during consumption, which could explain why the green perception is lower to panelists. AEDA is independent of the matrix, whereas the sensory panel evaluates the avocado as a complete entity.

In order to better deal with the inherent variability among individual avocados, it was hypothesized that the variability in avocado ratings could be reduced by pureeing the avocados to give the panelists a homogenous product. All attributes except firmness and smoothness were evaluated in the pureed samples. The variability in the pureed sample was higher compared to the cubed sample within a given attribute, based on the width of the confidence interval for pureed and cubed treatments, disproving the hypothesis. The model used in Figure 1 included preparation as a fixed effect. The details of the model results and coefficients for the cubed and pureed treatments can be found in Table S3. Preparation was statistically significant, in relation to harvest 2 "3-29-5" puree, for only the attributes richness, bitter, and astringency. Informal comments from the DA panel suggest that panelists prefer eating cubed samples to pureed samples.

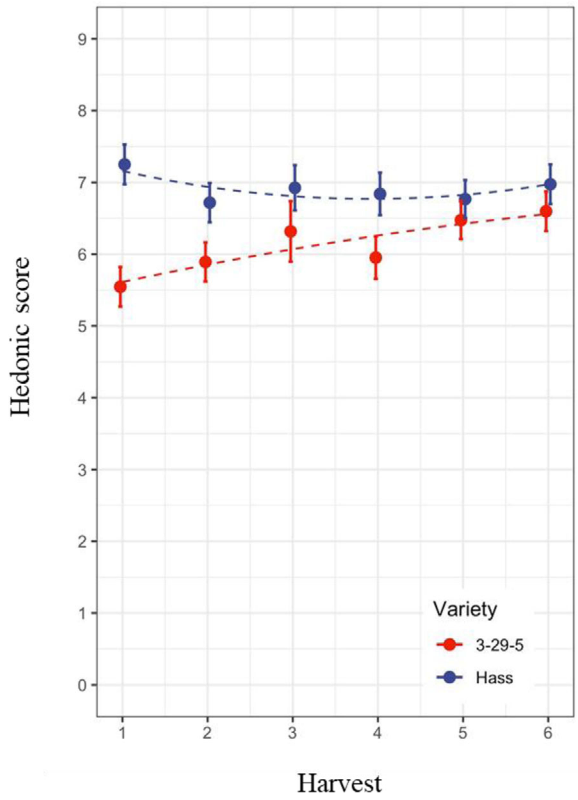

FIGURE 2 Overall consumer liking (hedonic score) of each avocado variety over the harvest season. Data points are means for each harvest with 95% confidence intervals. Harvest dates were February 6, March 8, April 3, May 8, June 25, and July 6

3.2 | Consumer panel

Figure 2 shows the likability of "Hass" and "3-29-5" changes over the season. Panelists indicated their liking on a 9-point scale ranging from dislike extremely to like extremely. The likability of "3-29-5" increased steadily over the harvest season from an average of approximately 5.75 to 6.5, where 5 indicated *neither like nor dislike*, 6 indicated *like slightly*, and 7 indicated *like moderately*. The liking for "Hass" was around 7 for the entire season, with a slight decline over time. This agrees well with the findings of Marín-Obispo et al. (2021), where "Hass" obtained an overall liking of 7.2 by the consumer panel, well above most

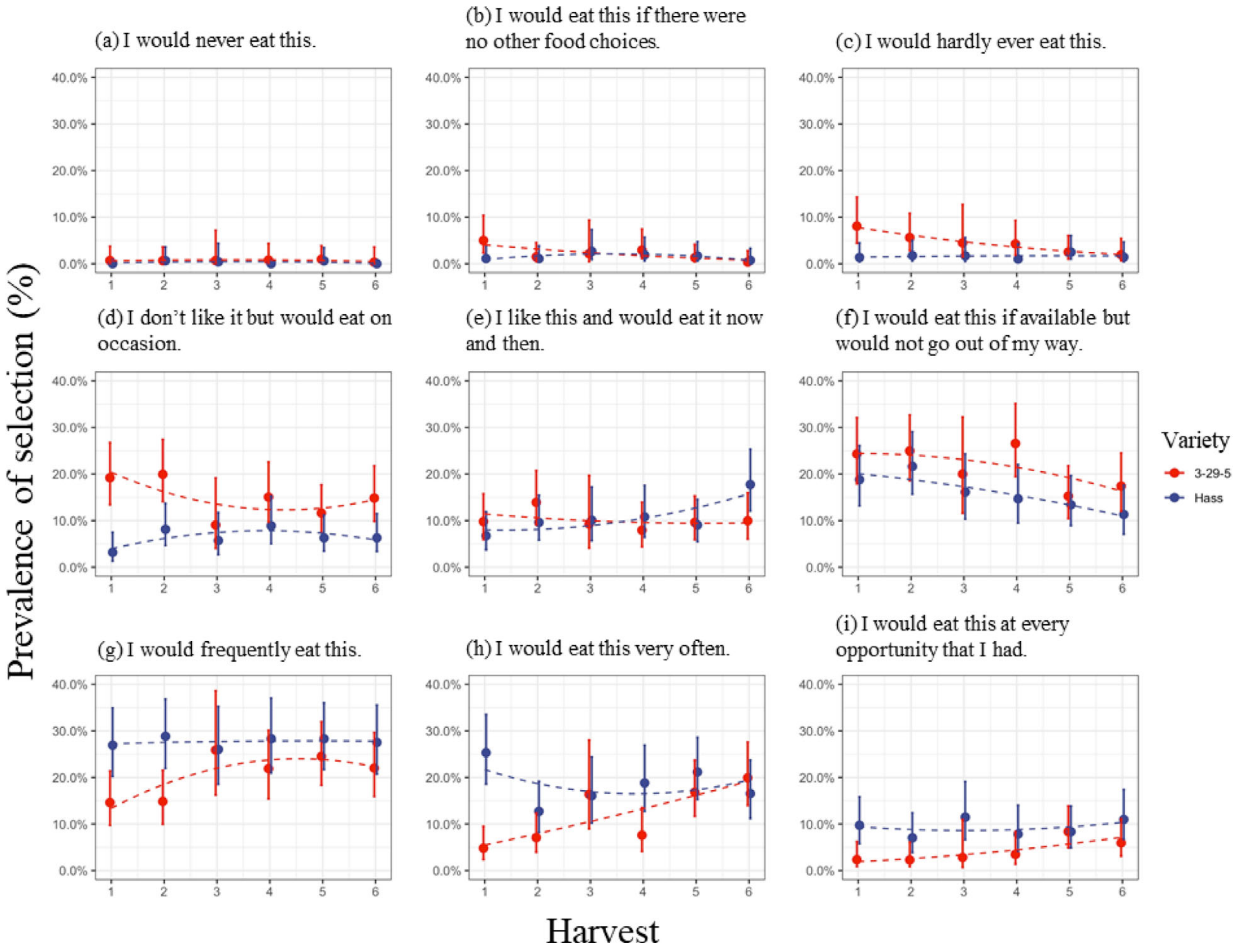

FIGURE 3 Consumer assessment of repeat eating behavior for "Hass" and "3-29-5." The panelists were asked to select the response that best matches their opinion. Data points show means for each harvest with 95% confidence intervals. Harvest dates were February 6, March 8, April 3, May 8, June 25, and July 6

cultivars in that study. The "Hass" dry weights showed little change over the time period of this study, although there was a statistically higher dry weight at harvest 6, compared to harvest 1. In contrast, the dry weight of "3-29-5" at harvest 1 was below the minimum maturity standard of 22.8% (S. Santander, personal communication, 2006). "3-29-5's" increase in dry weight (Table S2) over the season likely contributed to its increased likability. In 1983, Lee et al. established that avocado taste ratings are correlated to oil content and dry weight (Lee et al., 1983). Aroma-active volatiles such as methional (potato) and octanal (oily) show modest increases in late season "Hass" (Hausch et al., 2020). Potentially these compounds affected the likability of "Hass" in the late season; yet, sensory model studies would be needed to test this. "Hass" consistently earned a higher likability score than "3-29-5" until harvest 5, when likability between the two varieties was equivalent. Figure 3 provides information about how willing the consumers would be to eat the samples again, ranging from never to every opportunity. This scale is modified from the food action rating scale (Schutz & Pilgrim, 1957) and measures a quality that could be called sustained likability. Both varieties had few responses in the very negative categories: I would never eat this (1) and I would only eat this if there were no other food choices (2). For less negative categories: I would hardly ever eat this (3) and I don't like it but would eat on occasion (4), "3-29-5" had a greater number of positive responses than "Hass" early in the season. "Hass" was unchanged throughout the season in these two categories. Both varieties were similar in that they had a greater number of positive responses early in the season for: I would eat this if available but would not go out of my way (6). The varieties again contrasted in the very positive categories: I would frequently eat this (7), I would eat this very often (8), and I would eat these any opportunity I had (9). In these three categories, "Hass" was relatively unchanged throughout the season, whereas "3-29-5" increased with the progression of the season, becoming equivalent to "Hass" in late season. The overall conclusion is similar for Figures 2 and 3: panelists show a moderate

TABLE 3 Compilation of the check-all-that-apply data collected from the consumer panel across the harvest season[a]

	H1 "Hass"	H1 "3-29-5"	H2 "Hass"	H2 "3-29-5"	H3 "Hass"	H3 "3-29-5"	H4 "Hass"	H4 "3-29-5"	H5 "Hass"	H5 "3-29-5"	H6 "Hass"	H6 "3-29-5"	Sum
Creamy	**47**	**17**	**44**	**31**	**38**	**15**	**41**	**29**	**53**	**55**	**52**	**43**	**465**
Smooth	**51**	**29**	**49**	**36**	**33**	**13**	**42**	**31**	**51**	**44**	**49**	**44**	**472**
Stringy	2	6	3	9	4	2	2	1	3	3	1	4	40
Oily	9	12	10	10	11	5	8	11	10	13	9	12	120
Watery	**12**	**43**	**8**	**33**	**4**	**12**	**12**	**26**	**9**	**11**	**14**	**19**	**203**
Firm	17	12	18	4	7	8	8	4	24	12	7	13	134
Mushy	**15**	**25**	**9**	**29**	**16**	**9**	**8**	**26**	**15**	**19**	**16**	**17**	**204**
Sweet	12	6	12	13	12	3	13	9	10	14	13	7	124
Sour	2	2	4	7	2	2	2	4	4	8	4	9	50
Bitter	4	14	15	15	6	2	7	14	11	22	8	15	133
Salty	7	1	8	5	7	3	6	7	7	12	13	7	83
Savory	**36**	**16**	**33**	**19**	**24**	**7**	**29**	**17**	**27**	**25**	**30**	**29**	**292**
Astringent	3	4	4	6	0	3	1	5	6	7	2	8	49
Buttery/rich	**35**	**13**	**40**	**18**	**29**	**5**	**29**	**13**	**40**	**23**	**31**	**27**	**303**
Nutty	20	15	25	18	10	8	12	15	18	24	18	16	199
Green	**26**	**39**	**17**	**22**	**15**	**7**	**11**	**13**	**13**	**19**	**16**	**15**	**213**
Flavorless[b]	1	3	0	0	0	2	0	0	0	0	1	0	7
Bland[b]	2	6	1	6	5	2	4	8	6	3	5	4	52
Mild[b]	1	2	0	1	0	0	3	0	0	0	0	1	8
Total number of panelists	73	73	75	75	55	30	63	64	80	80	72	73	

[a]Harvest dates (H) were February 6, March 8, April 3, May 8, June 25, and July 6. Most prominent terms are bolded.

[b]Panelists had the option to write-in terms, in addition to the provided terms. Flavorless, bland, and mild were added to the table, as they were used by at least 10% of panelists across the entire harvest.

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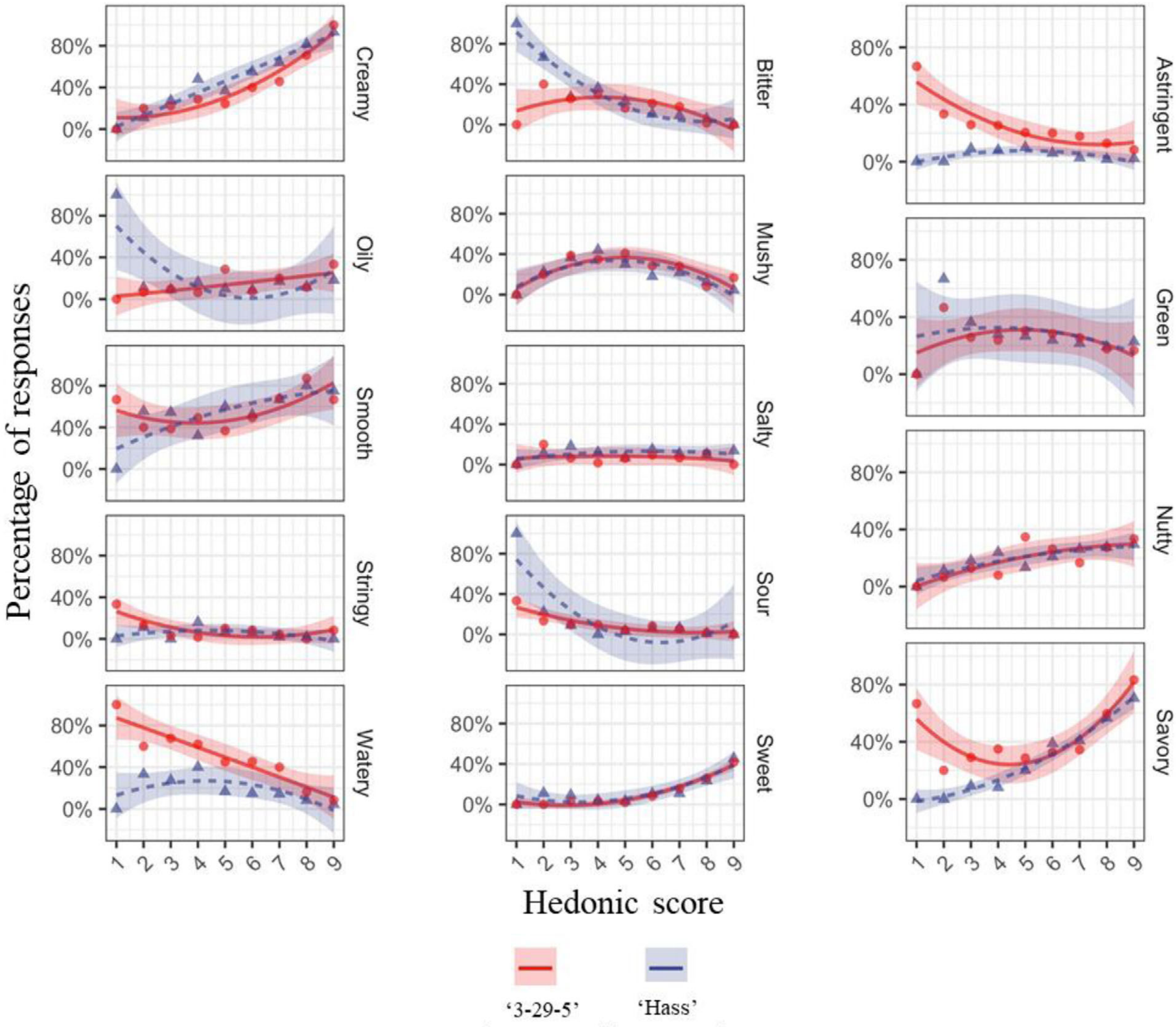

FIGURE 4 Relationship between hedonic scores and the frequency of a given CATA attribute. The number of times an attribute was selected at each hedonic score was determined and then divided by the number of panelists at each hedonic score. This method of plotting the data demonstrates attributes that are positively/negatively correlated with liking. Trendlines for the response for each attribute are shown with 95% confidence intervals in red or blue

increase in their liking for "3-29-5" as the season progress, whereas "Hass" is more stable across the season.

The consumers' perception of the "Hass" and "3-29-5" avocados, as characterized by descriptors from CATA, is shown in Table 3. The free response data are shown in Table S4. Overall, the CATA and free response data agree well; therefore, the emphasis will be placed on CATA results in this discussion. As expected, a set word choice for the panelists allows dominant attributes to clearly emerge with less noise. The most frequently given terms over all samples related to texture, specifically creamy (465 incidences over the harvest season), smooth (472), watery (203), and mushy (204). Panelists selected "watery" more frequently for "3-29-5" than for "Hass," especially early in the season, which agrees well with the findings of the descriptive panel. Savory was by far the most reported basic taste, with 292 instances, in contrast to the second most important basic taste, bitter, which was reported 133 times. Two flavor attributes also arose as very important: buttery/rich (303) and green (213). The attribute green was most selected at harvest 1. The importance of green in the CATA data is quite interesting in comparison to the descriptive panel. Although the descriptive panel was more neutral to green, they start rating avocados for analysis on harvest 2 where the average dry matter for both varieties was greater than the legal minimum maturity. Therefore, timing likely obscured the importance of the attribute green to the descriptive panel.

The good agreement among the DA panel and consumer panel CATA scores indicates that using CATA is a good tool when a trained panel is not possible. The CATA word list in this study was based on the DA panel's lexicon; therefore,

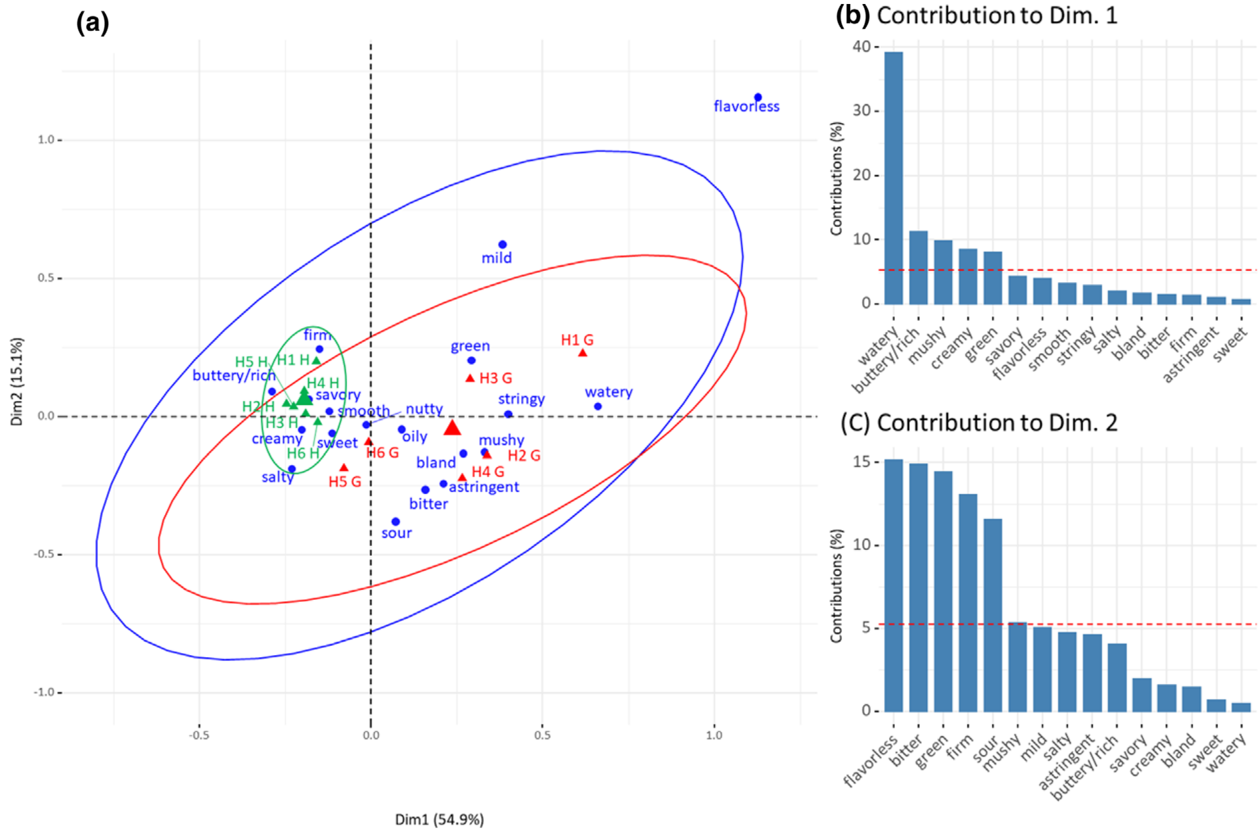

FIGURE 5 Correspondence analysis of CATA data showing biplot (a) and bar plots of contributing attributes to dimension 1 (b) and dimension 2 (c). Labels in biplot are as follows: "Hass" harvests (H, green), "3-39-5" harvests (G, red), and attributes (blue). Large triangles represent the center of the ellipses for each variety

a focus group to develop a lexicon is important. Regional and varietal variations in avocado may prevent this lexicon from applying to avocados universally, as some flavor differences are observed between the lexicon reported here compared to the lexicons developed in New Zealand and Mexico.

Figure 4 shows relationships between the hedonic scores and CATA descriptors used. Creamy, smooth, and savory increase in incidence in avocados that were well liked. These correlations agree with those found by Obenland et al. (2012). Further, Obenland et al. found that a decline in grassiness corresponded to increased liking, whereas the current work found that green was neutral in regards to liking. Yet, grassiness would convey a sharper/more intense perception of green. The avocados initially used in the work by Obenland et al. were more immature and likely grassier than those used in this study. Sourness, bitterness, astringency, and watery are negatively associated with likability, although there are some varietal differences in how strongly these attributes are negatively associated with low hedonic scores.

The CATA and free response data were analyzed with CA, which is shown in Figures 5 and S1. CA was used to visualize "Hass" and "3-29-5" samples in relation to their attributes as points in a two-dimensional space. When one or more attributes are plotted close to a sample in the biplot, the attributes were commonly used by panelists to describe a sample. Each dimension (*x* and *y* axes) is derived as a combination of multiple attributes (Figures 5b, c and S1b, c). Figure 5b shows that the attributes watery, buttery/rich, mushy, creamy, and green account for most of the variability of the data. Thus, they are the attributes that mark a strong difference between samples. Figure 5a shows that buttery/rich and creamy attributes are adjacent in a compact area of the graph that is also populated by Hass samples, indicating an association between them. On the other hand, "3-29-5" samples are spread over a larger area, indicating a larger variability depending on the sampling time; in that area, we can also find watery, mushy, and green attributes. Figure S1 refers to free responses data. This data collection method, when compared to CATA, provided a larger number of attributes, thus a more detailed but less accurate picture (when confined to a two-dimensional plot) of the relationship between samples, harvesting times, and attributes. Similar to Figure 5, Figure S1 shows that "Hass" samples are found in a more compact area of the graph and are associated with creamy, firm, savory, and flavorful attributes. On the other hand, "3-29-5" are sparsely located over a larger attribute space where we can also find watery, bland, and mild attributes.

Overall, the figures show that the positive *x*-axis quadrants contain the negative attributes: watery, stringy, mushy, green, and flavorless. Conversely, the negative *x*-axis quadrants contain the desirable attributes in avocado: buttery/rich, savory, smooth, and creamy. All the "Hass" samples are clustered in this desirable attribute region, whereas "3-29-5" is scattered and more frequently associated with less palatable characteristics. Of all "Hass" samples, harvest 1 fruit had the strongest correlation to any descriptor, which was firm. Harvest 1 "3-29-5" has the strongest correlation of any samples to specific descriptors, which are green and an inverse relationship to salty. By late in the harvest season (time points 5 and 6), "3-29-5" has become a neutral eating experience and cannot be distinguished from other samples, when confined to a two-dimensional plot.

4 | CONCLUSION

The sensory eating experience of both "Hass" and "3-29-5" increased in richness, creaminess, and oiliness during the last two harvest points in the study. Notable changes in "3-29-5" were found by the consumer panel, which applied the terms watery and bland less frequently to "3-29-5" as the season progressed. These changes in "3-29-5" are supported by its increasing maturity as measured by dry weight. Texture attributes were the dominant features of both varieties' eating experience. The sensory profile differences between "Hass" and "3-29-5" were more modest than expected. This may be due to several reasons, including that avocado's taste and flavor attributes are subtle, as seen by DA panelists' use of the lower third of the magnitude scale. To compound this, the changes in the avocado over the harvest season are small compared to the extremes of the line scale and, despite many hours of training, the DA panelists are still variable instruments. Greater differences between the two avocado types would be observed if the study had been initiated earlier in the season. Further, in future DA panel work with avocados, it could be helpful to "zoom in" on the line scale so that the small changes between avocados can be quantitated better. For example, the line scale for umami used with avocado should have different extremes than the line scale for umami used with pork.

Subjective (consumer) differences showed differences among the avocados slightly more than the quantitative data (DA panel). The consumer panel demonstrated an increased liking of "3-29-5" over the harvest season. "3-29-5's" liking was noted by the consumer panel to be negatively correlated to wateriness, in accordance with the DA panel finding wateriness to decline over the harvest. Yet, "Hass" was preferred to "3-29-5" over the whole season until harvest 5, where the likability of both varieties was equivalent. The findings of this study give more insight into avocado flavor over the season and provide a sensory lexicon to be used with California-grown avocados.

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AUTHOR CONTRIBUTIONS

Bethany Hausch: conceptualization; investigation; methodology; writing-original draft; writing-review and editing. Mary Lu Arpaia: conceptualization; writing-original draft; writing-review and editing. Salvatore Campisi-Pinto: formal analysis. David Obenland: conceptualization; writing-original draft; writing-review and editing. BJH conceptualized and planned the experimentation with some assistance from MLA and DO. SCP did the statistical analysis. BJH wrote the manuscript. It was reviewed by MLA, SCP, and DO and revised by BJH and DO.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

Abdi, H., & Williams, L. J. (2010). Principal component analysis. *WIREs Computational Statistics*, *2*, 433–459. http://staff.ustc.edu.cn/~zwp/teach/MVA/abdi-awPCA2010.pdf

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bost, J. B., Smith, N. J. H., & Crane, J. H. (2013). History, distribution and uses. In B. Schaffer, B. N. Wolstenholme, & A. W. Whiley (Eds.), *Avocado: Botany, production and uses* (2nd ed., pp. 10–30). CAB International.

Cañete, M. L., De Los Cobos, R. P., & Hueso, J. J. (2018). Influence of harvest date on sensory quality attributes of avocado 'Hass.' *Acta Horticulturae*, *1194*, 1127–1131. https://doi.org/10.17660/ActaHortic.2018.1194.161

Handwerk, B. (2017, July 28). *Holy guacamole: How the Hass avocado conquered the world*. Smithsonian Magazine.

https://www.smithsonianmag.com/science-nature/holy-guacamole-how-hass-avocado-conquered-world-180964250/

Hausch, B. J., Arpaia, M. L., Kawagoe, Z., Walse, S., & Obenland, D. (2020). Chemical characterization of two California-grown avocado varieties (*Persea americana* Mill.) over the harvest season with an emphasis on sensory-directed flavor analysis. *Journal of Agricultural and Food Chemistry*, *68*, 15301–15310. https://doi.org/10.1021/acs.jafc.0c05917

Kassambara, A. (2017). *Practical guide to principal component methods in R (Multivariate Analysis 2): PCA, M(CA), FAMD, MFA, HCPC, factoextra*. STHDA.

Lahav, E., & Lavi, U. (2013). Genetics and breeding. In B. Schaffer, B. N. Wolstenholme, & A. W. Whiley (Eds.), *The avocado: Botany, production and uses* (2nd ed., pp. 51–85). CAB International.

Lahne, J., Trubek, A. B., & Pelchat, M. L. (2013). Consumer sensory perception of cheese depends on context: A study using comment analysis and linear mixed models. *Food Quality and Preference*, *32*, 184–197. https://doi.org/10.1016/j.foodqual.2013.10.007

Lawton, M., Kinchla, A., & McKeag, L. (n.d.). Produce wash water sanitizers: Chlorine and PAA. https://ag.umass.edu/vegetable/fact-sheets/produce-wash-water-sanitizers-chlorine-paa

Lee, S. K., Young, R. E., Schiffman, P. M., & Coggins, C. W. (1983). Maturity studies of avocado fruit based on picking dates and dry weight. *Journal of the American Society for Horticultural Science*, *108*(3), 390–394. http://avocadosource.com/Journals/ASHS/ASHS_1983_108_PG_390-394.pdf

Mahieu, B., Visalli, M., Thomas, A., & Schlich, P. (2020). Free-comment outperformed check-all-that-apply in the sensory characterisation of wines with consumers at home. *Food Quality and Preference*, *84*(February), 103937. https://doi.org/10.1016/j.foodqual.2020.103937

Marín-Obispo, L. M., Villarreal-Lara, R., Rodríguez-Sánchez, D. G., Del Follo-Martínez, A., da la Cruz Espíndola Barquera, M., Jaramillo-De la Garza, J. S., Díaz de la Garza, R. I., & Hernández-Brenes, C. (2021). Insights into drivers of liking for avocado pulp (*Persea americana*): Integration of descriptive variables and predictive modeling. *Foods*, *10*(99), 1–21. https://doi.org/10.3390/foods10010099

Martin, G. E., & Bergh, B. O. (2003). Avocado tree named "3-29-5" (US Patent No. US PP14,239 P3). U.S. Patent and Trademark Office.

Meilgaard, M., Civille, G. V., & Carr, B. T. (2006). *Sensory evaluation techniques* (4th ed.). CRC Press.

Obenland, D., Collin, S., Sievert, J., Negm, F., & Arpaia, M. L. (2012). Influence of maturity and ripening on aroma volatiles and flavor in 'Hass' avocado. *Postharvest Biology and Technology*, *71*, 41–50. https://doi.org/10.1016/j.postharvbio.2012.03.006

Pisani, C., Ritenour, M. A., Stover, E., Plotto, A., Alessandro, R., Kuhn, D. N., & Schnell, R. J. (2017). Postharvest and sensory evaluation of selected 'Hass' × 'Bacon' and 'Bacon' × 'Hass' avocado hybrids grown in east-central Florida. *Hortscience*, *52*(6), 880–886. https://doi.org/10.21273/hortsci11375-16

Schöbel, N., Radtke, D., Kyereme, J., Wollmann, N., Cichy, A., Obst, K., Kallweit, K., Kletke, O., Minovi, A., Dazert, S., Wetzel, C. H., Vogt-Eisele, A., Gisselmann, G., Ley, J. P., Bartoshuk, L. M., Spehr, J., Hofmann, T., & Hatt, H. (2014). Astringency is a trigeminal sensation that involves the activation of G protein-coupled signaling by phenolic compounds. *Chemical Senses*, *39*(6), 471–487. https://doi.org/10.1093/chemse/bju014

Schutz, H. G., & Pilgrim, F. J. (1957). Differential sensitivity in gustation. *Journal of Experimental Psychology*, *54*(1), 41–48.

Symoneaux, R., Galmarini, M. V., & Mehinagic, E. (2012). Comment analysis of consumer's likes and dislikes as an alternative tool to preference mapping. A case study on apples. *Food Quality and Preference*, *24*(1), 59–66. https://doi.org/10.1016/j.foodqual.2011.08.013

Tamaru, S., Igura, N., & Shimoda, M. (2018). Effectiveness of water-air and octanol-air partition coefficients to predict lipophilic flavor release behavior from O/W emulsions. *Food Chemistry*, *239*, 712–717.

Westlaw (2020). § 1408.6. Avocados, Maturity. Retrieved March 20, 2020 from https://govt.westlaw.com/calregs/Document/IBB4442F0277711E186AE8E470DB943DB?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Yahia, E. M., & Woolf, A. B. (2011). Avocado (*Persea americana* Mill.). In E. M. Yahia (Ed.), *Postharvest biology and technology of tropical and subtropical fruits Volume 2: Acai to citrus* (pp. 125–185). Woodhead Publishing. https://www.sciencedirect.com/book/9780857090904/postharvest-biology-and-technology-of-tropical-and-subtropical-fruits

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Sensory characterization of two California-grown avocado varieties (*Persea americana* Mill.) over the harvest season by descriptive analysis and consumer tests

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Supplementary information

Table S1. Selected free response data from consumer panel to demonstrate coding for analysis.

Original free response	Response after coding
I like the texture and color. It was slightly sweet and refreshing. It was moist.	sweet, refreshing, moist
A little bland. Slightly bitter aftertaste. Creamy texture. Not too firm.	bland, bitter, creamy, between soft/firm
This one had a good texture. Tasted good with good flavor.	response omitted because only hedonic comments given.
Texture was more soft the flavor wasn't as rich a little soft and didn't feel as fresh as 583	soft, mild, less fresh
Mildly sweet with some savory notes. Adequate saltiness for flavor. Not bitter or sour.	sweet, savory, salty, not bitter, not sour
A bit of a strong astringent aftertaste but smooth, buttery. Could be creamier, stronger flavor.	astringent, smooth, buttery, less creamy, mild

[z]Data collected from consumer panels conducted on 6 dates in 2019: Feb 6, Mar 8, Apr 3, May 8, Jun 25 and Jul 6.

Table S2. Average dry weights of avocados over the harvest season [x]

	Harvest [y]					
	1	2	3	4	5	6
'Hass', dry weight (unripe)	23.50 ± 2.63 b[z]	25.77 ± 1.71 ab	26.48 ± 1.90 ab	26.04 ± 2.88 ab	26.82 ± 2.05 ab	29.23 ± 2.15 a
'3-29-5', dry weight (unripe)	20.01 ± 0.84 d	23.03 ± 1.41 cd	24.96 ± 1.64 bc	26.07 ± 2.39 bc	28.60 ± 0.79 ab	31.72 ± 2.12 a

[x] Data taken from companion manuscript (Hausch et al., 2020). Established minimum maturity is 20.8% for 'Hass' and 22.8% for '3-29-5'.

[y] Sample size, n=3. Harvest dates were Feb 6, Mar 8, Apr 3, May 8, Jun 25 and Jul 6.

[z] Different letters in each row denote significance at the $\alpha = 0.05$ level using Tukey's Test.

Table S3. Results of the mixed effect model for the descriptive analysis of '3-25-9' (Gem) and 'Hass' avocados over harvests 2-6[a]. The fixed effects were variety, harvest and preparation. Panelist was a random effect.

	Richness			**Creamy**			**Smooth**			**Watery To Oily**		
Predictors	Estimates	CI	p	Estimates	CI	p	Estimates	CI	p	Estimates	CI	p
(Intercept)	6.23	5.19 – 7.28	**<0.001**	5.93	5.05 – 6.81	**<0.001**	6.27	5.13 – 7.41	**<0.001**	5.58	5.08 – 6.07	**<0.001**
Harvest3	-0.2	-1.16 – 0.75	0.677	-0.3	-1.10 – 0.49	0.455	0.71	-0.38 – 1.79	0.202	-0.1	-0.58 – 0.37	0.67
Harvest3:VarietyHass	1.6	0.30 – 2.89	**0.015**	1.42	0.34 – 2.49	**0.01**	-1.17	-2.57 – 0.22	0.099	0.81	0.17 – 1.45	**0.013**
Harvest4	0.18	-0.76 – 1.12	0.705	0.13	-0.65 – 0.91	0.741	-0.16	-1.25 – 0.93	0.772	-0.05	-0.52 – 0.41	0.822
Harvest4:VarietyHass	1.21	-0.06 – 2.48	0.062	0.7	-0.36 – 1.76	0.194	-0.03	-1.42 – 1.37	0.969	0.71	0.08 – 1.34	**0.027**
Harvest5	1.4	0.42 – 2.38	**0.005**	1.19	0.37 – 2.01	**0.004**	0.6	-0.50 – 1.71	0.285	0.95	0.46 – 1.43	**<0.001**
Harvest5:VarietyHass	-0.2	-1.56 – 1.16	0.77	0.1	-1.03 – 1.23	0.858	-0.69	-2.14 – 0.76	0.349	-0.24	-0.92 – 0.43	0.477
Harvest6	2	1.01 – 2.98	**<0.001**	1.6	0.78 – 2.42	**<0.001**	0.31	-0.81 – 1.43	0.587	0.96	0.47 – 1.45	**<0.001**
Harvest6:VarietyHass	-0.32	-1.66 – 1.02	0.639	0.11	-1.01 – 1.22	0.85	-0.13	-1.58 – 1.32	0.858	0	-0.66 – 0.67	0.998
'3-29-5'	*Reference*			*Reference*			*Reference*			*Reference*		
'Hass'	0.72	-0.22 – 1.67	0.134	0.13	-0.66 – 0.92	0.746	0.25	-0.83 – 1.33	0.651	0.28	-0.19 – 0.75	0.245
Pureed	*Reference*			*Reference*						*Reference*		
Cubed	0.55	0.14 – 0.96	**0.009**	-0.28	-0.62 – 0.06	0.109	*Reference*			0	-0.21 – 0.20	0.979
Random Effects												
σ^2	3.99			2.76			2.04			0.98		
τ_{00}	1.59 $_{Panelist}$			1.16 $_{Panelist}$			1.46 $_{Panelist}$			0.33 $_{Panelist}$		
ICC	0.29			0.3			0.42			0.26		
N	11 $_{Panelist}$			11 $_{Panelist}$			11 $_{Panelist}$			11 $_{Panelist}$		
Observations	368			368			180			368		
Marginal R^2 / Conditional R^2	0.151 / 0.393			0.119 / 0.379			0.025 / 0.432			0.158 / 0.373		

Table S3 continued

	Buttery			Nutty			Sweet			Salty		
Predictors	Estimates	CI	p	Estimates	CI	p	Estimates	CI	p	Estimates	CI	p
(Intercept)	4.63	3.34 – 5.93	**<0.001**	3.81	2.86 – 4.77	**<0.001**	1.46	0.96 – 1.96	**<0.001**	1.09	0.79 – 1.38	**<0.001**
Harvest3	-0.33	-1.25 – 0.58	0.477	-0.68	-1.44 – 0.07	0.076	-0.25	-0.66 – 0.15	0.226	-0.26	-0.52 – 0.00	0.053
Harvest3:VarietyHass	0.91	-0.33 – 2.15	0.15	0.59	-0.43 – 1.61	0.258	-0.06	-0.61 – 0.49	0.826	0.14	-0.22 – 0.49	0.451
Harvest4	-0.27	-1.17 – 0.62	0.549	-0.78	-1.52 – -0.04	**0.038**	-0.39	-0.79 – 0.00	0.052	-0.25	-0.50 – 0.01	0.056
Harvest4:VarietyHass	0.37	-0.86 – 1.59	0.557	0.49	-0.51 – 1.50	0.337	0.2	-0.34 – 0.74	0.462	-0.03	-0.38 – 0.32	0.864
Harvest5	0.33	-0.62 – 1.27	0.498	-0.9	-1.68 – -0.12	**0.023**	0.2	-0.22 – 0.61	0.358	-0.19	-0.45 – 0.08	0.17
Harvest5:VarietyHass	-0.44	-1.75 – 0.86	0.505	-0.54	-1.62 – 0.53	0.322	0.05	-0.53 – 0.62	0.873	-0.05	-0.42 – 0.32	0.803
Harvest6	0.11	-0.84 – 1.06	0.819	-0.8	-1.59 – -0.02	**0.044**	0.01	-0.41 – 0.43	0.955	-0.26	-0.53 – 0.01	0.062
Harvest6:VarietyHass	0.18	-1.11 – 1.47	0.786	0.04	-1.02 – 1.10	0.943	-0.16	-0.73 – 0.40	0.571	-0.02	-0.38 – 0.35	0.923
'3-29-5'	*Reference*			*Reference*			*Reference*			*Reference*		
'Hass'	0.35	-0.56 – 1.26	0.446	0.18	-0.57 – 0.93	0.645	0.03	-0.37 – 0.43	0.888	0.07	-0.19 – 0.33	0.591
Pureed	*Reference*			*Reference*			*Reference*			*Reference*		
Cubed	-0.16	-0.56 – 0.23	0.414	-0.06	-0.38 – 0.27	0.736	0.08	-0.09 – 0.25	0.368	0	-0.11 – 0.11	0.998
Random Effects												
σ^2	3.68			2.5			0.72			0.3		
τ_{00}	3.40 $_{Panelist}$			1.66 $_{Panelist}$			0.44 $_{Panelist}$			0.13 $_{Panelist}$		
ICC	0.48			0.4			0.38			0.31		
N	11 $_{Panelist}$			11 $_{Panelist}$			11 $_{Panelist}$			11 $_{Panelist}$		
Observations	368			368			368			368		
Marginal R^2 / Conditional R^2	0.021 / 0.491			0.048 / 0.428			0.035 / 0.400			0.028 / 0.331		

Table S3 continued

	Bitter			**Umami**			**Astringency**		
Predictors	Estimates	CI	p	Estimates	CI	p	Estimates	CI	p
(Intercept)	1.55	0.98 – 2.13	**<0.001**	3.08	2.50 – 3.67	**<0.001**	1.6	1.27 – 1.92	**<0.001**
Harvest3				-0.79	-1.36 – -0.22	**0.007**	-0.52	-0.78 – -0.26	**<0.001**
Harvest3:VarietyHass				0.98	0.21 – 1.76	**0.013**	0.04	-0.32 – 0.39	0.829
Harvest4	-0.13	-0.61 – 0.36	0.609	-0.42	-0.98 – 0.14	0.146	-0.53	-0.78 – -0.27	**<0.001**
Harvest4:VarietyHass	0.01	-0.67 – 0.70	0.972	0.86	0.10 – 1.62	**0.027**	0.1	-0.25 – 0.45	0.561
Harvest5	-0.26	-0.77 – 0.26	0.331	-0.1	-0.69 – 0.49	0.735	-0.65	-0.92 – -0.39	**<0.001**
Harvest5:VarietyHass	-0.04	-0.77 – 0.70	0.921	0.2	-0.62 – 1.01	0.637	0.12	-0.26 – 0.49	0.537
Harvest6	-0.43	-0.95 – 0.09	0.108	-0.11	-0.70 – 0.49	0.725	-0.68	-0.95 – -0.41	**<0.001**
Harvest6:VarietyHass	0.43	-0.29 – 1.15	0.245	0.12	-0.68 – 0.92	0.77	0.19	-0.18 – 0.55	0.324
'3-29-5'	*Reference*			*Reference*			*Reference*		
'Hass'	-0.13	-0.62 – 0.37	0.61	-0.23	-0.79 – 0.34	0.435	-0.14	-0.40 – 0.12	0.288
Pureed	*Reference*			*Reference*			*Reference*		
Cubed	-0.33	-0.58 – -0.08	**0.011**	0.12	-0.13 – 0.36	0.354	-0.12	-0.24 – -0.01	**0.032**
Random Effects									
σ^2	1.23			1.43			0.3		
τ_{00}	0.54 $_{\text{Panelist}}$			0.42 $_{\text{Panelist}}$			0.19 $_{\text{Panelist}}$		
ICC	0.3			0.23			0.39		
N	11 $_{\text{Panelist}}$			11 $_{\text{Panelist}}$			11 $_{\text{Panelist}}$		
Observations	296			368			368		
Marginal R^2 / Conditional R^2	0.025 / 0.320			0.038 / 0.258			0.096 / 0.445		

Table S3 continued

	Strings			Green		
Predictors	Odds Ratios	CI	p	Odds Ratios	CI	p
(Intercept)	0.34	0.12 – 0.96	**0.042**	1.8	0.48 – 6.74	0.38
Harvest3	0.53	0.17 – 1.71	0.291	0.65	0.21 – 2.04	0.46
Harvest3:VarietyHass	0.48	0.09 – 2.76	0.414	1.88	0.39 – 9.13	0.433
Harvest4	0.49	0.15 – 1.53	0.216	0.64	0.21 – 1.96	0.432
Harvest4:VarietyHass	0.53	0.09 – 2.98	0.471	0.91	0.19 – 4.45	0.911
Harvest5	0.23	0.06 – 0.86	**0.029**	0.14	0.04 – 0.52	**0.003**
Harvest5:VarietyHass	0.31	0.03 – 3.66	0.35	3.36	0.54 – 21.05	0.196
Harvest6	0.08	0.02 – 0.45	**0.004**	0.21	0.06 – 0.74	**0.016**
Harvest6:VarietyHass	0.73	0.05 – 10.85	0.821	2.66	0.45 – 15.60	0.279
'3-29-5'	*Reference*			*Reference*		
'Hass'	0.65	0.21 – 1.98	0.443	0.38	0.12 – 1.20	0.098
Pureed	*Reference*			*Reference*		
Cubed	1.77	0.93 – 3.36	0.08	0.87	0.51 – 1.49	0.617
Random Effects						
σ^2	3.29			3.29		
τ_{00}	0.96 $_{\text{Panelist}}$			2.75 $_{\text{Panelist}}$		
ICC	0.23			0.45		
N	11 $_{\text{Panelist}}$			11 $_{\text{Panelist}}$		
Observations	365			365		
Marginal R^2 / Conditional R^2	0.207 / 0.387			0.061 / 0.488		

Creamed is indicated as pureed in the manuscript.

[a] Example of reading the table to determine the model value for a particular variety, harvest and preparation:
Richness, harvest 5, Gem, (Creamed) = 6.23 + 1.4 = 7.63
Richness, harvest 5, Hass, (Creamed) = 6.23 + 1.4 - 0.2 + 0.72 = 8.15
Richness, harvest 5, Gem, (Cubed) = 7.63 + 0.55
Richness, harvest 5, Hass, (Cubed) = 8.15 + 0.55

Table S4. Compilation of the free response data collected from the consumer panel across the harvest season[a].

	H1 'Hass'	H1 '3-29-5'	H2 'Hass'	H2 3-29-5'	H3 'Hass'	H3 '3- 29-5'	H4 'Hass'	H4 '3-29-5'	H5 'Hass'	H5 '3-29-5'	H6 'Hass'	H6 '3-29-5'	SUM
between soft/firm	0	5	0	0	2	0	2	0	1	1	2	1	14
bitter	**10**	**10**	**14**	**14**	**10**	**6**	**10**	**10**	**9**	**16**	**12**	**19**	**140**
bland	**4**	**15**	**7**	**11**	**2**	**6**	**7**	**15**	**9**	**11**	**6**	**6**	**99**
buttery	8	4	9	5	12	2	8	3	5	6	12	3	77
buttery texture	4	2	1	0	1	0	0	0	0	1	1	2	12
creamy	**24**	**7**	**15**	**7**	**7**	**3**	**17**	**13**	**18**	**21**	**21**	**24**	**177**
firm	12	1	3	1	2	1	2	1	7	4	4	7	45
flavorful	5	0	5	0	0	0	4	1	4	2	2	5	28
flavorless	0	2	1	3	0	1	0	1	0	2	3	0	13
fresh	1	5	3	1	0	0	0	0	4	0	0	1	15
grainy/gritty	0	2	0	0	0	1	1	0	0	4	0	1	9
grassy	3	5	2	3	2	2	4	2	2	4	1	4	34
green	0	0	3	1	0	0	0	1	5	1	1	0	12
less creamy	0	1	2	2	1	1	0	1	2	0	1	1	12
less smooth	0	3	0	0	0	0	0	2	1	0	0	1	7
less sweet	0	0	1	1	0	1	2	3	2	2	0	2	14
melts in mouth	0	1	1	0	2	1	1	0	1	2	0	1	10
mild	2	13	7	10	4	0	4	2	4	7	5	2	60
mushy	1	5	1	2	0	0	1	3	1	0	1	1	16
not bitter	6	1	0	4	0	0	0	0	1	0	4	4	20
not sweet	1	1	0	2	1	0	1	0	0	1	2	1	10
nutty	4	5	8	5	4	0	8	4	4	6	4	3	55
off	0	3	0	0	0	0	1	0	3	2	3	2	14
oily	3	0	2	3	3	1	1	2	2	1	3	1	22
rich	8	1	2	0	1	1	2	1	2	2	3	4	27
ripe	1	1	0	3	0	0	1	0	2	1	1	1	11
salty	6	3	7	6	6	1	8	6	12	7	8	12	82
savory	**32**	**11**	**16**	**12**	**14**	**5**	**26**	**14**	**20**	**16**	**22**	**19**	**207**

smooth	**12**	**7**	**14**	**13**	**8**	**5**	**14**	**10**	**13**	**13**	**14**	**5**	**128**
soft	5	3	4	8	8	4	7	7	6	9	11	9	81
sour	5	1	3	2	2	2	0	5	6	7	5	6	44
stringy	0	0	1	1	2	1	0	1	1	1	0	0	8
strong	0	1	2	0	0	1	1	0	0	1	1	1	8
sweet	**15**	**16**	**13**	**15**	**7**	**3**	**10**	**9**	**17**	**14**	**13**	**13**	**145**
thick	1	0	0	1	0	0	0	0	2	2	2	0	8
vegetal	1	2	1	0	0	1	0	1	1	0	0	0	7
watery	**6**	**23**	**4**	**19**	**6**	**4**	**3**	**13**	**2**	**6**	**2**	**5**	**93**
yielding	0	0	0	1	1	0	0	1	0	1	1	2	7
Total number of panelists	73	72	72	73	51	28	63	64	77	76	72	71	

[a]Terms used by less than 10% of panelists across the entire harvest were eliminated. Harvest dates (H) were Feb 6, Mar 8, Apr 3, May 8, Jun 25 and Jul 6. Most prominent terms are bolded.

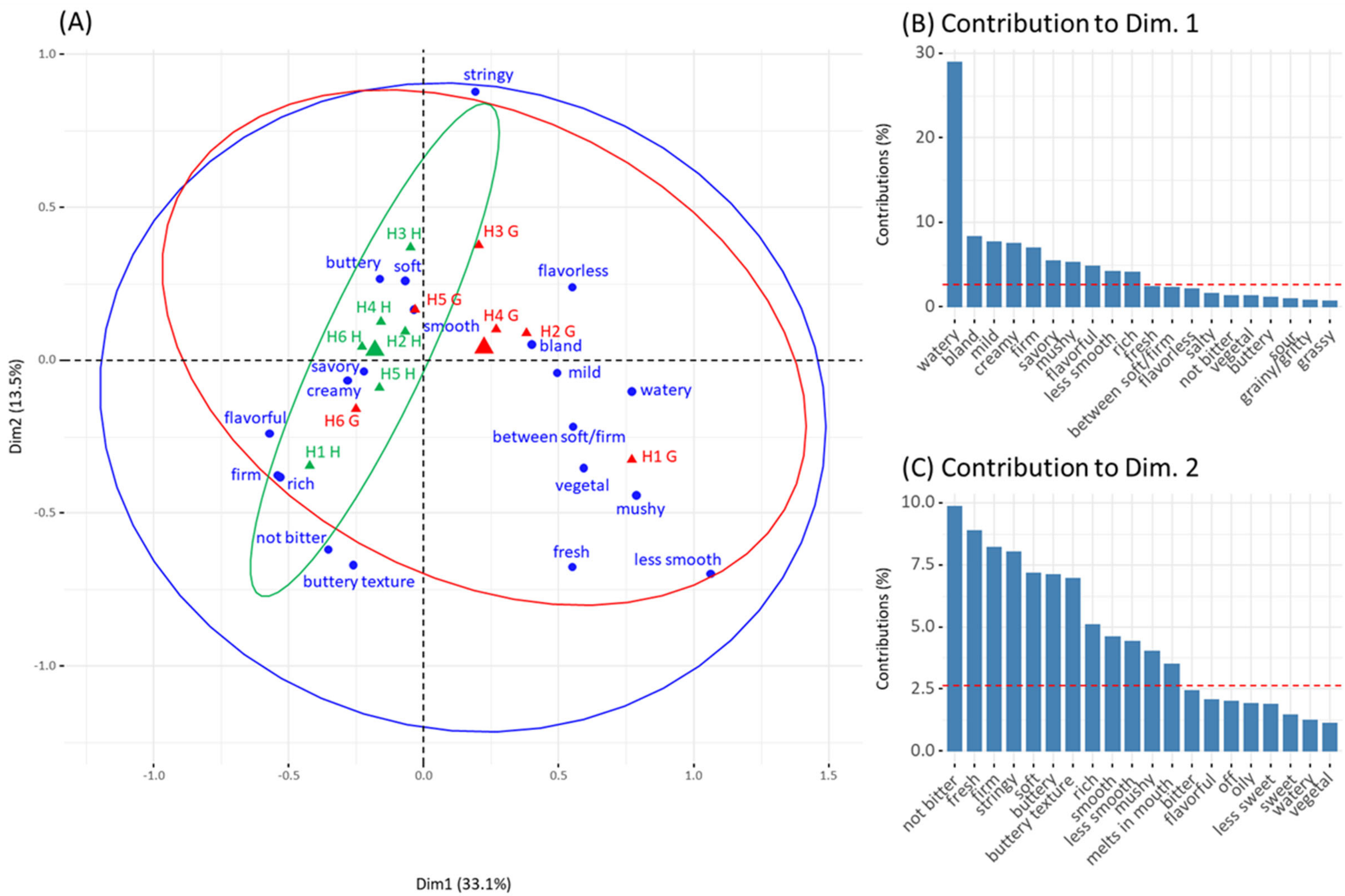

Figure S1. Correspondence analysis of free response data showing biplot (A) and bar plots of contributing attributes to dimension 1 (B) and dimension 2 (C). Labels in biplot are: 'Hass' harvests (H, green), '3-39-5' harvests (G, red), and attributes (blue). Large triangles represent the center of the ellipses for each variety.