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ORIGINAL ARTICLE

Sensory and Consumer Sciences

Sensory descriptive analysis of hard ciders from the Northeast and Mid-Atlantic United States

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Abstract

Although alcoholic or "hard" cider is a beverage of growing popularity throughout the Northeastern and Mid-Atlantic United States (US), the industry lacks a consistent language for describing the sensory quality of its products. The main objective of this research was to explore the sensory attributes that can be used to describe a large representative sample ($N = 42$ samples) of ciders from Virginia, Vermont, and New York, using classical descriptive analysis (DA). The secondary objective of the research was to determine if cider samples' sensory attributes differ based on extrinsic factors, such as style, packaging, and apple varieties. The study was conducted using a standard DA: 8 panelists were trained for 13 h to develop a lexicon of aroma, taste, and mouthfeel descriptors for 42 cider samples (15 single varietal ciders, 27 blended ciders). Then, subjects evaluated each cider in duplicate for all descriptive attributes in standard sensory-evaluation conditions. Results were analyzed to determine overall differences among the individual cider samples, geographic origins, cider styles, and packaging formats, as well as significant differences across individual attributes. Herein, we report on 29 attributes that can be used to discriminate cider samples, as well as a subset of attributes which differentiate ciders based on extrinsic product variables. These results provide a framework for describing ciders from the Northeast and Mid-Atlantic regions of the US, which may be further generalizable to other North American ciders. As well, these results highlight the potential for more descriptive, sensory-based style guidelines may inspire future research related to cider production practices and *terroir*.

KEYWORDS

descriptive analysis, fermentation, multivariate analysis, sensory, sensory and consumer sciences

1 | INTRODUCTION

Alcoholic cider, also known as "hard" cider in the United States (US), is of increasing importance in the alcoholic beverage marketplace. The cider industry in the US has grown substantially in the last 10 years overall, reportedly outpacing the growth of beer, wine, and distilled spirits (Bloom, 2020; Brager, 2019; Lombardo, 2020; Wood, 2022). Though the industry is predicted to continue growing in the coming years (Bloom, 2020; Wood, 2022), research has also reported a lack of sensory-based style guidelines and consumer confusion to be potential stumbling blocks for the industry. Therefore, a clear understanding of cider's sensory character and stylistic diversity is needed in order to overcome these stumbling blocks and move the industry forward.

In efforts to support and encourage the American cider industry's continued growth, many cider stakeholders, researchers, and producers have advocated for the development of cider style guidelines that emphasize sensory quality (Fabien-Ouellet & Conner, 2018). The main style distinction that has gained traction to date is between "modern" and "traditional" ciders. Modern ciders are identified as those produced from culinary or dessert apples, tending to be generally lower in tannin, higher in acidity, and light and refreshing sensorially. Traditional ciders are identified as those produced from primarily cider-specific apples, tending to have higher levels of tannins and complexity (Alexander & Ewing Valliere, 2020). Ciders are also classified by how many types of apples are contained within: Ciders made using only one apple variety are termed a "single varietal cider," and those made with multiple apple varieties are termed a "blend" or "blended" cider (Alexander & Ewing Valliere, 2020). Though these style guidelines cover a large spectrum of cider products produced in the US, they do so at the cost of failing to communicate specific sensory qualities (Fabien-Ouellet & Conner, 2018; Kessinger et al., 2020).

Broadly, some approaches to categorizing and communicating cider quality also draw on concepts related to *typicity* and *terroir*—related phenomena wherein the sensory characteristics of a product may be related to fruit variety, as well as sociocultural and geographical factors (Ballester et al., 2005, 2008; Leriche et al., 2020; Souza Gonzaga et al., 2020; Trubek, 2008). Typicity and terroir in American cider products has been minimally explored, though evidence suggests that geographical origin can contribute to cider chemical and sensory differences in cider products (Antón et al., 2014; Le Quéré et al., 2006; Nicolini et al., 2018; Qin et al., 2018; Uthurry et al., 2019; Valles et al., 2007; Villière et al., 2015). The American cider industry is dominated by prominent apple-growing regions in the northern Midwest, Northwest, Northeast, and Mid-Atlantic US. In the Northeast and Mid-Atlantic, New York, Virginia, and Vermont are the 1st, 8th, and 12th ranked states with the most cideries in the US, respectively (Conway, 2019, 2020; West, 2018).

To this date, researchers have made important contributions to understanding the objective sensory dimensions of US ciders and their origins (Alexander et al., 2018; Bingman et al., 2020; Cole et al., 2022; Kessinger et al., 2020; Littleson et al., 2022; Moss et al., 2021; Phetxumphou et al., 2020). Cider tannins, bitterness, and astringency are well-documented components of the cider sensory experience that can impact the perception of sweetness and sourness (Lea & Arnold, 1978; Symoneaux et al., 2014, 2015). Littleson et al. (2022) documented how sensory descriptors can vary significantly across ciders made according to different methods and with different apple varieties. Cole et al. (2022) recently reported on descriptive terms that can be used to characterize ciders from the US state of Virginia. Recent research has also described how consumers use sensory terms to discriminate samples, discern their liking and disliking, and even to judge products based on cider packaging (Cairns et al., 2022; Kessinger et al., 2020; Phetxumphou et al., 2020). In building from previous discussion about how extrinsic product factors (i.e., styles, geography, and apple varieties) can be related to sensory quality, research by Kessinger et al. (2020) emphasized how cider packaging is also correlated with different sensory attributes and different consumer perceptions. All of this is to say that apple varieties, geographic origin, cider styles, and product packaging are four primary factors that differentiate cider products and their sensory quality, according to consumers, in the current US cider industry.

The cider industry's leading trade group, the American Cider Association (ACA), has sought the development of tools to describe and communicate the sensory attributes of cider in order to put consumers and producers on the same wavelength when it comes to "talking cider"(Demmon, 2019; McGrath, 2019). At the same time, sensory researchers urge the development of more consumer-relevant sensory models that utilize language that is more approachable and understandable for average consumers (De Pelsmaeker et al., 2019; Lawless, 1995; Schiefer & Fischer, 2008; Varela & Ares, 2014). The use of language that should be understandable for consumers is particularly important for sensory research that aims to develop a sensory lexicon for consumers to use during their tasting experiences (Chambers et al., 2016; Drake & Civille, 2003; Imamura, 2016; Lawless & Civille, 2013; Lawless et al., 2012). Research has also suggested that different consumers may use different descriptors to describe a single cider (Phetxumphou et al., 2020), indicating that the

US cider industry is indeed in need of clearer descriptive language developed by trained panels.

Descriptive analysis (DA) is the "gold standard" of descriptive sensory research that utilizes trained panelists to create a meaningful "scientific" language for describing products (Heymann et al., 2014; Lawless & Heymann, 2010). DA has been used extensively to describe the sensory properties of a range of alcoholic beverages (Danner et al., 2018; Donaldson et al., 2012; Heymann & Ebeler, 2016; Lahne et al., 2019; Meilgaard et al., 1979; Noble et al., 1987; Senn et al., 2021; Souza Gonzaga et al., 2020) and recently has been used to describe limited sets of cider products (Cole et al., 2022; Littleson et al., 2022). Ultimately, the terms generated through DA become the framework for sensory lexicons, visual tools to be used by consumers and industry stakeholders or to be used in further consumer testing (Drake & Civille, 2003; Lawless & Civille, 2013; Spencer et al., 2016). Therefore, it is critical that DA research utilize descriptive terms that are broadly understandable to consumers yet still specific and descriptive (Lawless & Civille, 2013), as well as a large sample set of products that are representative of a whole product category (Lawless & Heymann, 2010).

With this background in mind, the objective of this study was to identify sensory attributes that can be used to describe a large representative sample ($N = 42$ samples) of ciders from key cider producing regions of the USA—Virginia, Vermont, and New York—using classical DA. The secondary objective of the research was to determine if these cider samples exhibit sensory differences based on other, possibly extrinsic factors, such as product style, packaging, and apple varieties.

2 | MATERIALS AND METHODS

2.1 | Sample selection

For this study, $N = 42$ representative ciders were selected from commercially available hard ciders produced in Virginia, Vermont, and New York. Ciders were purchased locally from Vintage Cellar (Blacksburg, VA, USA) or ordered online directly from producers. Only ciders made solely with apples were included: No flavored, hopped, or mixed-fruit ciders were included so as to focus on sensory attributes specifically related to apples and the cider-making processes. Products also were required to be made in one of the three states. Mixes of single varietal and blended ciders were included in the study as a preliminary investigation into how apple varieties can affect sensory quality.

For sample selection, cider products were randomly chosen (using a random number generator) from a list of all cider products made in Virginia, Vermont, and New York (compiled manually). The primary goal of sample selection was to have approximately equal representation of ciders produced in the three states selected for this study, with secondary consideration given to blended versus single varietal cider, and tertiary consideration given to packaging type. If any randomly selected cider sample was not available to be purchased locally or shipped from the producer, a new sample was selected at random from the list. Single varietal ciders and blended ciders were randomly selected separately because of the difference in the available population of ciders. For blended ciders, ciders randomly selected from repeat producers were eliminated from the study, and another cider was selected at random in their place. Because fewer single varietal ciders are made, some single varietal ciders were from the same producer. During sample selection, researchers found that many unflavored and canned ciders from New York were not available outside that state; therefore, most ciders randomly selected and available to be shipped from New York state were in the 750 mL glass bottle format. The final samples chosen for the study comprised 12 ciders from Vermont (1 single varietal, 8 traditional), 14 ciders from Virginia (7 single varietal, 10 traditional), and 16 ciders from New York (7 single varietal, 12 traditional), which are described in Table 1. All samples were purchased at retail prices and mention of any brand names or manufacturers does not imply financial support or endorsement from associated companies.

2.2 | Subjects

Panelists ($N = 8$: 9 initially with 1 drop out) were recruited from the Virginia Tech and Blacksburg, VA, USA communities. To participate in the study, panelists must have been at least 21-year old, willing to taste hard cider, and available for training and evaluation sessions. Panelists received two gift cards following completion of the training and evaluation phases of the study. An assortment of snack foods and desserts were also provided as further incentive after all sessions.

2.3 | Sensory evaluation

2.3.1 | Training

In all consensus training sessions, participants were given 1.5-ounce samples in opaque, black wine glasses covered with plastic watch glasses and labeled with randomly generated 3-digit codes. Samples were served chilled (5°C) in a sequential monadic order, with 4–6 samples served per

TABLE 1 Cider samples used in the descriptive analysis (DA), including cider producer and product name, location, retail price, and ABV.

Cider producer, product name	Location	Retail price (US $)	Packaging	ABV (%)	Single varietal or blend	Cider style
Woodchuck Cidery, Amber	Middlebury (VT)	1.83	12-ounce can/bottle	5.0	Blend	Modern
Fable Farm Fermentory, 2019 Emanation	Barnard (VT)	20.00	750 mL bottle	7.75	Blend	Traditional
Flag Hill Farm, Vermont Still Hard Cyder	Vershire (VT)	11.99	750 mL bottle	8.5	Blend	Traditional
Stowe Cider, High and Dry	Stowe (VT)	3.25	16-ounce can	6.5	Blend	Modern
Windfall Orchard, Farmhouse Hard Cider	Cornwall (VT)	15.00	500 mL bottle	9.0	Blend	Traditional
Citizen Cider, Unified Press	Burlington (VT)	3.00	16-ounce can	5.2	Blend	Modern
Tin Hat Cider, Fipenny Bit	Roxbury (VT)	12.00	500 mL bottle	7.0	Blend	Traditional
Shacksbury, Deer Snacks IV	Vergennes (VT)	5.00	12-ounce can/bottle	6.0	Blend	Traditional
Eden Specialty Ciders, Arborealis	Newport (VT)	28.00	750 mL bottle	7.5	Blend	Traditional
SILO Distillery, Semi-Dry Cider	Windsor (VT)	5.00	16-ounce can	6.5	Blend	Modern
Champlain Orchards, Crimson Topaz	Shoreham (VT)	3.25	12-ounce can/bottle	5.8	Single	Traditional
Shelburne Vineyards, Iapetus Cider	Shelburne (VT)	23.00	750 mL bottle	6.8	Blend	Traditional
Buskey Cider, RVA	Richmond (VA)	3.25	16-ounce can	5.5	Blend	Modern
Bold Rock Hard Cider, Premium Dry	Nellysford (VA), USA	2.15	16-ounce can	6.0	Blend	Modern
Blue Bee Cider, Charred Ordinary	Richmond (VA), USA	15.50	750 mL bottle	8.3	Blend	Traditional
Blue Bee Cider, Orchard Potluck (Yarlington Mill)	Richmond (VA), USA	16.25	750 mL bottle	8.5	Single	Traditional
Winchester Ciderworks, Malice	Winchester (VA), USA	3.25	16-ounce can	6.9	Blend	Modern
Big Fish Cider Company, Wild Meadow	Monterey (VA), USA	18.95	750 mL bottle	7.7	Blend	Traditional
Blue Toad Hard Cider, Blue Ridge Blond	Roseland (VA), USA	2.74	16-ounce can	4.9	Blend	Modern

(Continues)

TABLE 1 (Continued)

Cider producer, product name	Location	Retail price (US $)	Packaging	ABV (%)	Single varietal or blend	Cider style
Tumbling Creek Cider Company, Ridgerunner Dry	Abingdon (VA), USA	18.00	750 mL bottle	7.1	Blend	Traditional
Albemarle Ciderworks, Black Twig	North Garden (VA), USA	16.00	750 mL bottle	7.9	Single	Traditional
Albemarle Ciderworks, Royal Pippin	North Garden (VA), USA	22.00	750 mL bottle	7.8	Single	Traditional
Potter's Craft Cider, Hewe's Cuvee	Charlottesville (VA), USA	22.00	750 mL bottle	9.5	Single	Traditional
Potter's Craft Cider, Dabinett	Charlottesville (VA), USA	22.00	750 mL bottle	8.2	Single	Traditional
Potter's Craft Cider, Harrison	Charlottesville (VA), USA	22.00	750 mL bottle	8.2	Single	Traditional
Courthouse Creek Cider, 2019 Revival	Maidens (VA), USA	20.00	750 mL bottle	9.0	Single	Traditional
Pennings Farm Cidery, Cold Crash	Warwick (NY), USA	4.92	12-ounce can/bottle	5.6	Blend	Modern
Angry Orchard Cider Company, Crisp Apple	Walden (NY), USA	1.92	12-ounce can/bottle	5.0	Blend	Modern
New York Cider Company, Scrappy Dog #2	Ithaca (NY), USA	18.00	750 mL bottle	8.4	Blend	Traditional
Brooklyn Cider House, Half Sour	New Paltz (NY), USA	12.00	750 mL bottle	5.8	Blend	Traditional
Rootstock Ciderworks, 2020 Heritage	Williamson (NY), USA	17.60	750 mL bottle	6.0	Blend	Traditional
Nine Pin Ciderworks, Signature	Albany (NY), USA	11.11	650 mL bottle	6.7	Blend	Modern
Eve's Cidery, 2020 Albee Hill	Van Etten (NY), USA	17.00	750 mL bottle	8.4	Blend	Traditional
Bellwether Hard Cider, Liberty Spy	Trumansburg (NY), USA	16.00	750 mL bottle	6.8	Blend	Traditional
Redbyrd Orchard Cider, 2020 Workman's Dry	Trumansburg (NY), USA	14.00	750 mL bottle	8.2	Blend	Traditional
Westwind Orchard, 2019 NATIVO	Accord (NY), USA	23.00	750 mL bottle	8.5	Single	Traditional
Rose Hill Farm, SV3 Ellis Bitter	Red Hook (NY), USA	24.00	750 mL bottle	7.7	Single	Traditional
South Hill Cider, Baldwin	Ithaca (NY), USA	19.00	750 mL bottle	8.5	Single	Traditional

(Continues)

TABLE 1 (Continued)

Cider producer, product name	Location	Retail price (US $)	Packaging	ABV (%)	Single varietal or blend	Cider style
Orchard Hill Cider Mill, 2019 Northern Spy	New Hampton (NY), USA	17.99	750 mL bottle	6.44	Single	Traditional
Embark Craft Ciderworks, 2018 Reserve	Williamson (NY), USA	15.00	750 mL bottle	6.9	Single	Traditional
Original Sin Cider, Unfiltered McIntosh	*Unknown* (NY), USA	2.25	12-ounce can/bottle	6.0	Single	Modern
Abandoned Cider, GoldRush	Woodstock (NY), USA	15.00	500 mL bottle	6.9	Single	Traditional

training session. Panelists smelled and tasted all samples and were required to expectorate all samples after tasting. Panelists were provided with room-temperature spring water and unsalted saltine crackers throughout the study and directed to cleanse their palate among all samples. Panelists were told that they were evaluating cider from Virginia, Vermont, and New York but were not informed of the nature of specific samples or the purpose of the study.

Panelists participated in 11, 60–90-min training sessions totaling 13 h of training. In every training session, panelists evaluated 3–6 samples ensuring that panelists were exposed to every cider sample at least once during training. Training sessions were carried out in a group setting following the consensus method that has been used extensively for DA and lexicon development (Drake & Civille, 2003; Heymann et al., 2014; Hood White & Heymann, 2015; Imamura, 2016; Lahne et al., 2019; Lawless & Heymann, 2010; Lawless et al., 2012). All training sessions were supplemented with reference standards for a single sensory descriptor and single intensity thereof, and all members of the panel agreed on each reference standard and its relative intensity. Throughout training, the panel moderator verbally encouraged panelists to "generate terms that they believed to be broadly understandable to most cider consumers." For example, the suggested term "ethyl acetate" was consolidated into the final descriptor "solvent" because the panelists agreed that the chemical compound term was not an easily understandable sensory term.

In the last four training sessions, panelists practiced evaluating samples by rating the intensity of each sensory descriptor using Compusense20 (Compusense, Inc., Guelph, ON, Canada). During these training sessions, panelist performance was monitored by the panel leader, and significant panelist differences were discussed and consensus ratings were agreed upon. Based on these sessions, the panel requested to use structured intensity scales, including two numerical values at respective points on the 15-point scale ("5" and "10"). Though structured line scales have been discouraged in sensory studies (Galvez & Resurreccion, 1990; Ledahudec et al., 1992) panelists used structured line scales during group discussions to achieve consensus with their intensity ratings (e.g., "Sample 199 is about a 5 for sour"). The final set of descriptors and verbal definitions agreed upon by the panel is supplied in Table 2.

2.3.2 | Evaluation

Data collection was carried out in individual sensory booths in standard conditions as described by Lawless and Heymann (2010). The main exception to generic DA practice was in order to avoid loss of carbonation in samples without wasting a financially untenable amount of sample: On each evaluation day, the same cider samples were evaluated by all panelists. Samples were transferred to a 1 L glass, screw-top bottle to prevent CO_2 loss over the course of the evaluation day. All samples were served chilled (5°C) and kept in the refrigerator (5°C). Each evaluation session lasted a total of 3 h, with panelists able to schedule a session during this period. The above procedure was adapted from a procedure for sparkling-wine evaluation developed by Hood White and Heymann (2015).

Panelists evaluated each sample in duplicate using the terms generated from the consensus training phase. Six samples were evaluated during each session, for a total of 14, 60-min evaluation sessions. Formal evaluation sessions were conducted once per day, 3–5 days per week, over the course of 6 weeks. All panelists were required to smell and taste the references defined during panelist training before each evaluation session, and panelists were provided a hard copy of Table 2 to review while practicing with the reference standards before their evaluation sessions.

TABLE 2 Final list of descriptive terms and reference standards, with verbal description confirmed by panelists and used in descriptive analysis panel.

Attribute	Reference	Consensus verbal description
	Aroma (orthonasal)	
Oaky/barrel	20 mL of solution: 7 g oak chips, 250 mL Josh Cellars® Sauvignon Blanc (Deutsch Family Wine & Spirits, Stamford, CT, USA); soaked for 4 h	"like a rum or bourbon barrel, aged wine"
Smokey	5 drops liquid smoke (The Colgin Companies, Dallas, TX, USA), 500 mL distilled water	"like campfire must, related to barbeque"
Floral	2 tsp rose water (Ziyad Brand, Cicero, IL, USA), 400 mL distilled water	"like roses or other common flowers"
Earthy	3 sprigs fresh cut grass, 1 tsp soil (Virginia Tech, Blacksburg, VA, USA)	"combination of grassy, mineral, vegetal scents; related to green pepper, moist rocks"
Metallic	*(Verbal definition)* rubbing together coins on your fingers	"like blood/iron; also associated with cutting your lip and tasting blood"
Citrus	1 fresh lemon peel, 1 fresh orange peel	"combination of orange, lemon, and lime aromas without the sourness"
Apple	6 g Honeycrisp apple; diced	"smell of fresh apples; also related to smell of an autumn orchard or apple-scented products"
Overripe fruit	1/4 bruised apple, 1 Sunsweet® dried prune (Sunsweet Growers, Stockton, CA, USA); ripped into 2 pieces	"related to extremely ripe, almost cooked fruity flavor but not moldy or rancid"
Solvent	20 mL of solution: 50 mL Luksusowa vodka (Wyborowa S.A., Poland), 0.5 mL Kroger® Brand nail polish remover (100% Acetone) (The Kroger Co., Cincinnati, OH, USA), 0.5 mL Kroger Brand glass cleaner (The Kroger Co., Cincinnati, OH, USA), 100 mL distilled water	"combination of alcohol, cleaner, acetone, ethyl acetate, nail polish aromas"
Latex/rubber	2 × 1 in. piece of medical latex glove	"related to plastic-y aromas"
Yeasty	One-fourth tsp Fleischmann's® RapidRise instant yeast (Fleischmann, Heilsbronn, Germany), 250 mL distilled water, 1 tsp granulated sugar (The Kroger Co., Cincinnati, OH, USA)	"bread-y like aroma"
Barnyard/leather	10 mL Oude Geuze Lambic Ale Cuvée René (Brouwerij Lindemans, Vlezenbeek, Belgium)	"funky; related to animal, horse, mouse, leather"
Moldy	1 tsp Murray's® French Roquefort cheese (The Kroger Co., Cincinnati, OH, USA)	"funky; not animal related"
Cinnamon	1 bag ®Celestial Seasonings Cinnamon Apple Spice tea (Celestial Seasonings, Inc., The Hain Celestial Group, Inc., Boulder, CO, USA, 250 mL distilled water, 1/8 tsp ground cinnamon (The Kroger Co., Cincinnati, OH, USA); steeped 5 min	"explicit fresh cinnamon aroma"
Rotten eggs (sulfuric)	1 tsp hard-boiled egg (The Kroger Co., Cincinnati, OH, USA); finely crushed	"explicit egg smell"
Dirty sponge (mildew)	1 × 1 × 1 in. piece used, moist kitchen sponge	"related to mildew-y, slightly soapy aroma"
Candy	Half crushed Spangler® Circus Peanut (Spangler Candy Company, Bryan, OH, USA), 1/2 piece of Dubble Bubble bubble gum (®Concord Brands, ULC, Tootsie Roll Ind., LLC, Chicago, IL, USA), 1 blue Jolly Rancher (The Hershey Company, Hershey, PA, USA)	"Circus Peanuts, bubblegum candy aromas; also slightly artificial sweet smell"

(Continues)

TABLE 2 (Continued)

Attribute	Reference	Consensus verbal description
Flavor (retronasal)		
Sour	20 mL of solution: 1.5 g citric acid, 250 mL distilled water	"like a Sour Patch candy or lemon; not vinegar-like"
Bitter	20 mL Founders 4 Giants Imperial IPA (Founders Brewing, Grand Rapids, MI, USA)	"like extra dark chocolate, coffee, a very hoppy beer; comes on the palate slightly after swallowing"
Sweet	6 g Kroger Brand granulated sugar (The Kroger Co., Cincinnati, OH, USA), 100 mL distilled water	"plain sugar-sweetness"
Buttery	15 mL Butter Barefoot® Chardonnay wine (E. & J. Gallo Winery, Modesto, CA, USA)	"explicit butter flavor"
Vinegary	20 mL of solution: 40 mL Great Value™ apple cider vinegar (Walmart Apollo, LLC, Bentonville, AR, USA), 250 mL distilled water	"explicit vinegar-like flavor"
Dark Fruit	10 mL Juicy Juice® Cherry (Juicy Juice, Harvest Hill Beverage Company, USA), 10 mL RW Knudsen Family® Just Blueberry juice (©Knudsen & Sons, Inc., The J.M. Smucker Company, Orrville, OH, USA)	"flavor of dark berries or other fruits such as blackberry, cherry, strawberry, plum etc."
Pear	3 pieces of Kroger Brand diced pears (artificial sweetened, packed in water) (The Kroger Co., Cincinnati, OH, USA)	"explicit fresh pear flavor"
Grape	2 red table grapes; sliced in half	"explicit fresh grape flavor"
Apricot	1 tsp Bonne Maman® Apricot Preserves (Andros Foods USA, Inc., Rye, NY, USA)	"explicit apricot flavor"
Lingering	20 mL Founders 4 Giants Imperial IPA (Founders Brewing, Grand Rapids, MI, USA)	"stays on your palate for a while after swallowing"
Caramelized Sugar	20 mL of solution: half cup Kroger Brand granulated sugar (lightly caramelized) (The Kroger Co., Cincinnati, OH, USA), 500 mL water	"slightly burnt sugar flavor; reminiscent of roasted marshmallows and other rich-sugar flavors such as caramel, honey, brown sugar, and molasses"
Mouthfeel		
Fizzy	20 mL La Croix® Sparkling Water Pure (©LaCroix Beverages, Inc., National Beverage Corp., Fort Lauderdale, FL, USA)	"in-your-face, big bubbles; small bubbles and slight effervescence is in the middle of the scale"
Astringent	20 mL RW Knudsen Family Just Pomegranate juice (Knudsen & Sons, Inc., The J.M. Smucker Company, Orrville, OH, USA)	"gripping, waxy experience in the mouth; like drinking chapstick"
Thick	15 mL Guinness™ Draught Stout (nitrogenated) (Guinness & Co., Dublin, Ireland)	"viscous sensation in throat during swallowing; slight film left on mouth"
Puckering	10 mL fresh lemon juice, 40 mL distilled water	"pinching/squeezing of mouth; occurring with intense sourness, but also with any other harsh flavors"
Burning	11 mL Luksusowa vodka (Wyborowa S.A., Poland), 25 mL distilled water	"hot, strong feeling toward back of the mouth and up back of the nose, primarily associated with alcohol burn"

At the request of the panel, panelists were also provided a blank sheet of paper and a pencil during each evaluation session to record their thoughts and experiences as they evaluated the cider samples.

Samples were randomized for each evaluation session according to a Latin Square design (see Supporting Information II for presentation order) within the limitations imposed by the need to serve all panelists the same samples in each session. During each evaluation, samples were presented to panelists in a sequential, monadic design. Samples were served in the same order to all panelists for each session. Panelists were instructed to smell and taste samples, and to rate each sample for each descriptor on a 9-cm line scale, anchored with "None" on the left end and "Very High" on the right end. The line scale was structured with end points of 0 (far left), 15 (far right), 5, and 10 at their respective spatial points on the scale, at the request of the panel. All data was collected with Compusense20 (Compusense, Inc., Guelph, ON, Canada). All procedures and methods for this study were approved by the Virginia Tech Institutional Review Board (IRB 20-527). Subjects gave their informed consent for participation.

2.4 | Data analysis

The DA results were analyzed using 3-way (*panelist* × *replication* × ⟨*factor*⟩) multivariate analyses of variance (MANOVA) to determine overall significant differences in sensory profile ($p < 0.05$) across each of the following factors: cider samples, location (state) of production, cider style, and packaging format. Subsequently, three-way univariate analyses of variance (ANOVA; *panelist* × *replication* × ⟨*factor*⟩) were conducted for each of the sensory attributes (Table 2) to identify variation from the same factors: cider samples, location (state) of production, styles, and packaging. A pseudomixed model, suggested by Heymann et al. (2014, p. 19), was used to test whether variation for each factor was still significant after accounting for interactions between the factor and blocking factors (*replication* or *panelist*). Radar plots were created to visualize sensory differences across the significant attributes, as well as to highlight sensory differences across the factors described before. Multivariate results were further analyzed using principal components analysis (PCA) to visualize relationships among the cider samples, the significant attributes, and among ciders made with specific apple varieties. PCA was conducted on normalized attribute scores (i.e., PCA explained the correlations among samples). All data was analyzed using RStudio ver. 4.1.2 (R Core Team, 2018). Code and data are available from the corresponding author upon reasonable request.

Because of the large number of samples used in the study and subsequent time requirements requested of the sensory panelists, three individual panelists missed one evaluation session each. Simple missing data imputation was adapted from Heymann et al. (2014, p. 18) and Beale and Little (1975).

3 | RESULTS AND DISCUSSION

3.1 | Overall sensory results

Panelists generated 33 total terms (17 aroma terms, 11 taste terms, and 5 mouthfeel terms) using consensus-derived reference standards (see Table 2) to describe the cider samples. During sample evaluation, three panelists missed three evaluation sessions for a total of 594/22,176 missing attribute-intensity evaluations. This accounts for 2.6% of the data, which was below the threshold for acceptability (5%) recommended by Heymann et al. (2014). To impute missing data, the average of all other panelists' intensity rating for each attribute, for that given sample and replication, were used.

Results of the MANOVA tests indicated significant variation in the sensory profiles of the cider samples (Wilk's $\Lambda = 0.0002$, $p < 0.05$). A three-way pseudomixed ANOVA test that accounted for significant panelist and sample interaction (due to high panelist variability) was conducted, resulting in 29 sensory attributes that were found to significantly vary across the cider samples. A mean intensity table (with standard error measures) for all cider samples and significant attributes is provided in Supporting Information I. Multivariate analyses using PCA (on the correlation matrix) visualize correlations among sensory attributes and the cider samples, as shown in Figure 1a,b. The first (PC1) and second (PC2) dimensions account for 52.26% of the variation among the samples and descriptive sensory attributes. In both figures, attributes and cider products that are plotted closer together are more similar. For example, the terms "dirty sponge," "barnyard/leather," and "moldy" are very closely correlated, suggesting that although such terms may be specific, they correspond to a broader descriptive term such as "funky." In addition, terms like "vinegary," "puckering," "sour," and "citrus" clustered closely in the positive direction of PC1, and fruit-related terms clustered in the negative direction of PC1. Figure 1b plots the cider samples into the PCA space and highlights the diversity of sensory profiles among the samples, which were segmented into six groups based on their sensory similarity using hierarchical clustering. In comparing both Figure 1a,b, samples, such as Windfall Orchard Farmhouse, Shacksbury Deer Snacks IV, and Blue Bee Charred Ordinary, are associated with "citrus," Bold

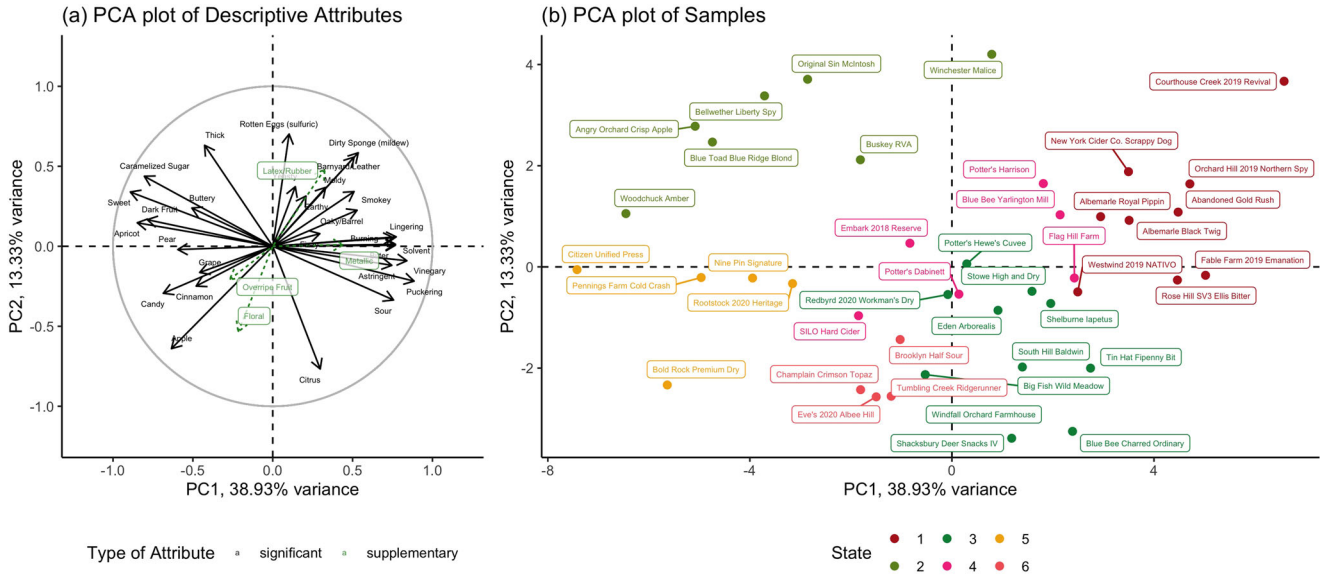

FIGURE 1 Principal component analysis (PCA) plots showing (a) significant and nonsignificant descriptive attributes ("loadings") that varied across the cider samples using three-way analyses of variance (ANOVA), and (b) the separation of cider samples ("factor") based on sensory profile and coloring based on geographic origin ("factor"). In subplot (a), descriptive sensory attributes are visualized as correlations, where closely correlating descriptors are close together and longer vectors are more relevant for describing and differentiating the cider products. In subplot (b), samples that cluster near each other are similar and areas on the plot can be further understood in terms of subplot (a). For example, samples clustered in the positive space of the first dimension, the negative space of the second dimension, and close to the right of the vertical axis are closely correlated with "citrus".

Rock Premium Dry is associated with "apple," Woodchuck Amber is associated with fruity terms (e.g., "apricot," "dark fruit"), "sweet," and "caramelized sugar," and New York Co. Scrappy Dog, Orchard Hill 2019 Northern Spy, and Courthouse Creek 2019 Revival are associated with funky terms (e.g., "dirty sponge (mildew)," "barnyard/leather," and "moldy"), "smokey," and "oaky."

Several of the descriptive terms generated from the current panel that significantly distinguish the cider samples are similar to terms used in other sensory analyses with American cider from the US. For example, Littleson et al. (2022) included the terms "chemical," "alcohol," and "nail polish remover," all of which culminate to form the current panel's definition of "solvent" (see Table 2). More researchers have also utilized diverse sweetness-related terms, such as "candied," "maple syrup," and "honey" to describe different types of sweetness in cider products (Kessinger et al., 2020; Phetxumphou et al., 2020), which are similar to the current panel's use of "caramelized sugar," "candy," and "sweet." This consistency across various studies in the terms used to describe the sensory space of cider from the US is valuable for developing a sensory lexicon that is relevant to industry needs.

Figure 2 uses hierarchical clustering to identify sets of cider products that are similar based on the mean intensity ratings of sensory attributes that significantly varied across the cider products. Figure 2a separates all 42 cider samples used in the present study into 6 groups. Figure 2b is a radar plot of mean intensity ratings to showcase the representative sensory qualities of the six groups, where the same colors are shared across subplots (a) and (b) as well as Figure 1. These plots suggest that the dark red cluster (Group 1) of samples is distinguished by higher average intensity ratings for "astringent," "barnyard/leather," "bitter," "vinegary," "dirty sponge (mildew)," "lingering," and "puckering" attributes. The bright green cluster (Group 3) of samples is distinguished by moderate intensity "sour," "puckering," "fizzy," "lingering," and "citrus" attributes and lower average intensity ratings for "astringent," "barnyard," and "bitter" attributes. The dark yellow and sage-green clusters (Groups 2 and 5) are distinguished by higher average intensity ratings for "sweet"; however, Group 2 has comparably higher mean intensity ratings for "rotten eggs (sulfuric)" and "barnyard/leather." Results of the hierarchical clustering relevant to intrinsic sensory characteristics are also described in Table 3, which summarizes trends in the discrimination of ciders according to the different sensory modalities. Sensory clustering of the cider samples is similar to that of Cole et al. (2022), which found similar sensory clusters of cider products that were noticeable to trained panelists as well as untrained consumers.

Although sensory similarity is the basis of the hierarchical clustering modeled in Figure 2a, the sensory-based

TABLE 3 Summary of extrinsic and intrinsic factors which comprise the six sensory-based clusters generated through hierarchical clustering

					Strongest sensory descriptors		
					Sensory modality		
Hierarchical cluster	**Packaging formats**	**Geographical origin**	**Blend vs. single varietal**	**Cider style**	***Flavor***	***Aroma***	***Mouthfeel***
Group 1	Bottle (9)	Vermont (1) New York (5) Virginia (3)	Blend (3) Single varietal (6)	Traditional (9)	Sour Lingering	Solvent Barnyard/leather	Fizzy Puckering
Group 2	Can (5) Bottle (2)	Vermont (1) Virginia (3) New York (3)	Blend (6) Single varietal (1)	Traditional (1) Modern (6)	Sweet Lingering	Apple Barnyard/leather	Thick Fizzy
Group 3	Can (2) Bottle (9)	Vermont (6) New York (2) Virginia (2)	Blend (9) Single varietal (2)	Traditional (10) Modern (1)	Sour Lingering	Apple Solvent	Fizzy Puckering
Group 4	Can (1) Bottle (5)	Vermont (2) New York (1) Virginia (3)	Blend (2) Single varietal (4)	Traditional (5) Modern (1)	Lingering Bitter	Apple Solvent	Astringent Thick
Group 5	Can (3) Bottle (2)	Vermont (1) New York (3) Virginia (1)	Blend (5)	Traditional (1) Modern (4)	Sweet Caramelized sugar	Apple Candy	Fizzy Thick
Group 6	Can (1) Bottle (3)	Vermont (1) New York (2) Virginia (1)	Blend (3) Single varietal (1)	Traditional (4)	Sour Lingering	Apple Candy	Fizzy Astringent

Note:The number in parenthesis after each factor indicates how many cider samples were described by that factor characteristic. The "strongest sensory descriptors" refers to the sensory descriptors with the highest mean intensity ratings for each sensory cluster.

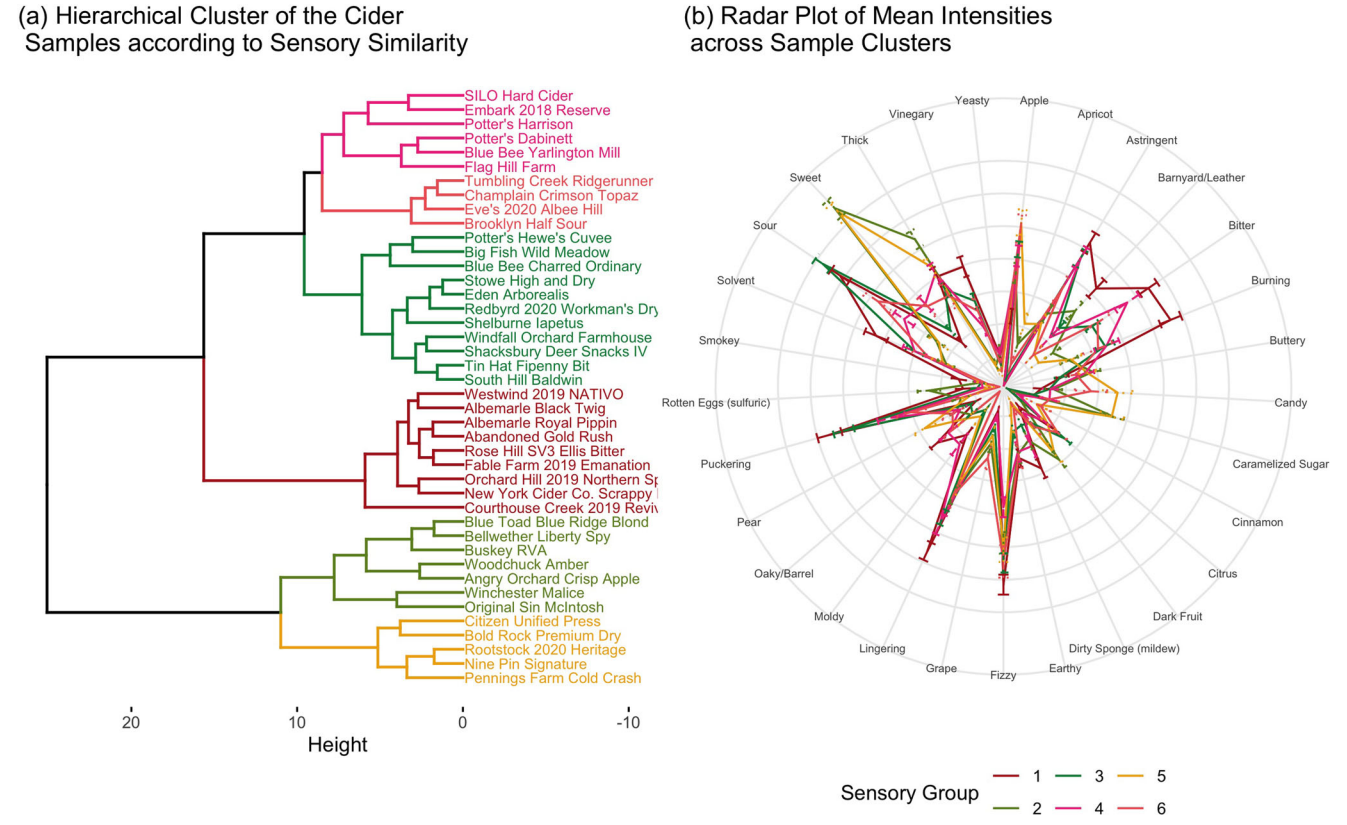

FIGURE 2 (a) Hierarchical clustering of cider samples based on sensory similarities, and (b) radar plots showing the mean intensity ratings of sensory attributes that varied significantly across the samples by three-way analyses of variance (ANOVA). Together, these plots visualize sensory groupings which may be valuable for segmenting cider products according to their sensory similarities in future consumer-oriented research.

clusters also had notable patterns based on extrinsic product factors. For example, Groups 1 and 4 contain mostly single varietal ciders, whereas Groups 2, 9, and 5 contain predominantly blended ciders. Though most groups have a mix of traditional-style ciders, Groups 2 and 4 predominantly contain modern-style cider. Based on Table 3, there are not obvious group trends in how cider products cluster based on their geographic origin. How sensory trends vary across extrinsic product factors are further elaborated upon in the following sections. Taken together, Figures 1 and 2 and Table 3 highlight the breadth of sensory descriptors for American cider and suggest that broadening cider styles to include more meaningful and specific sensory attributes is relevant for discriminating cider products.

3.2 | Extrinsic product factor results

Results of the MANOVA tests (*panelist* × *replication* × ⟨*factor*⟩) across the three remaining, extrinsic factors (location [state] of production, style, and packaging) indicated significant variation in the sensory profiles of products from the three states (Wilk's $\Lambda = 0.82884$, $p < 0.05$), significant variation in the sensory profiles across the product styles (Wilk's $\Lambda = 0.59820$, $p < 0.05$), and significant variation in the sensory profiles across product packaging (Wilk's $\Lambda = 0.76098$, $p < 0.05$). Following MANOVA testing, three-way, pseudomixed univariate ANOVA tests were conducted to determine which sensory attributes differed significantly across the states, cider styles, and packaging, while also accounting for panelist interactions. The ANOVA model revealed 11 sensory attributes that significantly varied across the states, and 17 sensory attributes which significantly varied across styles and packaging.

Figure 3 visualizes the mean intensity ratings of attributes that were significantly different across the three states in a radar plot. Significant variation in the descriptive sensory attributes of cider products from the three states suggest that sensory quality may indeed vary with geographic origin. It is particularly interesting to observe specific sensory differences among the states; where Vermont ciders are significantly more "sour," "apple," and "citrus," Virginia ciders are significantly more "bitter" and "sulfuric," and New York ciders have significantly higher intensities for "sweet," "caramelized sugar," and "buttery."

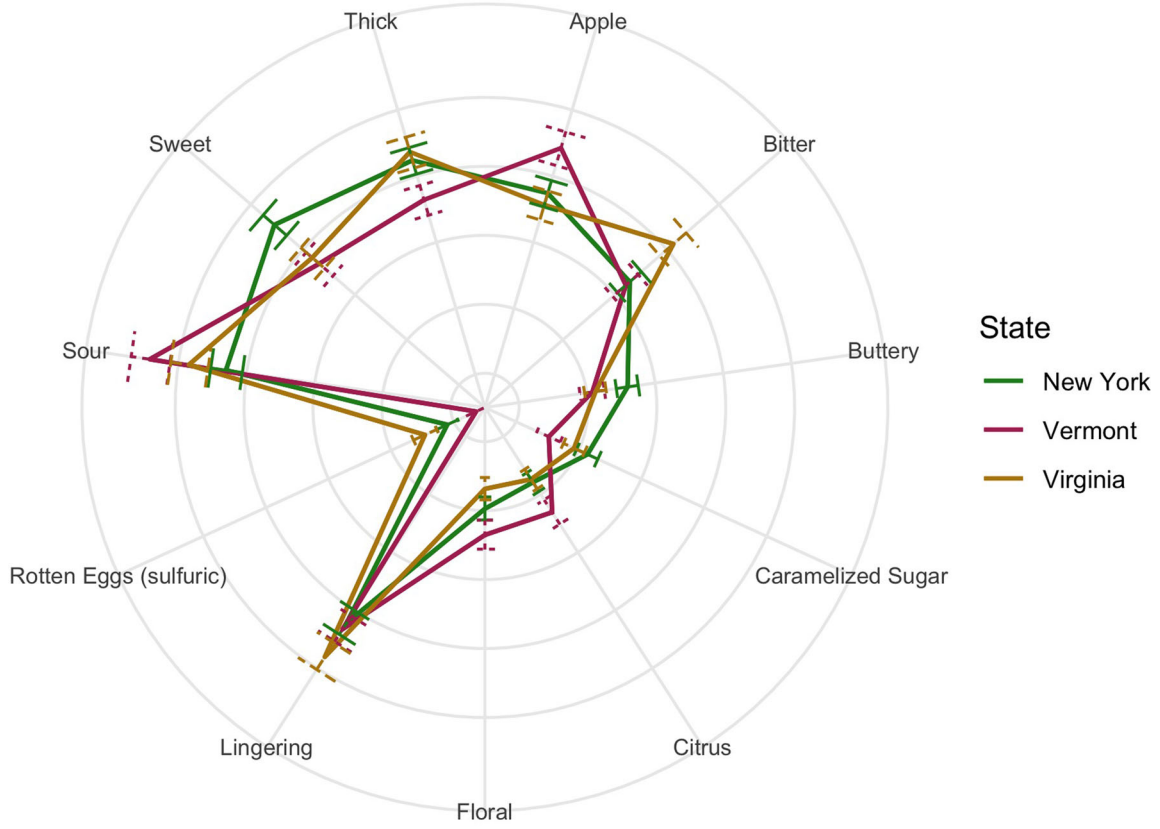

FIGURE 3 Radar plots showing differences in mean intensity ratings for sensory attributes that varied significantly across the states. These results visualize subtle yet meaningful differences in the cider sensory quality across the states.

These findings may be due to sample selection effects (as the current study, although large for a DA study, represents only a small random sample of ciders from these states), but they could also indicate broader trends that are relevant for industry stakeholders. Traditionally, cider quality and typicity has been thought to originate from some combination of geographic origin, apple varieties, and production methods (Lea, 2008; Proulx & Nichols, 1980). American cider products from the US, however, can be made using extremely diverse production methods and types of apples that are not yet tied to geographic regions, and which can have important implications for cider sensory quality (Littleson et al., 2022; Merwin et al., 2007; Rosend et al., 2019). Thus, more research is needed to confirm long-held beliefs about how place also plays into sensory quality, typicity, and *terroir* for American cider specifically (Brennan, 2019; Lea, 2008; Pucci & Cavallo, 2021).

To explore common beliefs (Lea, 2008; Proulx & Nichols, 1980) and prior research findings on the broad effects of apples varieties on sensory quality (del Campo et al., 2006; Keller et al., 2004; Littleson et al., 2022; Nicolini et al., 2018; Rosend et al., 2019), Figure 4 shows the PCA factor plot from Figure 2b colored and labeled to highlight single varietal ciders and the apples used to make them. Though cider can be made according to many different production practices that can heavily influence sensory quality, this visualization highlights how ciders made using a blend of apples and those made using only one apple variety can be different. Specifically, many of the single varietal ciders cluster together in the positive direction of PC1, indicative of more sour (e.g., "sour," "citrus," "puckering," and "vinegary"), or funky (e.g., "dirty sponge (mildew)," "moldy," "barnyard/leather," "earthy," "smokey," "oaky," and "bitter") flavors, or "astringent," "puckering" and "burning" mouthfeels (Figure 1a), in comparison to more fruit-related and sweet flavors that are associated with ciders made from blends. Littleson et al. (2022) found that single varietal ciders made from Harrison and GoldRush apples had different flavor profiles when made according to different production methods, which is interesting to note in relation to our findings of separation among different cider products made using the same apple varieties in Figure 4 (e.g., two Harrison single varietal ciders and two Golden Russet single varietal ciders).

As previously described, the ACA and others (United States Association of Cider Makers 2018; Alexander & Ewing Valliere, 2020) have proposed two primary styles:

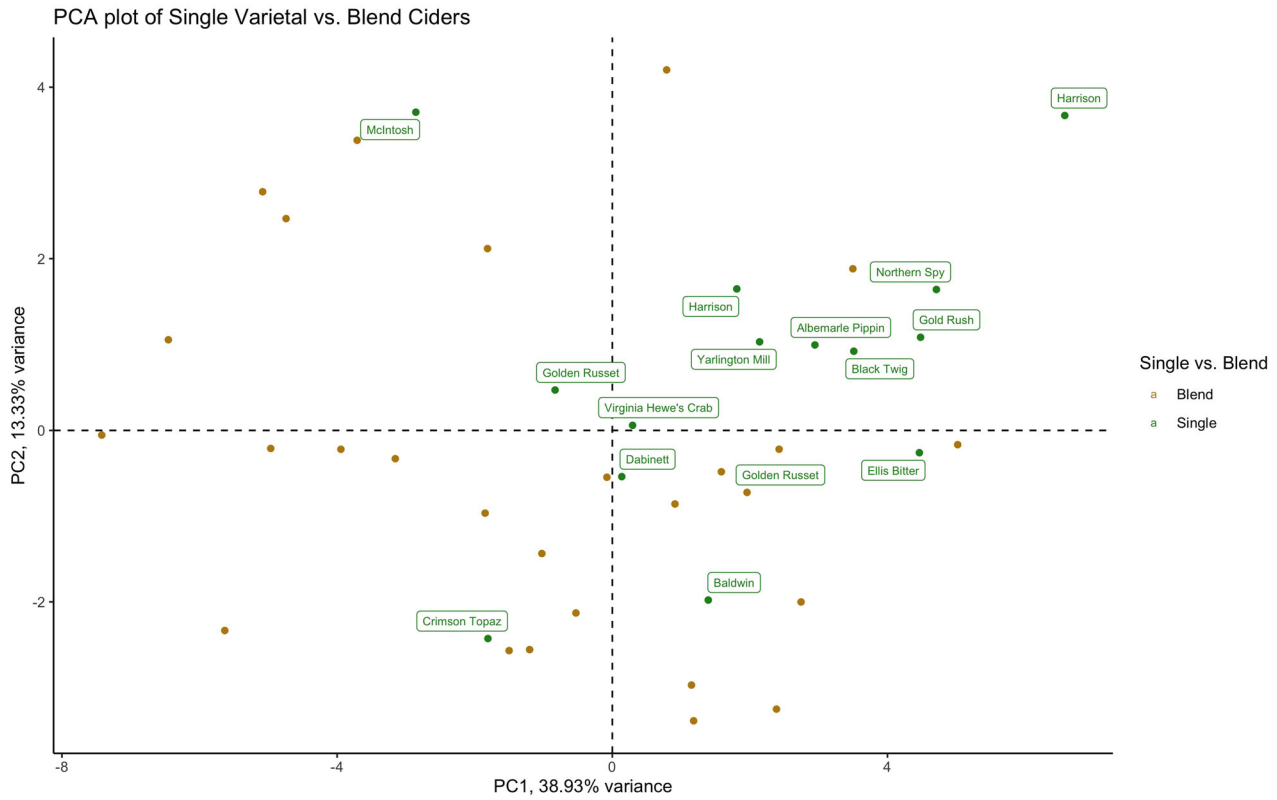

FIGURE 4 Principal component analysis (PCA) of cider samples ("factor") based on sensory descriptors and colored to highlight differences across single varietal and blend cider products. Labels indicate apple varieties used in the single varietal samples.

traditional cider or modern cider. For the purposes of this study, ciders were categorized as "modern" or "traditional" from information provided on websites and packaging that either made this declaration explicitly or were inferred by consulting the ACA style guidelines. In the sample set evaluated in this study, we found that almost all traditional ciders were packaged in larger-format (500 mL or larger) glass bottles, whereas almost all modern ciders were packaged in cans (Table 1). Figure 5 highlights sensory differences in the mean intensity ratings of attributes that significantly varied across the cider samples, for both cider styles and cider packaging. Multivariate testing found significant differences in the sensory attributes used to describe traditional versus modern ciders, as well as cider packaging. Further ANOVA testing found 17 attributes that significantly differed across cider styles (i.e., traditional vs. modern), as well as across cider packaging (i.e., cans vs. bottles). Modern-style ciders are distinguished by higher average intensities of "sweet," "apple," "caramelized sugar," "candy," "apricot," and "dark fruit." Because these ciders are more likely to be made using apple juice concentrates, higher intensities of sweet-related flavors may be a side effect of the use of reconstituted apple juice concentrate that has been observed to leave behind residual fructose after fermentation (Rosend et al., 2020). However, higher sweet-related flavors may also be a stylistic choice on behalf of the producer; so, more research is needed to understand these differences. Traditional-style ciders are distinguished by higher average intensities of "sour," "puckering," "lingering," "citrus," "burning," "bitter," "vinegary," "astringent," and "solvent." The large difference in mean intensity ratings for "sweet" across modern and traditional-styles (seen in Figure 5a) contributes to evidence that a single dryness–sweetness scale for quantifying and describing the sweetness of different styles of cider may be ineffective (Calvert et al., 2022). Also of note, traditional-style ciders have significantly lower mean intensity ratings for "apple" although these products are made with primarily cider-specific apples, suggesting that cider apples and these styles of cider offer unique flavors beyond the classic "apple" flavor. This compliments evidence of cider apples creating products with overall stronger flavor profiles (Littleson, et al., 2022; Thornton, 2014).

It is important to note that the ACA and other entities define cider styles in terms of flavor and ingredients, with little to no emphasis on production methods. Because cider can be made according to diverse production practices (Alexander & Ewing Valliere, 2020; Lea, 2008; Merwin et al., 2007; Proulx

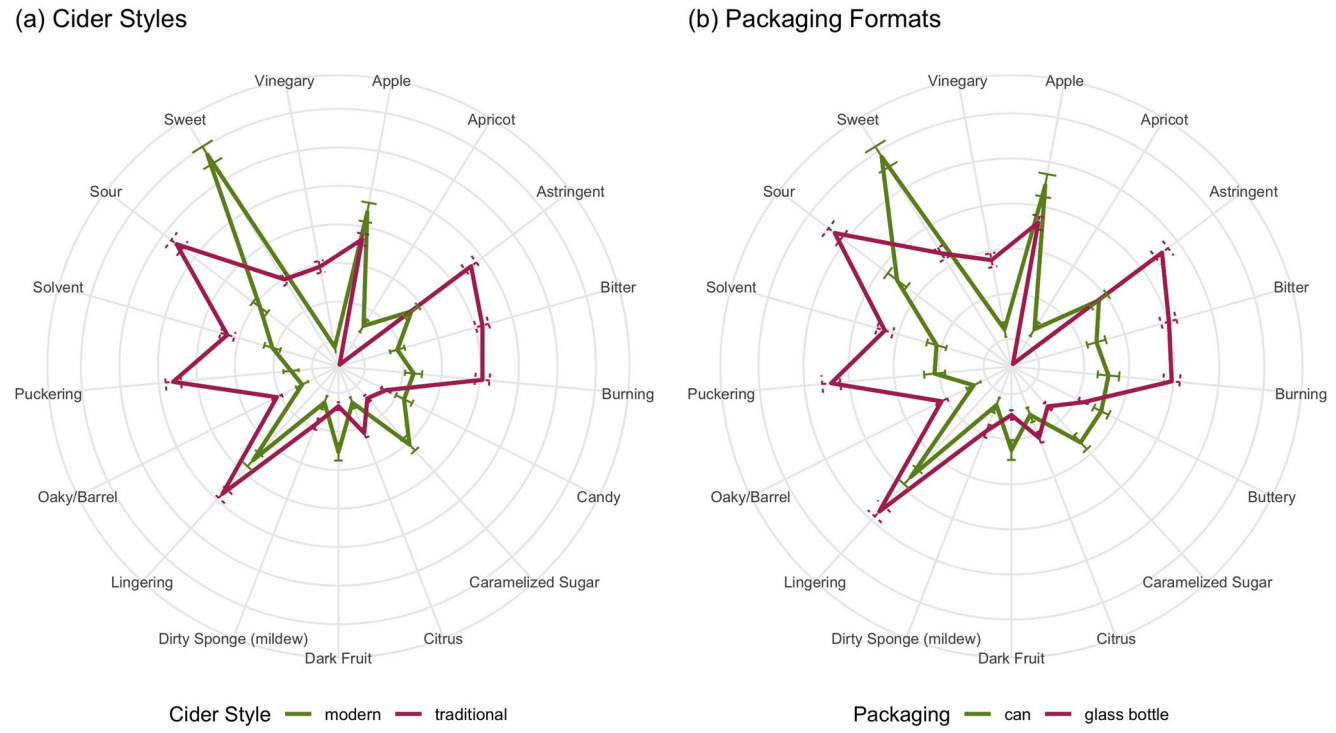

FIGURE 5 Radar plots showing differences in mean intensity ratings for sensory attributes that varied significantly across cider styles (traditional and modern) in subplot (a), and across cider packaging (can and glass bottle) in subplot (b), by three-way analyses of variance (ANOVA). Broad differences can be seen across the different types of cider styles and packaging. Modern and canned ciders tend to be more correlated with rich (e.g., "sweet," "caramelized sugar," "buttery," and "candy") and fruity flavors (e.g., "dark fruit," "apple"), whereas traditional and bottled ciders tend to be more correlated with acidic (e.g., "puckering," "sour," "vinegary," and "citrus"), alcohol (e.g., "solvent," "burning"), and tannin-related descriptors (e.g., "astringent," "bitter").

& Nichols, 1980), and because new terms for describing cider based on production methods are becoming more common, more research into the relationship between production methods and sensory quality is imperative.

Because of the potential confound between cider style and packaging observed in this sample set, the sensory profiles of modern and traditional ciders closely parallel sensory attributes that distinguish canned and bottle cider, with the only difference being that "candy" was a significant attribute across the cider styles but was replaced by "buttery" across cider packaging. Empirically, modern-style ciders tend to be in cans and traditional-style ciders tend to be in glass, 750 or 500 mL bottles, which likely explains the close overlap in sensory characteristics across style and packaging. Does this reflect marketing and distribution concerns, or is there a cider-chemistry and flavor reason for this difference? More research is needed to evaluate the true effects of packaging on the sensory profiles and consumer perception and valuation of American cider from the US.

Key limitations of this study were the difficulty of selecting a representative sample of ciders in the US given the diversity of products in the current US cider industry, and the concomitant difficulty of training a panel on the resulting, large representative sample. Sample selection was limited to products available online or available for distribution to distributed in Southwestern Virginia, USA. Despite the large, representative sample size (42 samples of cider) and consequently long study timeline (a total of 77 days), which doubtless contributed to the significant panelist and sample interactions in M/ANOVA, the panel was still able to find differences in samples for 29/33 consensually defined attributes. Finally, although the present research produced provocative preliminary evidence of how cider packaging, apple varieties, style, and geographic origin relate to cider sensory quality, the study was not designed or powered to rigorously investigate these factors, and future studies will have to take on this task. Nonetheless, these findings will be valuable for the future development of a sensory lexicon for American cider products that is likely to be understandable to consumers and which may develop a form of sensory objectivity in the American cider marketplace.

4 | CONCLUSION

American cider is an increasingly broad and growing market, especially in the Northeast and Mid-Atlantic US. Thus,

many researchers and industry stakeholders have aimed to better understand and define the sensory features of American cider. In this study, we identified sensory attributes that can be used to describe a large representative sample of ciders from the US states Virginia, Vermont, and New York, using classical DA. This was done to gain a better understanding of the actionable descriptive terms that can be used to describe and discriminate a sample of cider products made in the US. In this study, we also gained preliminary insights into whether a trained panel can significantly distinguish cider samples based on factors, such as packaging, apple varieties, and cider style. Lastly, we identified distinct clusters of cider samples based on sensory differences. Overall, modern-style, canned ciders were significantly different from traditional-style, bottled ciders. Sensory quality was also significantly different across cider products from different states, indicating the potential for cider sensory quality to vary based on geography. Though more research is needed to further clarify factors contributing to American cider sensory quality, the results of this research highlight diverse descriptive attributes that can be used to distinguish American cider products produced in the Northeast and Mid-Atlantic US. These findings are meaningful for informing a shared language among cider consumers, producers, and industry stakeholders as the American cider industry moves forward.

AUTHOR CONTRIBUTIONS

Martha D. Calvert: Conceptualization; investigation; writing—original draft; methodology; visualization; formal analysis; software; data curation. **Clinton L. Neill**: Conceptualization; funding acquisition; writing—review and editing; supervision. **Amanda C. Stewart**: Conceptualization; writing—review and editing; supervision; resources. **Jacob Lahne**: Software; conceptualization; investigation; funding acquisition; writing—review and editing; methodology; visualization; project administration; formal analysis; supervision; resources; data curation; validation.

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CONFLICT OF INTEREST

No potential conflicts of interest are reported by the authors.

DATA AVAILABILITY STATEMENT

Code and data are available from the corresponding author upon request.

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SUPPORTING INFORMATION

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

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