Drivers of liking for Cheddar cheese shreds

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ABSTRACT

The prepackaged cheese shred category has steadily increased over the past few years, and Cheddar shreds represent the highest volume in this category. Recent studies have established extrinsic attributes that drive purchase in this category, but no published studies have addressed the intrinsic flavor and texture properties that drive consumer liking. The objective of this study was to determine the desirable flavor and functional attributes for Cheddar cheese shreds. We conducted a category survey of commercial Cheddar cheese shreds ($n = 25$, collected in duplicate). We documented sensory properties (shred appearance, flavor, texture, and hot texture) using a trained sensory panel. Analytical instrumental tests performed included shred-size distribution, proximate analysis, sugars (lactose, glucose, galactose), lactic acid, Cheddar meltability, pH, and color. Then, representative shreds ($n = 10$) were evaluated by cheese shred consumers ($n = 151$) for overall, appearance, flavor, and texture liking. Analysis of variance, principal component analysis, and external preference mapping were used to interpret results. Shreds were differentiated by color, whey, diacetyl, sulfur, nutty, and brothy flavors, as well as by hot and cold texture attributes and instrumental tests. Mild or medium shreds exhibited greater firmness, stretchability, and elasticity when hot than did sharp shreds. We identified 3 consumer clusters, defined by high acceptance for all Cheddar shreds or preferences for sharp or mild shreds. Bitterness was an overall driver of dislike. Visible powder negatively affected appearance and overall liking for some consumers. Sensory properties strongly affected consumer acceptance and purchase intent for Cheddar cheese shreds. Results from this study can be used to optimize the intrinsic sensory properties of Cheddar cheese shreds.

Key words: Cheddar cheese shreds, consumer liking, drivers of liking

INTRODUCTION

Cheese sales increased by 10% between 2012 and 2017, and total category sales are predicted to rise an additional 8%, reaching \$25.5 billion in annual sales by 2022 (Mintel Group Ltd., 2017). In 2016, Cheddar cheese had the second highest consumption per capita in the United States, with roughly 4.7 kg consumed per year, slightly less than mozzarella at roughly 5.3 kg per year (USDA Economic Research Service, 2018). The rate of cheese consumption is driven primarily by flavor; although this is an important factor for most foods, for cheese, roughly 8 in 10 cheese consumers cited purchasing cheese for the taste, significantly more often than the next most frequently cited drivers—easy snacking and food-pairing versatility (Mintel Group Ltd., 2017). Cheese is available in a variety of packaging formats, driven by consumer desire for versatility and convenient healthy snacking.

Objective sensory lexicons have been established for Cheddar cheese flavor and texture (Piggott and Mowat, 1991; Roberts and Vickers, 1994; Drake et al., 2001; Brown et al., 2003; Rogers et al., 2009). Previous studies have also developed texture and performance lexicons for Cheddar cheese shreds, which include stretchability, meltability, fracture, amount of crumbles, surface smoothness, shred length, uniformity of shreds, shred-to-shred adhesiveness, visual perception of oiliness, and residual oiliness during shred handling (Brown et al., 2003; Serrano et al., 2004, 2005). Cheese shreds have additional concerns for consumer liking, including shred length, width, and anticake agents. Anticake agents are typically combinations or sole applications of potato starch, corn starch, calcium sulfate, or powdered cellulose to prevent shreds from sticking and caking. Additionally, a mold inhibitor, typically natamycin, is added to inhibit mold growth and prolong shelf life (Elayedath and Barringer, 2002).

The majority of Cheddar cheese flavor development occurs during aging or ripening (Walstra et al., 1999; Singh et al., 2003). With respect to prepackaged shredded Cheddar cheese, the US Food and Drug Administration requires that the products must meet the same definitions and standards of identity for block Cheddar

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cheese. For Cheddar cheese, a maximum moisture content of 39% and a milk fat requirement of 50% by weight of the solids is required for a standard of identity (US Code of Federal Regulations, 2017). Standard Cheddar cheese usually has 25.5% protein, which is predominantly casein (O'Callaghan et al., 2000). The ratio of all of these components is highly important to achieve an ideal Cheddar cheese shred product with respect to flavor, texture, and functionality for consumers.

Several studies have addressed consumer preferences for Cheddar cheese, including flavor and texture (Roberts and Vickers, 1994; Young et al., 2004; Caspia et al., 2006; Drake et al., 2008). However, few studies have specifically focused on consumer preferences for prepackaged Cheddar cheese shreds. Understanding consumer liking for prepackaged Cheddar cheese is essential for continued growth in this category. Recent research indicated that price, flavor, color, and performance/meltability were primary drivers of purchase for Cheddar cheese shreds (Speight et al., 2019). This study addressed extrinsic Cheddar shred attributes and drivers for purchase intent in a survey format. Actual consumer perception of Cheddar cheese shred appearance, flavor, and texture is also critical information for establishing preferred intrinsic properties. To our knowledge, previous studies have not examined consumer drivers of liking for Cheddar cheese shreds using a central location test. Given the growing Cheddar cheese shred market, it is pertinent to investigate all intrinsic properties of consumer perception of this product. The objective of this study was to understand the drivers of liking of Cheddar cheese shreds using sensory evaluation by trained panelists and consumers to provide further clarification on key sensory attributes.

MATERIALS AND METHODS

Experimental Overview

The sensory properties of 25 commercial Cheddar cheese shreds were evaluated by descriptive analysis. We also documented composition and physical properties. Then, a consumer acceptance test of representative Cheddar cheese shreds with 151 consumers was conducted.

Cheddar Shreds

Commercial Cheddar cheese shreds ($n = 25$) were purchased locally or online. All samples were common retail-sized bags (226–906 g) and ranged in terms of brand (national, regional, store), sharpness (mild to extra sharp), color (white, orange, or mixed), and cut thickness (fancy, feather, and farm). Cheese shreds are

most commonly cut in a feather style, in which cheese is shredded to a standard size of 3.2 to 1.6 mm, or in a fancy style, which is 0.8 to 0.4 mm (Ni and Guansekaran, 2004). Less common is the farm-style cut, which is the thickest type of shredded cheese, at 9.6 mm. If samples were not purchased locally, they were shipped overnight on ice packs and examined for damage upon arrival. Products were purchased in multiples (2.25–4.5 kg) on different occasions (3 wk apart) and subjected to analytical sensory and instrumental evaluations to ensure that representative evaluations were conducted. All shreds were a minimum of 90 d from code date. Cheese shreds were stored in the dark at 4°C and analyzed within 60 d of receipt.

Proximate Analysis

Moisture, fat, pH, protein, sugar, color, melting quality, and shred size on all Cheddar cheese shreds were analyzed in triplicate. Moisture content was measured by vacuum oven drying (method 926.08; AOAC International, 2016) with 2 g of cheese. The Mojonnier method was used to measure fat content (method 989.05; AOAC International, 2016). We used an InLab Solids glass electrode (Mettler-Toledo GmbH, Schwerzenbach, Switzerland) to measure pH by inserting the pH electrode probe (VWR International, Radnor, PA) into roughly 20 g of shredded cheese pressed into a 50-mL beaker at 25°C. Before testing, the pH meter was calibrated using buffers (Thermo Scientific, Chelmsford, MA) at pH 4, 7, and 10. The pH probe was then inserted into the cheese shreds. Results for each cheese were collected from 3 different locations and averaged. Protein was determined using a Sprint Rapid Protein Analyzer (CEM Co., Matthews, NC).

Lactic acid and sugar content (lactose, glucose, and galactose) of the Cheddar cheese shreds were measured using HPLC (Zeppa et al., 2001). Cheeses were prepped for analysis by finely shredding 5 g of each sample and adding it to 10 mL of 0.0045 *N* H₂SO₄ (Sigma Aldrich, St. Louis, MO) heated to 60°C. Samples were vortexed for 2 min, followed by agitation for another 10 min. Mixed samples were centrifuged at $7,000 \times g$ for 10 min. Samples were then cooled at 4°C to solidify the top fat layer, which allowed the solidified fat to be removed with a microspatula to sample the aqueous layer below. The aqueous layer was centrifuged again with a benchtop centrifuge at $21,000 \times g$ for 5 min to separate any remaining fat. Samples were filtered through a 0.45- μ m nylon filter (VWR International) into a 2-mL HPLC sample vial (Phenomenex, Torrance, CA). Extracted sugars were then evaluated using an HPLC (Waters 1525 Binary Pump; Waters, Milford, MA) equipped with an autosampler (Waters 2707 Autosam-

pler; Waters) onto a Aminex HPX-87H 300 mm $\times$ 7.8 mm ion exclusion column (Bio-Rad Labs, Richmond, CA) heated to 55°C. The mobile phase was 0.0045N H₂SO₄ (Sigma Aldrich) at a flow rate of 0.6 mL/min. Injections of 20 μ L of each sample were performed in duplicate. Sugars were detected using refractive index (RI; Waters 2414 Refractive Index Detector; Waters; 35°C). Lactose, glucose, and galactose were detected at 7.32, 8.52, and 9.19 RI, respectively. Lactic acid was detected at 210 nm (Waters 2998 PDA; Waters) at a retention time of 11.74 min. Seven-point standard curves were developed for each compound of interest using reference standards (Sigma Aldrich).

Instrumental Color Measurement

We determined instrumental color by pressing 30 g of each cheese into a separate 100 $\times$ 15 mm Pyrex glass Petri dish (Olson, 2011). Color measurements were taken at 25°C both before baking and after baking. Lightness (**L***), red-green color (**a***), and yellow-blue color (**b***) values were measured using a handheld colorimeter (Chroma Meter CR-410; Konica Minolta Sensing; Tokyo, Japan) that was calibrated before any measurements. The hand-held colorimeter was fitted with a CR-A104 protective cap (Konica Minolta Sensing) and positioned flush against the pressed Cheddar cheese samples to collect 4 measurements before baking. The disks were rotated between each measurement. Following initial color evaluations, shreds were heated at 130°C for 75 min in a conventional oven and then cooled to room temperature (Olson et al., 2011). We collected 4 color measurements again on all disks by pressing the hand-held colorimeter flush against the cheese samples. We used the averages of the **L***, **a***, and **b*** values to calculate the magnitude of the total color difference (ΔE) before and after heating using the following equation (Hunter, 1975): $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$.

Instrumental Melt and Shred Size

A modified version of the Schreiber melt test was used to determine meltability and spread (Kosikowski and Mistry, 1997). Fifteen grams of cheese was weighed out and pressed into a cylinder (4 cm interior diameter) until shreds formed a uniform solid mass in the middle of a 100 $\times$ 15 mm Pyrex glass Petri dish. The cylinder was removed, and the glass dish was placed in a convection oven at 232°C for 5 min and then cooled for 30 min at room temperature. The glass Petri dish was centered over a concentric numbered target-type graph; the outer edge of the flow line was measured

along 8 evenly spaced points. A value of 1.0 indicated no change in disk diameter, and the value increased by 1.0 for every 1.0-cm increase in diameter. The average of the 8 values indicated the meltability (Kosikowski and Mistry, 1997).

Shred-size composition was determined by sorting cheese shreds with metal sieves as described by Childs et al. (2007). Cheese shreds were weighed and then placed on top of 4 sieve plates with openings of 1.27, 0.635, 0.3175, and 0.1679 cm, and a bottom plate. The stacked sieves were shaken by hand for 60 s, vertically and horizontally. Larger shreds trapped by the top 1.27 cm sieve were classified as long shreds. Shreds that passed through the largest sieve but were trapped by the next largest (0.635 cm) were classified as short shreds. Shreds that passed through the top 2 sieves but not the 0.3175 cm sieve were classified as fines. Shreds that passed through the top 3 sieves but not the 0.1679 cm sieve were classified as crumbs. Shreds that passed through all sieves and collected on the bottom plate were classified as attrition. Results from the test are presented as percentages of the total weight.

Descriptive Sensory Analysis

Flavor, cold texture, and hot texture descriptive analysis was performed in compliance with North Carolina State University Institutional Review Board for Human Subjects approval. Panelists expectorated samples and cleansed palates with room-temperature deionized water between samples. Data were collected using Compusense Cloud (Compusense, Guelph, ON, Canada).

Flavor, cold texture, and hot texture were evaluated in separate sessions by 2 cohorts of trained panelists, one specializing in flavor and the other specializing in texture. For flavor analysis, a trained sensory panel ($n = 8$; 5 women, 3 men; age 23–54 yr; each with at least 150 h of prior experience with the descriptive analysis of cheese flavor) evaluated the cheeses using an established Cheddar cheese flavor lexicon (Drake et al., 2001) and a 15-point universal intensity scale Spectrum method. Cheddar cheese shreds were served in lidded 59 mL clear plastic soufflé cups (Dart Container, Mason, MI) with random 3-digit blinding codes, and evaluated at 15°C.

For texture evaluation, a trained descriptive sensory panel ($n = 7$ women; age 34–52 yr; each with at least 60 h of prior experience with the descriptive analysis of cheese texture) evaluated the cheese shred attributes in triplicate using a 0 to 15 point product-specific scale for both hot and cold Cheddar cheese shreds (Table 1). The cheese texture lexicon was adapted from several previ-

Table 1. Cheese shred sensory texture attributes (adapted from Drake et al., 1999; Gwartney et al., 2002; Asato, 2003; Brown et al., 2003)

Texture	Attribute	Definition
Visual color intensity and cold texture	Color intensity	Degree of color intensity from light to dark
	Visible powder	Amount of visible powder on the shreds (0 = no visible powder; 10 = every shred surface is coated in powder)
	Hand cohesiveness	Degree to which the sample forms a mass and does not break apart after compressing 30% and release
	Degree of breakdown	Degree to which the sample breaks down during mastication
	Tackiness	Amount of force required to pull teeth apart after biting down into the sample during the first bite
	Cohesiveness	Degree to which the sample forms a mass and does not break apart after 5 chews
	Adhesiveness	Degree to which the sample sticks to any of the mouth surfaces during mastication
	Smoothness of mass	Lack of gritty or grainy particles perceived in the mass while chewing
	Smoothness of mouthcoat	Degree of smoothness felt in the mouth after expectoration
	Mouthcoat	Amount of any mouthcoating (particles, oil, moisture) remaining after swallowing or expectorating
Hot texture	Visible surface moisture	Amount of visible oil on the surface
	Meltedness	Homogeneity of the sample (higher number = more melted)
	Stretchability	Length the melted cheese will stretch with a plastic fork within 1 min of oven removal
	Oiliness to lips	Amount of oil felt on lips
	Hardness	Amount of force to bite between molars during first bite
	Tackiness	Amount of force required to pull teeth apart after biting down into the sample during first bite
	Cohesiveness	Degree to which the sample forms a mass and does not break apart after 5 chews
	Adhesiveness	Degree to which the sample sticks to any of the mouth surfaces during mastication
	Oiliness	Amount of oil or any coating perceived in the mouth
	Smoothness of mass	Lack of gritty or grainy particles perceived in the mass while chewing
	Mouthcoat	Amount of any mouthcoating (particles, oil, moisture) remaining after swallowing or expectorating

ously published studies: Drake et al. (1999), Gwartney et al. (2002), Asato (2003), Brown et al. (2003) and Rogers et al. (2009). We added and subtracted terms specific to cheese shreds and the temperature of evaluation (Table 1). Approximately 15 g of cold cheese shreds were served at 4°C in lidded 120-mL soufflé cups with 3-digit blinding codes. For hot texture, approximately 15 g of each Cheddar cheese shred was baked in clean metal desiccation dishes 7.62 cm in diameter (VWR International) in a conventional oven set to 230°C for 4 min. Cheese texture was evaluated within 1 min of removal from the oven.

Consumer Acceptance Test

From the category survey, 10 representative Cheddar cheese shreds were selected based on an examination of descriptive analysis results using multiple factor analysis, product mean attributes, and market share. We conducted consumer acceptance testing to determine consumer preferences for flavor and texture attributes of cold Cheddar cheese shreds. Testing was conducted in accordance with the North Carolina State University Institutional Review Board for the Protection of Human Subjects in Research regulations. Consumer acceptance testing was performed over 2 d; each consumer evaluated a randomized partial presentation of 5 cheese shreds per day. Self-reported Cheddar cheese shred consumers

(n = 151) were recruited using a survey launched in an online database of 11,000 people maintained by North Carolina State University. All consumers were primary shoppers with an annual household income >\$15,000 who purchased and consumed Cheddar cheese shreds at least once a month. The consumer group contained equal numbers of men and women, and was split equally among income ranges to achieve a broad sample of consumers. Panelists were compensated with a \$25 gift card for a local store upon completion of the 2-d test. We used Compusense Cloud (Compusense) for data collection.

Shreds for the consumer test were prepared in a fashion similar to that used for the descriptive analysis. Approximately 15 to 20 g of each sample was served in lidded 120-mL soufflé cups with 3-digit blinding codes. Cheeses were served at 8°C. As consumers arrived for their test, they first presented photo ID to ensure the consumers who participated were the consumers screened for the test. Consumers were then told that they would be tasting 5 cheese samples per day, and that they should consume as much of the sample as they needed to form an opinion. Each day, shreds were presented monadically using a Williams design serving order to balance for sample position throughout the course of the test (Compusense). Panelists were first asked to evaluate overall appearance liking, color liking, color just-about-right (**JAR**) from dark to light,

color JAR from yellow to orange, shred-size liking, shred-size JAR from too short to too long, shred-size liking from too thin to too thick, and open-ended comment questions about product likes and dislikes. After evaluating appearance, consumers consumed several bites and were asked to evaluate cheese flavor and texture. Questions asked included overall liking, overall flavor liking, overall flavor JAR, saltiness liking, saltiness JAR, savory liking, savory JAR, sour liking, sour JAR, texture liking, texture JAR from too soft to too hard, and texture JAR from too crumbly/dry to too rubbery. Consumers were also asked about perceived flavor sharpness, check-all-that-apply (CATA) consumption, purchase intent, and CATA Cheddar cheese shred flavor, texture, and color attributes. A 3 min rest was enforced between samples, and during this time, consumers were asked to take several bites of unsalted cracker and drink spring water. After completing all samples, consumers were asked to identify their ideal cheese using a CATA list similar to the attribute question asked previously.

Liking questions were scored on a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). The JAR questions used a 5-point scale (1 or 2 = too little, 3 = JAR, and 4 or 5 = too much). Perceived flavor sharpness options included mild, medium, sharp, and extra sharp. Purchase intent was scored on a 5-point scale (1 or 2 = would not buy, 3 = may or may not buy, and 4 or 5 = would buy). The CATA Cheddar cheese shred attribute question contained milky/dairy, buttery, milk fat (creamy), sulfur/eggy, brothy (meaty), nutty, sour, bitter, salty, sweet, savory, soft, hard, dry/crumbly, rubbery, long shreds, short shreds, thick shreds, thin shreds, orange, yellow, white, and the option of other with a comment box to clarify this selection. The ideal CATA Cheddar cheese attribute question used the list from the sample-specific attribute question but also contained the words powdery and powderless.

Statistical Analysis

Statistical analysis was conducted using XLSTAT software (version 2017; Addinsoft, New York, NY). Compositional, descriptive analysis, and consumer liking scores were analyzed by ANOVA with Fisher's least significant difference test at a significance level of $P < 0.05$. Principal component analysis (PCA) was applied to descriptive analysis to determine product differentiation and to select a proper representation of the Cheddar cheese shred market for the consumer test. Consumer JAR scores were evaluated using χ^2 analysis, and purchase intent using a Kruskal–Wallis test with Dunn's post hoc test. Penalty analysis was conducted to relate JAR scores with overall liking. Check-all-that-

apply questions were analyzed using Cochran's Q test and visualized using correspondence analysis with χ^2 distance. For consumer segmentation, we used hierarchical agglomerative clustering and k-means analysis to determine the number of clusters. We validated clusters using discriminant analysis. Partial least squares regression analysis was then conducted on descriptive means and consumer data to identify drivers of liking and disliking for each cluster.

RESULTS AND DISCUSSION

Compositional Analysis

Compositional analysis for moisture, fat, pH, protein, sugar, color, melting quality, and shred-size composition varied among the shreds ($P < 0.05$; Table 2). Cheese shreds with higher fat were correlated with increased hand cohesiveness and adhesiveness by cold texture descriptive analysis evaluation ($r = 0.466$ and 0.446 ; $P < 0.05$), as well as increased oiliness to lips, visual oil, and mouthcoat in hot texture evaluation ($r = 0.525$, 0.435 , 0.436 , respectively; $P < 0.05$; results not shown). Cheese shreds with a higher percentage of protein were correlated with increased stretchability in the hot texture evaluation ($r = 0.571$; $P < 0.05$).

Descriptive Analysis

Distinguishing flavor differences among the 25 Cheddar cheese shreds were documented by the trained panel ($P < 0.05$; Figure 1). Three principal components explained 60% of the variability. Based on factor loadings (not shown), principal component 1 (33%) differentiated shreds by brothy, sulfur, and nutty flavors; and salty, umami, and sweet tastes (all positively loading); and whey and cooked flavors (negatively loading). Principal component 2 (16%) differentiated cheeses by milk fat and diacetyl flavors (positively loading); and grassy flavor (negatively loading). Principal component 3 (not shown) was represented by bitter taste (positively loading). Cheese shreds 3, 4, 6, and 20 were characterized by sulfur, brothy, and nutty flavors, and umami and sweet tastes. Drake et al. (2001) classified these flavors as "aged/developed" due to their prevalence in Cheddar cheeses aged over 1 year. Cheese shreds 8, 10, 13, 18, 19, 21, 23, and 25 were characterized by higher intensities of cooked and whey flavors, which are typical of young or mild Cheddar cheeses (Drake et al., 2001). Cheddar cheese shreds 1 and 18 were the only cheeses with grassy flavors, and these shreds were the only organic samples. Grassy flavor has been attributed to pasture-based feeding regimens and might also be associated with organic cheese as a result (Drake et al.,

Table 2. Sieve pan percentage, moisture, pH, fat, instrumental color, protein, melt, and sugar content values of Cheddar cheese shreds

No. ¹	Cut	Sharp ²	Color ³	Sieve pan, ⁴ cm				Moisture, %					Fat, %	Color measurement ⁵					Sugar content, g/g of cheese				
				1.27	0.635	0.3175	0.1679	Pan	pH	L*	a*	b*		ΔE	Protein %	Melt	Lactose	Glucose	Galactose	Lactic acid			
1	Feather	M	W	2.0	49.7	40.2	6.3	1.9	39.5	5.36	31.7	80.7	-4.1	36.4	45.7	23.2	16.9	0.020	ND ⁶	0.017	0.128		
2	Fancy	M	Y/O	1.0	18.9	42.8	32.5	4.9	37.7	5.14	30.3	39.3	16.7	22.2	48.1	23.5	15.6	0.021	0.030	0.042	0.121		
3	Fancy	S	Y/O	0.0	2.0	30.9	60.3	6.9	37.1	4.91	31.8	38.8	14.6	19.4	45.7	21.7	15.1	0.026	0.041	0.011	0.159		
4	Feather	S	W	0.3	14.6	62.4	19.2	3.5	42.2	5.35	33.1	83.7	-3.3	25.0	54.2	22.1	17.4	0.044	0.026	0.013	0.115		
5	Fancy	M	Y/O	7.4	31.1	33.6	24.3	3.6	36.0	5.43	32.5	71.6	14.6	61.8	45.3	24.5	12.5	0.026	ND	0.043	0.107		
6	Feather	S	Y/O	32.1	39.6	25.4	2.2	0.6	39.0	5.39	33.0	69.9	15.8	58.9	52.5	23.0	15.4	0.022	ND	0.032	0.127		
7	Fancy	S	Y/O	0.6	32.6	34.1	28.4	4.3	36.6	5.21	31.6	71.4	15.8	58.2	43.1	23.4	13.6	0.040	0.040	0.013	0.152		
8	Feather	M	Y/O	0.3	31.1	58.0	9.4	1.2	37.8	5.41	32.2	70.7	12.9	49.3	15.4	23.2	13.1	0.041	0.032	0.013	0.131		
9	Feather	ES	Y/O	2.2	48.4	45.1	3.6	0.7	38.4	5.37	31.6	71.4	15.0	59.9	53.6	22.4	14.8	0.027	0.011	0.038	0.122		
10	Feather	Me	Y/O	3.7	59.3	33.8	2.4	0.8	39.2	5.29	32.5	71.5	14.5	58.0	47.8	23.6	14.9	0.035	ND	0.027	0.124		
11	Feather	S	W	3.0	58.9	35.3	2.3	0.5	39.8	5.34	30.8	79.9	-3.7	27.9	47.3	23.1	16.6	0.025	ND	0.036	0.129		
12	Fancy	S	Y/O	3.0	26.1	33.7	29.9	7.3	35.6	5.20	32.7	74.0	13.7	57.3	30.8	21.6	14.3	0.017	ND	0.022	0.122		
13	Feather	M	Y/O	3.5	56.2	34.8	4.4	1.0	40.6	5.25	28.6	74.5	6.0	43.0	37.9	24.6	12.9	0.022	ND	0.031	0.103		
14	Feather	S	Y/O	0.4	18.3	63.3	14.8	3.1	35.3	5.25	33.1	71.2	14.2	56.1	36.5	23.5	15.9	0.026	ND	0.035	0.135		
15	Fancy	S	W	1.5	30.8	36.6	27.7	3.4	35.1	5.45	33.4	81.1	-3.6	26.1	41.7	21.8	13.8	0.016	0.014	0.032	0.126		
16	Feather	M	Y/O	3.5	45.9	39.9	9.2	1.5	37.3	5.25	31.3	70.3	18.2	59.1	49.9	22.5	17.6	0.033	ND	0.032	0.155		
17	Feather	M	Y/O	0.2	16.3	67.7	13.8	2.0	37.6	5.11	33.2	56.2	17.1	43.0	72.8	23.8	16.6	0.013	ND	0.005	0.075		
18	Fancy	M	W	0.4	18.3	63.3	14.8	3.1	36.9	5.29	32.3	81.6	-4.2	34.4	17.6	23.7	16.4	0.017	ND	0.038	0.113		
19	Feather	Me	Mix	2.0	43.1	41.1	12.2	1.6	37.0	5.32	31.7	75.1	10.8	45.1	29.2	22.6	17.3	0.039	0.023	0.010	0.134		
20	Feather	S	Y/O	3.4	52.2	40.5	3.0	0.9	37.5	5.25	32.0	71.2	14.4	57.8	47.4	22.0	16.5	0.019	0.017	0.030	0.127		
21	Farm	Me	Y/O	7.1	68.5	19.2	3.8	1.4	35.6	4.91	33.9	52.0	16.1	35.0	66.6	24.1	16.2	0.027	0.014	ND	0.167		
22	Farm	S	Y/O	9.1	64.4	20.5	4.4	1.6	34.9	5.11	34.1	44.2	16.6	25.4	53.6	23.4	18.0	0.013	0.010	ND	0.070		
23	Feather	M	Y/O	65.7	4.2	11.8	15.2	3.1	36.9	5.16	32.2	38.4	17.4	21.4	47.3	22.9	15.3	0.012	0.023	0.012	0.068		
24	Feather	S	Y/O	0.4	19.7	65.3	12.6	2.0	36.3	5.03	31.7	52.8	19.6	40.4	69.3	23.7	16.5	0.015	ND	0.007	0.074		
25	Feather	Me	Y/O	1.6	61.7	30.7	4.8	1.2	37.6	5.36	33.8	70.0	16.3	59.7	48.7	23.2	13.8	0.029	0.0098	0.037	0.117		
LSD ⁷				4.2	12.1	8.2	5.8	1.7	1.2	0.04	2.2	0.8	0.4	0.9	3.5	0.5	2.3	0.0026	0.0016	0.0011	0.0031		

¹Numbers represent commercial Cheddar cheese shreds; samples in bold were selected for consumer testing.²Labeled sharpness on the packaging: M = mild; Me = medium; S = sharp; ES = extra sharp.³W = white; Y/O = yellow/orange; Mix = mixed white and yellow/orange.⁴Results in each column represent the percentage by weight of cheese left on each sieve.⁵Initial color measurements of cheese shreds: L* = lightness, a* = red-green color; b* = yellow-blue color; ΔE = color change measurement after baking. Equation from Hunter (1975).⁶ND = not detected.⁷Means that differed by the LSD were different ($P < 0.05$).

Figure 1. Principal component (PC) biplot of descriptive analysis of Cheddar cheese shred flavor. Numbers represent commercial Cheddar cheese shreds (Table 2); underlined samples represent samples chosen for consumer testing. ffa = free fatty acid.

2005; Croissant et al., 2007). Cheddar cheese shreds varied widely by flavor and texture within the same sharpness category, because no legal definition exists for “sharp” or “aged.” The labeled sharpness and color for the Cheddar shreds selected for consumer testing can be seen in Table 2.

Correlation analysis between descriptive flavor and instrumental data (results not shown) demonstrated that cheese shreds with higher intensities of “mild” flavors, such as cooked and whey, tended to have fewer short shreds ($r = -0.486$ and -0.500 ; $P < 0.05$), suggesting that mild cheeses break less and remain whole. As Cheddar cheese ages, gradual proteolysis alters the protein matrix to become less cohesive, resulting in a decrease of rheological fracture strain and springiness (Muthukumarappan and Swamy, 2017). This means

that younger Cheddars are more likely to maintain shape during mechanical stress, such as shredding. As well, cheese shreds with “sharp” flavors such as sulfur and brothy, and tastes such as bitter, salty, sweet, and umami, tended to have increased browning (ΔE ; $r = 0.448, 0.550, 0.536, 0.517, 0.478, 0.420$, respectively; $P < 0.05$). As Cheddar cheese ages, proteolysis results in increased free amino acids and peptides, affecting Maillard browning (Kelly and Fox, 2012).

The cold texture sensory data were explained with 3 principal components (85% of the variability) (Figure 2). Principal component 1 (58%) differentiated shreds by hand cohesiveness, degree of breakdown, tackiness, cohesiveness in mouth, adhesiveness, smoothness of mass, and smoothness of mouthcoating (positively loading). Principal component 2 (16%) differentiated

cheese shreds by degree of mouthcoating and visible powder (positively loading). Principal component 3 (12%) differentiated shreds by color intensity (positively loading). Hot shred texture data were explained with 3 principal components (79% of variability; Figure 3). Principal component 1 (40%) differentiated shreds by visible surface moisture, meltedness, oiliness to the lips, and visual oiliness (positively loading), and stretchability and hardness (negatively loading). Principal component 2 (26%) differentiated shreds by adhesiveness (positively loading), and tackiness and cohesiveness (negatively loading). Principal component 3 (not shown; 13%) differentiated samples by smoothness of chewed mass (positively loading).

In hot texture sensory evaluation, “mild” cheese shreds tended to be less oily to the lips and oily in mouthfeel than “sharp” cheeses (Table 3). Cheddar cheese shreds with increased “sharp” flavor intensities and sour, salty, sweet, or umami basic tastes tended to have decreased stretchability in hot texture evaluation. Cheese shreds with higher visible powder tended to be less cohesive and adhesive in mouth during cold texture evaluation. Increased visible powder on cheese shreds was also correlated with increased hardness and reduced mouthcoating and oiliness to the lips and in mouth. Hand cohesiveness, degree of breakdown, tackiness, cohesiveness, adhesiveness, smoothness of mass, and smoothness of mouthcoat for cold texture evalu-

Figure 2. Principal component (PC) biplot of descriptive analysis of Cheddar cheese shred cold texture. Numbers represent commercial Cheddar cheese shreds (Table 2); underlined samples represent shreds chosen for consumer testing. mct = mouthcoating.

ation and oiliness to the lips, oiliness in mouth, and mouthcoating for hot texture evaluation were all positively correlated. These terms were negatively correlated with hot texture stretchability and hardness. Fat and protein content are the most influential components to the texture of cheese. Bryant et al. (1995) reported that reducing fat in Cheddar cheese altered the protein microstructure, resulting in reduced adhesiveness and cohesiveness. Similarly, Rogers et al. (2009) reported that decreased fat in Cheddar cheese increased hand springiness, rate of recovery, and bite fracture. These authors also reported that as full fat cheeses aged, cheese firmness and associated terms (hand springiness, rate of recovery, and bite fracture) decreased (Rogers et al., 2009). It is well established that cheese aging degrades the casein network over time, resulting in a

less firm and easily deformable cheese (Tunick et al., 1990; Banks, 2007; Rogers et al., 2009).

Consumer Acceptance

The cheese shreds selected for consumer testing ($n = 10$) varied in color, shred size, and labeled sharpness (Table 2), as well as in sensory properties (Figures 1 to 3, Table 4). Cheddar cheese shred consumers differed by sex, age, income, cheese consumption, types of cheese shreds consumed, and factors influencing Cheddar cheese shred purchase choices (Table 5). Cheese shreds with mild flavors (13, 18, 19, 21) scored lower in overall liking than those with more sharp flavor (4, 12, 20), suggesting that consumers generally preferred some level of “sharp” or “aged” flavor (Table 6). However,

Figure 3. Principal component (PC) analysis biplot of descriptive analysis of Cheddar cheese shred hot texture. Numbers represent commercial Cheddar cheese shreds (Table 2); underlined samples represent shreds chosen for consumer testing.

Table 3. Pearson correlation matrix (r) between hot and cold texture descriptive analysis data¹

Texture	Visible powder	Color intensity	Hand cohesiveness	Degree of breakdown	Tackiness	Cohesiveness	Adhesiveness	Smoothness of mass	Smoothness of mouthcoat	Degree of mouthcoat	Visible surface moisture	Meltdness	Stretchability	Oiliness to lips	Hardness	Tackiness	Cohesiveness	Adhesiveness	Oiliness	Smoothness of mass	Mouthcoating
Cold texture																					
Visible powder	1.00																				
Color intensity	0.13	1.00																			
Hand cohesiveness	-0.36	1.00	1.00																		
Degree of breakdown	-0.02	0.87	0.87	1.00																	
Tackiness	-0.12	0.87	0.87	0.87	1.00																
Cohesiveness	-0.37	0.87	0.87	0.87	0.87	1.00															
Adhesiveness	-0.09	0.87	0.87	0.87	0.87	0.87	1.00														
Smoothness of mass	-0.18	0.73	0.73	0.73	0.73	0.73	0.73	1.00													
Smoothness of mouthcoat	-0.09	0.65	0.65	0.65	0.65	0.65	0.65	0.65	1.00												
Degree of mouthcoat	-0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.00											
Visible surface moisture	-0.28	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	1.00										
Meltdness	-0.15	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	1.00									
Stretchability	0.36	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	1.00								
Oiliness to lips	-0.50	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	1.00							
Hardness	0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	1.00						
Tackiness	-0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	1.00					
Cohesiveness	0.32	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	1.00				
Adhesiveness	-0.27	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00			
Oiliness	-0.64	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	1.00		
Smoothness of mass	-0.23	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	1.00	
Mouthcoating	-0.61	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	1.00

¹Values in bold are significant ($P < 0.05$).

Table 4. Descriptive flavor attribute means for Cheddar cheese shreds selected for consumer testing^{1,2}

Sample ³	Sensory attribute												
	Aromatics								Basic tastes				
	Cooked	Whey	Diacetyl	Milk fat	Sulfur	Brothy	Nutty	Grassy	Sour	Bitter	Salty	Sweet	Umami
3	3.3	1.5	ND	3.1	2.3	2.4	1.7	ND	3.9	1.1	4.1	2.8	2.9
4	3.1	1.5	ND	3.8	1.8	2.9	2.9	ND	3.3	ND	3.9	3.0	3.4
6	3.3	2.6	ND	3.1	2.9	3.1	ND	ND	3.1	1.0	3.7	2.7	2.8
11	3.5	2.1	ND	3.1	1.2	2.1	1.4	ND	3.0	0.6	3.6	2.5	2.7
12	3.8	3.1	1.4	3.7	1.3	1.3	0.0	ND	4.0	ND	3.8	2.4	3.1
13	4.0	3.8	1.4	3.7	ND	ND	ND	ND	3.7	ND	3.8	2.0	3.0
18	3.3	2.5	ND	3.2	ND	ND	ND	1.4	2.8	ND	3.1	2.0	2.0
19	3.8	2.8	1.2	3.3	ND	ND	ND	ND	3.2	ND	3.3	2.1	2.3
20	2.7	2.0	ND	3.1	2.6	2.6	ND	ND	3.0	ND	3.6	2.9	3.5
21	4.2	3.5	1.0	3.1	ND	1.1	ND	ND	3.1	ND	3.6	2.1	2.8
LSD	0.2	0.2	0.1	0.2	0.2	0.2	0.2	NA	0.2	0.1	0.2	0.2	0.2

¹NA = not applicable; ND = not detected.

²Intensities were scored on a 15-point universal scale consistent with the Spectrum intensity scale. Cheddar cheese flavors fell between 0 and 5 on this scale (Drake et al., 2001, 2008, 2009).

³Numbers represent commercial Cheddar cheese shreds.

penalty analysis showed that shreds with more aged flavors were also penalized for too much overall flavor and savoriness ($P < 0.05$; Table 7). Other Cheddar shreds (6, 11, 13, 12, 18, 19, and 21) were penalized for having too mild a flavor. Wadhwani and McMahon (2012) reported similar findings, in that consumers considered all sharp cheeses too flavorful and all mild cheeses too mild, suggesting segmentation among consumers similar to that found in the current study. Cheese shred 3 was characterized by some of the most intense aged flavors, including sulfur, brothy, and nutty, and higher intensities of sour, sweet, umami, salt, and bitter tastes. This shred scored the lowest in overall liking out of all samples across all consumers. The overall liking scores for shred 3 showed very clear bimodal distribution, indicating that intense sharp flavors were polarizing to Cheddar cheese shred consumers (Figure 4).

Analysis of the CATA attribute question showed that consumers struggled to communicate the differences between Cheddar cheese shreds (Table 8). All cheese shreds scored at parity for aromatics (milky/dairy, buttery, milk fat/creamy, sulfur/eggy, brothy/meaty, and nutty). However, consumers did differentiate between cheese shreds in terms of appearance, texture, and some basic tastes: bitter, salty, and umami (savory). As well, when asked to identify the labeled sharpness of the cheese shreds, consumers were correct most of the time. These results were consistent with those of Wadhwani and McMahon (2012), who found that consumers could distinguish between a mild and sharp cheese when asked to rate the sharpness using a JAR scale. The sharpness evaluation results, as well as differences in overall liking scores, showed that consumers can recognize differences among cheese shreds but

struggle to communicate what the perceived differences are, which would be expected. These results demonstrate the importance of descriptive sensory analysis with a trained panel. Affective sensory tests show only consumer preference and liking; descriptive analysis is needed to identify and document intensities of flavors (Singh et al., 2003; Drake, 2007). Typical consumers have varying concepts of flavor terms, which are shaped by previous experience (Lawless and Heymann, 2010). The lack of understanding of Cheddar flavor terms could be why consumers could not differentiate samples in the current study by flavors (aromatics) and relied on basic tastes, appearance, and texture. Still, other research has found discrepancies between consumer concepts for preference and actual preference. Haddad et al. (2007) reported that extrinsic factors such as nutrition influenced the initial purchase of products, but continued purchase was driven primarily by sensory properties. McCarthy et al. (2017) reported that self-reported skim milk consumers consistently preferred 2% milk over skim because of its appearance, flavor, and thickness. De Pelsmaeker et al. (2017) compared conjoint tests with a tasting sample versus a description and found that the same clusters existed. However, after tasting, the number of flavor-driven consumers increased. Whether a misunderstanding of flavor or idea-driven liking, consumer concepts may not match actual consumer preferences, and descriptors such as sharp and Cheddar mean different things to different consumers.

Consumers were not prompted or asked directly about anticaking agents on the cheese shreds. However, a review of the comments from purchase intent and overall appearance liking showed that many consumers

Table 5. Demographic information and consumption characteristics for Cheddar cheese shred consumers (n = 151)

Characteristic	Category	Value, %
Sex	Male	48.3
	Female	51.7
Age, yr	18–24	19.2
	25–34	33.8
	35–44	17.2
	45–54	17.2
	55–64	12.6
	>64	7.3
Income, \$000	15–24.9	7.3
	25–34.9	9.9
	35–49.9	17.2
	50–69.9	22.5
	70–99.9	21.9
	>100	21.2
Type of cheese shreds purchased ¹	Cheddar/Cheddar Jack	100.0
	Monterey Jack	49.7
	Colby Jack	44.4
	Nacho cheese	21.2
	Parmesan	69.5
	Gouda	21.9
	Mozzarella	87.4
	Four-Cheese Mexican	76.8
	Pepper Jack	52.3
	Queso Chihuahua	9.3
	Swiss	43.0
	Italian blend	47.7
	Other	0.7
	Mild	4.0
Typical sharpness purchased	Medium	21.2
	Sharp	57
	Extra sharp	17.9
	Fancy/fine	17.9
Cut	Regular/traditional	79.5
	Farm-style/extra-thick	2.6
	Eat it straight	59.6
How do you typically consume Cheddar cheese shreds? ¹	Cold as a complement/condiment	84.1
	Cold as an ingredient	76.2
	Hot as a complement/condiment	95.4
	Hot as an ingredient	90.7
Purchase influence factors ¹	Cost	80.1
	Convenience	35.8
	Flavor	89.4
	Sharpness	72.2
	Brand	45.0
	Texture	52.3
	Health/nutritional value	36.4
	Availability	53
	Organic	9.9
	Appearance	55.0
	Package size	49.0
Brands ¹	Package type	12.6
	Sargento	78.8
	Kraft	86.1
	Organic Valley	35.1
	Borden	30.5
	Horizon	29.1
	Tillamook	9.9
	Cabot	21.2
	Velveeta	23.2
	Store brand	51.7
	Other	2.6
Ethnicity	Caucasian	70.9
	African American	13.2
	Asian	8.6
	Hispanic	4.6
	Other	2.6

¹Check-all-that-apply (CATA) question. Consumers were allowed to choose more than one category, so category percentages do not add up to 100.

($n = 61$) mentioned a visible “powder” on some cheese shreds. The words “powder,” “powdery,” “white,” “residue,” “dust,” “dusty,” “mold,” “moldy,” “anti-caking,” “preservative,” “chalk,” “chalkiness,” and “coating” were found multiple times throughout the comments. In the liking and purchase intent comments, 40.4% of consumers mentioned that they disliked the “powdery” appearance of some Cheddar shreds. Several consumers ($n = 17$) mentioned that the lack of the “powdery” appearance positively influenced their liking. Consumers ($n = 61$) who negatively mentioned anticaking agents gave lower appearance and overall liking scores than consumers who did not mention a powdery appearance (Figure 5). This result suggests that visible anticaking agents negatively affected liking. Speight et al. (2019) had similar findings, in that powdery appearance was a driver of dislike for Cheddar cheese shreds. Of the consumers who mentioned “powdery” appearance negatively in the current study, 2 attributed the powdery appearance to the presence of mold, indicating that some consumers may not be aware of the purpose of anticaking agents. With these findings, future studies need to specifically address consumer perception of anticaking agents. Analysis of the purchase intent influence question showed that for all cheese shreds, purchase intent was predominantly affected by flavor, followed by appearance and texture. However, 4 of the 10 cheese shreds received penalties for texture. Drake et al. (2008) reported similar findings, in that texture did not affect overall liking. However, consumers appeared to value and have specific expectations for Cheddar cheese texture.

We conducted cluster analysis to determine and refine preferences within particular consumer groups. Cluster analysis revealed 3 distinct groups of consumers, each with distinct preferences for the 10 Cheddar cheese shreds (Figure 6). Partial least squares regres-

sion analysis with the clusters showed segmentation preferences (Figure 7). The clusters were distinct, with no similar drivers of liking between the 3. The overall preferred Cheddar shred for consumers in segment 1 ($n = 35$) was a cheese shred characterized primarily by young or mild flavors such as whey, buttery (diacetyl), and cooked. These consumers disliked aged flavors such as the brothy, nutty, and sulfur flavors found in shreds 3, 4, and 20. Cluster 1 also had a high correlation with visible powder, which is not to say that this was a driver of liking, but simply an association with mild-flavored cheeses. Conversely, consumers in cluster 3 ($n = 48$) preferred Cheddar shreds with aged flavors such as brothy, sulfur, and nutty. Shreds 4 and 20 received the highest liking scores from cluster 3 and were both characterized by high sulfur and brothy flavors and sweet and umami tastes. Consumers in cluster 2 ($n = 68$) had the broadest acceptance and highest overall liking scores across all consumers and cheese shreds. These consumers liked profiles of all Cheddar shreds, and their only correlated driver of liking was savoriness (umami). These results were similar to those of Caspia et al. (2006), who found 6 consumer clusters for Cheddar cheese liking that were broken down by consumers who preferred “sharp” flavors, consumers who preferred “mild” flavors, and consumers with high liking scores for all cheeses tested. Several studies have addressed consumer perception of Cheddar cheese flavor and found wide variations in consumer preferences (Young et al., 2004; Drake et al., 2008, 2009). The diversity of flavors, colors, and textures among Cheddar cheeses, even among cheeses with the same flavor designation (“mild,” “sharp”), means that ideal Cheddar flavor has different meanings among consumers. These findings indicate that descriptive analysis is paramount when discussing consumer preferences and drivers. Consumers address their like or dislike of products, and a

Table 6. Consumer liking means for Cheddar cheese shreds ($n = 151$)¹

Descriptive flavor attribute	Cheddar cheese shreds ²										LSD
	3	4	6	11	12	13	18	19	20	21	
Overall appearance liking	6.8	7.0	6.1	6.8	6.9	6.8	6.8	6.9	6.9	5.1	0.4
Color liking	7.2	7.0	6.6	6.8	7.0	7.1	6.8	6.9	7.1	5.8	0.3
Shred size liking	6.5	6.9	6.9	6.9	6.7	6.7	6.6	7.0	6.8	4.9	0.4
Overall liking	5.7	6.9	6.2	6.6	6.8	5.9	6.0	6.6	7.1	6.1	0.4
Flavor liking	5.6	6.9	6.3	6.6	6.7	5.9	5.9	6.5	7.0	6.3	0.4
Saltiness liking	6.0	6.6	6.4	6.5	6.5	5.9	6.3	6.6	6.9	6.5	0.4
Savory liking	5.8	6.8	6.2	6.6	6.6	5.7	6.1	6.5	7.0	6.5	0.4
Sour liking	5.5	6.3	6.2	6.3	6.3	5.7	5.8	6.3	6.5	6.1	0.4
Texture liking	6.7	7.0	6.6	7.0	6.9	6.6	6.5	6.8	7.1	6.2	0.3

¹Attributes were scored on a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely).

²Numbers represent commercial Cheddar cheese shreds.

Table 7. Consumer just-about-right (JAR) scores and check-all-that-apply (CATA) results for Cheddar cheese shreds (n = 151)¹

JAR attribute ¹	Level ¹	Cheddar cheese shred number ²									
		3	4	6	11	13	12	18	19	20	21
Color JAR light	Too dark	6.6 ^{ab}	3.9 ^{ab}	7.2 ^{ab}	2 ^b	17.8 ^a	2 ^b	3.9 ^{ab}	5.2 ^{ab}	11 ^{ab}	1.3 ^b
	JAR	87.5 ^a	71.9 ^a	79.6 ^a	71.7 ^a	78.9 ^a	81.7 ^a	75.8 ^a	86.9 ^a	83.1 ^a	41.8 ^b
	Too light	5.9 ^{de}	24.2 ^{bc,3}	13.2 ^{b,de}	26.3 ^b	3.3 ^c	16.3 ^{b,de}	20.3 ^{b,cd,3}	7.8 ^{de}	5.8 ^{de}	56.9 ^a
Shred size JAR length	Too short	11.2 ^a	10.5 ^a	2.0 ^{ab}	3.3 ^{ab}	0.0 ^b	11.8 ^a	14.4 ^a	5.2 ^{ab}	3.2 ^{ab}	9.8 ^{ab}
	JAR	81.6 ^a	83.7 ^a	84.2 ^a	87.5 ^a	77.6 ^{ab}	79.7 ^{ab}	81.7 ^a	82.4 ^a	89.0 ^a	60.8 ^b
	Too long	7.2 ^{bc}	5.9 ^c	13.8 ^{abc}	9.2 ^{bc,3}	22.4 ^{ab}	8.5 ^{bc}	3.9 ^c	12.4 ^{abc}	7.8 ^{bc}	29.4 ^{a,3}
Shred size JAR width	Too thin	49.3 ^a	5.2 ^d	11.8 ^c	9.2 ^d	0.7 ^d	34 ^{ab}	47.1 ^a	15 ^{bc}	0 ^d	4.6 ^{cd}
	JAR	50.7 ^c	73.9 ^{ab}	75 ^a	77.6 ^a	69.1 ^{abc}	65.4 ^{abc}	52.9 ^{bc}	79.7 ^a	60.4 ^{abc}	27.5 ^d
	Too thick	0 ^e	20.9 ^{bc,3}	13.2 ^{cd}	33.2 ^{d,3}	30.3 ^{bc}	0.7 ^e	0 ^e	5.2 ^d	39.6 ^{b,3}	68.0 ^{a,3}
Overall flavor JAR	Too mild	13.2 ^{cd}	3.9 ^d	44.7 ^{ab,3}	34.9 ^{b,3}	63.2 ^a	37.9 ^{b,3}	35.9 ^{b,3}	32.0 ^{bc,3}	5.2 ^d	25.5 ^{bc,3}
	JAR	49.3 ^{bc}	69.9 ^{ab}	52 ^{bc}	58.6 ^{ab}	34.2 ^c	55.6 ^{bc}	50.3 ^{bc}	63.4 ^{ab}	77.9 ^a	63.4 ^{ab}
	Too strong	37.5 ^{a,3}	26.1 ^{ab,3}	3.3 ^{cd}	6.6 ^{cd}	2.6 ^d	6.5 ^{cd}	13.7 ^{bcd}	4.6 ^{cd}	16.9 ^{bc}	11.1 ^{bed}
Saltiness JAR	Too little	15.8 ^{bc}	5.2 ^c	19.7 ^{abc}	13.8 ^{bc,3}	36.8 ^a	20.9 ^{ab,3}	19 ^{abc}	13.1 ^{bc}	6.5 ^{bc}	11.1 ^{bc}
	JAR	64.5 ^{ab}	75.2 ^{ab}	77 ^{ab}	75 ^{ab}	57.9 ^b	72.5 ^{ab}	69.9 ^{ab}	77.1 ^{ab}	79.9 ^a	80.4 ^a
	Too much	19.7 ^a	19.6 ^a	3.3 ^b	11.2 ^{ab}	5.3 ^{ab}	6.5 ^{ab}	11.1 ^{ab}	9.8 ^{ab}	13.6 ^a	8.5 ^{ab}
Savory JAR	Too little	19.1 ^{bed}	7.8 ^{cd}	31.6 ^{ab,3}	23 ^{bc,3}	49.3 ^a	26.1 ^{b,3}	28.8 ^{ab,3}	25.5 ^{b*}	5.8 ^d	17 ^{bed}
	JAR	54.6 ^d	74.5 ^{abc}	65.1 ^{bed}	72.4 ^{abc}	48 ^d	69.9 ^{abcd}	60.8 ^{bed}	69.3 ^{abcd}	85.1 ^a	76.5 ^{ab}
	Too much	26.3 ^{a,3}	17.6 ^{ab}	3.3 ^c	4.6 ^{bc}	2.6 ^c	3.9 ^{bc}	10.5 ^{abc}	5.2 ^{bc}	9.1 ^{abc}	6.5 ^{bc}
Sour JAR	Too little	9.9 ^{bc}	2.6 ^c	15.8 ^{abc}	19.7 ^{ab,3}	28.9 ^a	15.7 ^{abc}	15.7 ^{abc}	13.7 ^{abc}	7.1 ^{bc}	4.6 ^c
	JAR	55.3 ^a	69.3 ^a	75.7 ^a	69.7 ^a	53.9 ^a	75.2 ^a	65.4 ^a	72.5 ^a	74 ^a	73.9 ^a
	Too much	34.9 ^{a,3}	28.1 ^{ab,3}	8.6 ^c	10.5 ^{bc}	17.1 ^{abc}	9.2 ^c	19 ^{abc}	13.7 ^{bc}	18.8 ^{abc}	21.6 ^{abc,3}
Firmness JAR	Too soft	8.6 ^a	3.9 ^a	17.1 ^a	7.9 ^a	7.9 ^a	12.4 ^a	10.5 ^a	9.2 ^a	7.1 ^a	5.2 ^a
	JAR	84.9 ^a	75.2 ^a	80.3 ^a	86.8 ^a	82.9 ^a	81.7 ^a	78.4 ^a	81.7 ^a	82.5 ^a	68.0 ^a
	Too hard	6.6 ^{bc}	20.9 ^{ab,3}	2.6 ^c	5.3 ^c	9.2 ^{abc}	5.9 ^{bc}	11.1 ^{abc}	9.2 ^{bc}	10.4 ^{abc}	26.8 ^{a,3}
Crumbly JAR	Too crumbly	10.5 ^{abc}	7.8 ^{abc}	13.8 ^{ab}	9.9 ^{abc}	1.3 ^c	5.2 ^c	21.6 ^{a,3}	9.8 ^{abc}	1.3 ^c	5.9 ^{abc}
	JAR	82.2 ^a	81.7 ^a	72.4 ^a	75 ^a	70.4 ^a	85 ^a	71.2 ^a	78.4 ^a	87 ^a	69.3 ^a
	Too rubbery	7.2 ^c	10.5 ^{abc}	13.8 ^{abc}	15.1 ^{abc}	28.3 ^{a,3}	9.8 ^{bc}	7.2 ^c	11.8 ^{abc}	11.7 ^{abc}	24.8 ^{ab,3}
Sharpness ⁴	Mild	19.7 ^{cd}	4.6 ^e	43.4 ^b	33.6 ^{bc}	67.8 ^a	36.6 ^{bc}	45.1 ^{ab}	30.7 ^{bc}	7.1 ^{de}	19.6 ^{cd}
	Medium	25.7 ^{abc}	15.7 ^c	42.1 ^{ab}	39.5 ^{ab}	23 ^{bc}	40.5 ^{ab}	28.1 ^{abc}	43.8 ^{ab}	24.7 ^{abc}	45.8 ^a
	Sharp	38.8 ^{abc}	45.8 ^{ab}	13.8 ^{de}	25.7 ^{abcde}	8.6 ^e	19 ^{de}	15.7 ^{de}	24.8 ^{bcde}	47.4 ^a	27.5 ^{abcd}
Consume ⁵	Extra sharp	15.8 ^{abc}	34 ^a	0.7 ^d	1.3 ^d	0.7 ^d	3.9 ^{cd}	11.1 ^{bed}	0.7 ^d	20.8 ^{ab}	7.2 ^{bed}
	Straight	25 ^a	48.4 ^{cb}	34.9 ^{ba}	41.4 ^{ba}	38.2 ^{ba}	38.6 ^{ba}	32.7 ^{ba}	34 ^{ba}	58.4 ^c	43.1 ^{cba}
	Cold condiment	59.9 ^a	64.1 ^a	61.8 ^a	69.7 ^a	57.2 ^a	71.9 ^a	63.4 ^a	66 ^a	71.4 ^a	54.9 ^a
Purchase intent influence ^{5,6}	Cold ingredient	59.2 ^a	64.1 ^a	59.9 ^a	64.5 ^a	52.6 ^a	66.7 ^a	56.9 ^a	65.4 ^a	70.1 ^a	54.9 ^a
	Hot condiment	78.9 ^{ba}	82.4 ^{ba}	79.6 ^{ba}	75.7 ^{ba}	67.8 ^a	85 ^{ba}	71.2 ^{ba}	88.2 ^b	84.4 ^{ba}	69.3 ^a
	Hot ingredient	67.1 ^a	81.7 ^a	71.7 ^a	80.3 ^a	67.1 ^a	73.9 ^a	68.6 ^a	79.7 ^a	83.8 ^a	75.8 ^a
	Appearance	50.7 ^a	61.4 ^a	55.9 ^a	54.6 ^a	50.7 ^a	53.6 ^a	49 ^a	57.5 ^a	59.1 ^a	54.9 ^a
	Flavor	70.4 ^a	77.1 ^a	72.4 ^a	76.3 ^a	69.7 ^a	74.5 ^a	68 ^a	73.2 ^a	87 ^a	68.0 ^a
	Texture	30.9 ^a	39.2 ^a	36.8 ^a	37.5 ^a	37.5 ^a	35.3 ^a	30.7 ^a	36.6 ^a	40.9 ^a	35.3 ^a

^{a-c}Means in a row that do not share a superscript letter are significantly different ($P < 0.05$).¹JAR questions were scored on a 5-point scale (1 or 2 = too little; 3 = just about right; 4 or 5 = too much). The percentage of consumers who selected these options is presented.²Numbers represent commercial Cheddar cheese shreds.³A significant penalty was assigned to liking for a JAR attribute.⁴The sharpness question asked consumers to identify their perceived sharpness of each cheese shred.⁵CATA question. Consumers were allowed to choose more than one category, so category percentages do not add up to 100.⁶Purchase intent influence allowed consumers to identify and comment on what characteristics affected their purchase intent for each cheese shred.

Figure 4. Frequency distribution of overall liking scores for cheese shred 3 ($n = 151$). Liking was scored on a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely).

trained sensory panel identifies and describes flavor and textural differences that consumers may not be able to communicate.

Data from the central location test and the partial least squares regression analysis suggested distinct differences in preferences among the clusters (Figure 7).

However, when we analyzed the ideal Cheddar shred CATA responses, we found no significant differences between any of the clusters (results not shown), consistent with consumers who were unable to specifically describe likes and dislikes for Cheddar shred flavor. In particular, consumers in cluster 3 (who preferred

Table 8. Consumer check-all-that-apply (CATA) attribute scores for Cheddar cheese shreds ($n = 151$)¹

Attribute	Cheddar cheese shred ²									
	3	4	6	11	12	13	18	19	20	21
Milky/dairy	54.3 ^a	61.6 ^a	70.2 ^a	71.5 ^a	64.2 ^a	65.6 ^a	60.9 ^a	65.6 ^a	66.9 ^a	61.6 ^a
Buttery	24.5 ^a	26.5 ^a	35.1 ^a	32.5 ^a	30.5 ^a	27.2 ^a	24.5 ^a	31.1 ^a	29.1 ^a	32.5 ^a
Milk fat (creamy)	13.9 ^a	23.8 ^a	24.5 ^a	28.5 ^a	32.5 ^a	29.1 ^a	17.2 ^a	24.5 ^a	30.5 ^a	26.5 ^a
Sulfur/eggy	17.2 ^a	13.2 ^a	3.3 ^a	6 ^a	4.6 ^a	5.3 ^a	11.3 ^a	6.6 ^a	11.3 ^a	6.6 ^a
Brothy (meaty)	14.6 ^a	17.9 ^a	11.3 ^a	11.3 ^a	9.3 ^a	6 ^a	8.6 ^a	11.9 ^a	15.2 ^a	15.2 ^a
Nutty	17.9 ^a	19.9 ^a	10.6 ^a	15.9 ^a	11.3 ^a	7.3 ^a	19.2 ^a	10.6 ^a	19.2 ^a	14.6 ^a
Bitter	28.5 ^{ab}	31.8 ^a	5.3 ^c	9.9 ^c	4.6 ^c	7.9 ^c	18.5 ^{abc}	11.3 ^{bc}	11.9 ^{bc}	12.6 ^{bc}
Salty	39.7 ^{ab}	54.3 ^a	36.4 ^{ab}	49.7 ^a	33.8 ^{ab}	21.2 ^b	41.1 ^{ab}	42.4 ^{ab}	49.7 ^a	39.7 ^{ab}
Sweet	7.9 ^a	6.6 ^a	12.6 ^a	8.6 ^a	12.6 ^a	7.3 ^a	7.3 ^a	11.3 ^a	9.3 ^a	7.9 ^a
Savory	43 ^{ab}	48.3 ^a	36.4 ^{ab}	40.4 ^{ab}	33.8 ^{ab}	25.2 ^b	37.1 ^{ab}	36.4 ^{ab}	51.7 ^a	49.7 ^a
Sour	10.6 ^a	11.3 ^a	5.3 ^a	7.9 ^a	5.3 ^a	5.3 ^a	6.0 ^a	4.0 ^a	7.9 ^a	5.3 ^a
Soft	45.7 ^{ab}	24.5 ^b	55.0 ^a	55.0 ^a	58.9 ^a	48.3 ^a	41.7 ^{ab}	49.7 ^a	41.1 ^{ab}	25.2 ^b
Hard	6.6 ^{bc}	29.1 ^a	3.3 ^c	6.0 ^c	2.6 ^c	13.9 ^{abc}	11.9 ^{abc}	8.6 ^{bc}	15.9 ^{abc}	22.5 ^{ab}
Dry/crumblly	8.6 ^{ab}	16.6 ^{ab}	17.2 ^{ab}	9.9 ^{ab}	7.9 ^b	3.3 ^b	25.8 ^a	15.2 ^{ab}	5.3 ^b	13.9 ^{ab}
Rubbery	7.3 ^b	11.3 ^{ab}	11.3 ^{ab}	15.2 ^{ab}	8.6 ^b	28.5 ^a	7.9 ^b	13.9 ^{ab}	11.3 ^{ab}	22.5 ^{ab}
Long shreds	26.5 ^{ab}	25.2 ^{ab}	37.7 ^{ab}	38.4 ^{ab}	23.2 ^{ab}	41.7 ^{ab}	20.5 ^b	33.1 ^{ab}	36.4 ^{ab}	44.4 ^a
Short shreds	25.2 ^{ab}	23.8 ^{abc}	15.2 ^{abc}	11.9 ^{bc}	31.8 ^a	7.9 ^c	31.8 ^a	19.2 ^{abc}	14.6 ^{abc}	9.9 ^{bc}
Thick shreds	2.0 ^d	47.0 ^b	39.7 ^{bc}	45.7 ^b	1.3 ^d	70.9 ^a	1.3 ^d	21.2 ^c	83.4 ^a	86.1 ^a
Thin shreds	84.8 ^a	14.6 ^{cd}	25.8 ^{bc}	15.9 ^{cd}	70.2 ^a	3.3 ^d	76.8 ^a	43 ^b	2.6 ^d	6.0 ^d
Orange	73.5 ^a	0.0 ^c	70.9 ^a	0.0 ^c	61.6 ^{ab}	75.5 ^a	0.7 ^c	62.9 ^a	76.2 ^a	39.1 ^b
Yellow	20.5 ^{bc}	6.0 ^{cd}	23.8 ^b	4.0 ^d	32.5 ^{ab}	18.5 ^{bc}	6.6 ^{cd}	23.8 ^b	19.2 ^{bc}	46.4 ^a
White	0.7 ^c	86.1 ^{ab}	2.6 ^c	91.4 ^a	0.0 ^c	0.0 ^c	85.4 ^{ab}	70.2 ^b	0.7 ^c	2.6 ^c

^{a-d}Means in a row that do not share a superscript letter are significantly different ($P < 0.05$).

¹Consumers were instructed to select attributes that described each cheese shred. The percentage of consumers who selected these options is presented. Consumers were allowed to select multiple categories to describe each cheese shred, so category percentages do not add up to 100%.

²Numbers represent commercial Cheddar cheese shreds.

Figure 5. Appearance and overall liking scores of consumers ($n = 61$) who negatively mentioned a (“powdery” appearance compared with those who did not ($n = 90$)). Standard error bars are included. Bars (means) with different letters (A, B) are significantly different ($P < 0.05$).

“sharp” Cheddar cheese shreds) had ideal selection frequencies that were statistically at parity with selections from cluster 1 (who preferred “mild” cheese shreds). Analysis of the frequencies of ideal cheese shred CATA selections for all consumers indicated that for cheese flavor, consumers selected the basic tastes “savory” and “salty” and “milky/dairy” most frequently. These results illustrate again that consumers struggle to communicate specific flavor-attribute preferences for Cheddar cheese shreds. Young et al. (2004) reported clear differences in consumer liking for Cheddars of varying ages and flavors, but consumers struggled to

identify the intensity of the aged flavors. Aged Cheddar is complex and varies in the market, resulting in different consumer concepts and expectations for Cheddar aged flavor. Dacremont and Vickers (1994) reported this same concept: consumer experience with Cheddar varieties shaped their concepts of Cheddar flavor, odor, and texture.

Across all consumers, bitterness was a driver of dislike. Traditionally bitterness in Cheddar is considered a defect. However, Drake et al. (2009) found that at low intensities, bitterness may not necessarily affect liking, and for some consumers it may be a desired “sharp” flavor attribute. In this study, grassiness was present in only 1 sample for the central location test, so it could not be suggested as a driver of like or dislike; however, it did not appear to be correlated with any cluster of consumers. In determining drivers of liking for mild Cheddar, Drake et al. (2008) also tested a cheese with grassy notes. They found that United States consumers were indifferent to a grassy flavor in Cheddar cheese, or disliked it. More research should be conducted to address consumer perception of the grassy flavor that is typical of organic, grass-fed Cheddar cheeses. Analysis of liking means showed variation in shred-size preference between groups. Clusters 2 and 3 gave higher scores to feather-cut shreds compared with fancy and farm-style shreds (mean = 7.4 and 6.7, respectively; $P < 0.05$), and cluster 1 scored fancy shreds the highest (mean = 6.0; $P < 0.05$). All 3 clusters scored farm-style the lowest of the 3 cuts with mean = 4.9 ($P < 0.05$).

Figure 6. Overall liking scores of all consumers and identified consumer clusters for Cheddar cheese shreds. Numbers represent commercial Cheddar cheese shreds listed in Table 2. All consumers ($n = 151$), cluster 1 ($n = 35$), cluster 2 ($n = 68$), and cluster 3 ($n = 48$). Liking was scored on a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely).

Because shred 21 was the only farm-style shred in the central location test, this shred size could not be suggested as a driver of dislike. From focus groups and an online survey, Speight et al. (2019) reported that consumers preferred medium-thickness shreds, followed by fine and then thick shreds. The thicker farm-style shreds were not included in the Speight et al. (2019) study. Additional research should be conducted to determine the effect of shred size on consumer liking.

Cluster 3 consumers were the only segment that consistently had higher scores for white cheeses over orange cheeses in overall appearance liking, color liking, and overall liking (6.6–6.0, 6.6–6.3, and 6.3–5.6, respectively; $P < 0.05$). Cluster 3 was also marked by a preference for cheese shreds with “sharp” flavors, which are commonly found in commercially available white cheeses. This correlation for cluster 3 in the current study may simply be an association, not a driver of

liking, because white mild non-organic Cheddar shreds are not common in the market and were not included in the test. Drake et al. (2008) reported that United States Cheddar consumers who preferred sulfur and brothy flavors also preferred white-colored cheeses. On the other hand, Wadhvani and McMahon (2012) found that as the whiteness of Cheddar increased, the flavor perception tended to decrease, and the cheese was considered not flavorful enough. Similar to the current study, some consumers in the Wadhvani and McMahon (2012) study commented that the white cheese might be mozzarella and cause confusion. Additionally, Speight et al. (2019) reported that white Cheddar shreds were typically associated with “all-natural” products, and as a result may be associated with high cost. These multiple studies indicate that consumers may be confused by white Cheddar cheese, because yellow and orange Cheddar cheeses colored with annatto are more

Figure 7. Partial least squares regression for central location test (CLT) cheese shreds and consumer clusters. All consumers ($n = 151$), cluster (C)1 ($n = 35$), C2 ($n = 68$), and C3 ($n = 48$).

common in the United States. Additional research is required to investigate the effect of color on consumer preference and flavor expectations.

CONCLUSIONS

The current study demonstrated that the composition, flavor, and texture of Cheddar cheese shreds varied widely. As a result, consumer preference and expectations also varied. Specific consumer clusters (1 and 3) were identified by a preference for sharp or mild cheese shreds, with cluster 3 preferring “sharp” Cheddar flavors and cluster 1 preferring “mild” Cheddar flavors. Some consumers (cluster 2) were defined for their broad acceptance and high liking scores of Cheddar shreds in general. Bitterness was a consistent driver of dislike for all consumer clusters. Consumers struggled to understand and communicate specific flavor differences between shreds, regardless of preference, and relied primarily on basic tastes. Anticaking agents (“powdery” appearance) decreased overall liking for some consumers. These findings can help manufacturers create optimized Cheddar cheese shreds that will reach the broadest range of consumers.

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