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Identifying sensory drivers of liking for plant-based milk coffees: Implications for product development and application

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Abstract: The global plant-based product market is growing rapidly, and plant-based milks show promising potential in the coffee beverage sector. This study aimed to identify sensory drivers of liking of plant-based milk coffees for guiding the development of plant-based products with competitive advantages over dairy milk coffees. Twelve coffee samples were prepared with plant-based (oat, soy, almond, and coconut) and dairy (cow) milk. Quantitative descriptive analysis was used to generate sensory attribute terms for the 12 samples. Check-all-that-apply (CATA) questions were given to consumers to evaluate the sensory profiles and consumer acceptance of the 12 samples. Correspondence analysis and cluster analysis of the CATA results from 80 consumers showed that the oat and soy milk coffee samples were closer to what the consumers perceived as "typical" milk products, while the coconut and almond milk coffee samples were closer to the "flavored" milk products. Partial least squares regression results revealed that the attributes smooth, milky, and thick were important drivers of liking for the milk coffee samples. On the contrary, rancid oil, greasy, astringent, and rice bran were the major sensory attributes lowering the panelists' acceptance of the milk coffee samples. The majority of consumers (53.5%) were "dairy milk lovers," who specifically liked the dairy milk coffee sample and had low acceptance for the plant-based milk coffee samples. There was also a group of consumers (46.2%) classified as "plant-based milk coffee lovers." They enjoyed coffees prepared with a wide range of milks (both dairy and nondairy milks) and represent high-potential consumers for plant-based milk coffee products.

KEYWORDS
alternatives, coffee, dairy, milk, sustainability

Practical Application: The positive and negative drivers of liking for plant-based milk coffee samples were identified. A competitive landscape analysis method for assessing the acceptability and sensory attributes of 12 milk coffee samples (11 commercial plant-based milks and 1 dairy milk product) in the

current Asian market was established. The sensory terms developed in this study can also be applied to evaluate sensory profiles of other plant-based and dairy milk coffee samples.

1 INTRODUCTION

Plant-based alternative foods are gaining popularity because of increasing consumer awareness about sustainable production of foods, ethical concerns (animal welfare and religious practices), and the health benefits from a plant-based diet (McClements et al., 2019). A number of life cycle analysis studies have shown that the environmental impacts of various plant-based milks (soy, almond, oat, and rice) are lower than those of dairy milk, but the extent of the environmental benefits depends on the type of milk alternative chosen (Grant & Hicks, 2018; Poore & Nemecek, 2018; Wenzel & Jungbluth, 2017). Plant-based milks were also found to be preferable to populations with health-related challenges such as lactose intolerance, cow's milk allergy, and hypocholesterolemia (Aydar et al., 2020). Furthermore, plant-based milks possess health benefits; they are free of cholesterol and cow milk hormones and rich in bioactive compounds (such as phytosterols, isoflavonoids, and polyphenols), unsaturated fatty acids, and dietary fiber (Aydar et al., 2020). All of these factors are driving the growth of the plant-based milk market.

The global market for plant-based dairy alternatives was valued at USD 22.6 billion in 2020 and is estimated to reach USD 40.6 billion by 2026 with a compound annual growth rate of 10.3% (Markets & Markets, 2021). The Asia Pacific region will account for the largest market share during this forecast period (Markets & Markets, 2021). Plant-based milks are potentially interchangeable with dairy milks in a broad range of application scenarios, and many dairy and nondairy companies are actively providing diverse plant-based dairy alternatives (plant-based milks, barista-style milks, creamers, yogurts, ice creams, and cheese) to their product portfolio to seize global growth opportunities.

Coffee is one of the world's most popular beverages. The addition of milks, sweeteners, and flavors influences the consumer preference for coffee beverages (Jervis et al., 2012; Komes et al., 2015). Dairy milk is especially recognized for its ability to reduce the bitterness, astringency, and acidity of black coffee (Akiyama, et al., 2009; Parat-Wilhelms, et al., 2005). The consumer perception of the astringency of coffees results from the formation of an insoluble complex between polyphenols in the coffee and proteins in saliva (Jobstl et al., 2004). The interaction of dairy milk proteins with polyphenols in the coffee reduces the perception of astringency (Rashidinejad et al., 2021). The addition of dairy milk not only increases the intensity of milk attributes (i.e., butter, milky, and creamy) but also reduces the intensity of coffee attributes (i.e., roasty, coffee, and burnt) by affecting the release of aroma and flavor release from coffee (Parat-Wilhelms, et al., 2005).

Plant-based milks, depending on the plant variety, tend to have sensory attributes such as beany, earthy, bitter, acrid, astringent, chalky, sandy, and thin mouthfeel (Tangyu et al., 2019). The introduction of these new sensory attributes when replacing dairy milk in coffee beverages with plant-based milk influences consumer acceptability of the new product (Gorman et al., 2021). For example, the attributes beany, earthy, and grassy were found to negatively influence the consumer acceptance (Gorman et al., 2021). However, there is limited information regarding the detailed sensorial attributes of coffees supplemented with diverse plant-based milk products. Most studies have measured consumer acceptability without using descriptive analysis tools and have focused on soy-coffee beverages (Felberg et al., 2010; Karaki & Ogle, 2012; Nindita & Nahdlah, 2017). Recently, Gorman et al. (2021) applied a check-all-that-apply (CATA) questionnaire to investigate consumer perceptions of coffee with dairy milk and plant-based milks (oat, soy, and almond). The terms in their study were based on a literature review of black coffee and plant-based milks and evaluations by researchers. Their results showed that sweetness increased the overall liking of the milk coffee samples for all consumers and that the plant consumers (who usually added plant-based milk to their coffee) liked dairy milk coffee samples less than the dairy consumers (who usually added dairy milk to their coffee). Since only four different coffee samples were evaluated in their study, evaluation of a wider range of samples would be useful for providing a better overall picture of the sensorial properties of plant-based milk coffees.

The objective of this study was to identify the important drivers of liking for diverse plant-based milk (oat, soy, almond, and coconut) coffees through the analysis of the correlations between overall liking scores and sensory attributes of coffees prepared using various brands of barista-style plant-based milks (designed for use in coffee drinks) and one brand of dairy milk available in the current market. A quantitative descriptive analysis (QDA) panel was assembled to generate terms for better describing these new types of samples. The CATA method was used for investigating the sensory properties of milk coffee samples from the consumers' perspective. Recommendations were made for the application of specific plant-based milk products based on their sensory characteristics. Directions for product development were determined based on the consumer preference for and perceptions of the tested products as well as their descriptions to ideal products.

2 | MATERIALS AND METHODS

2.1 | Preparation of the milk coffees

Twelve milk products (Table S1) were purchased from the internet, local distributors, and supermarkets. M1–6, M7–8, M9, and M10–11 are barista-style oat, soy, almond, and coconut milks, respectively. M12 is a brand of full-fat cow's milk. P1–12 are the coffee samples prepared using the corresponding milk products M1–12. The milk products were heated in a water bath at 82°C for 20 min to a temperature of 75°C. The espresso coffees were brewed on a fully automatic coffee machine (CAFFEO® CI®, Melitta, Germany). Coffee beans (Dark Roast, Kirkland Signature Espresso Bean, Costco Wholesale Corporation, Issaquah, WA, USA) were ground at a coarse grind setting. Ground coffee (14 g) was extracted with water (30 ml; Purewater, Taisun Enterprise Co., Ltd, Taiwan) at a regular temperature setting. The milk coffees (73–75°C) were prepared by adding espresso coffee (63–65°C) to milk (75°C) at a ratio of 1:5 (w/w). The coffee-to-milk ratio (1:5) was chosen based on the consensus by the researchers that the oat and dairy milk coffee samples prepared using this ratio have general flavor and texture characteristics similar to those of oat and dairy milk coffee products purchased from several local coffee shops. The milk coffees were stored in Thermos flasks (SF-CC20, Zojirushi Corporation, Japan), and 80 g of each coffee was poured into a small Thermos flask (TH-315, Matsuda, China) 60 min before the sensory evaluation. The panelists drank milk coffees directly from small Thermo flasks. The consumption temperature of milk coffees was maintained at 50–60°C.

2.2 | Panelist recruitment

This study was approved by the Research Ethics Committee of National Taiwan University (IRB#202101EM014). The recruitment criteria for both the QDA and the CATA/acceptance/ideal product test panels were an age of 20–65 years old, no food allergies/sensitivities/intolerance/restrictions, and the availability and willingness to participate. For the QDA panel, the recruited individuals were screened for taste/odor sensitivity using the following method modified from ISO 8586 (ISO8586, 2012). The concentrations (w/v) of the basic taste solutions were 0.02% citric acid (sour), 0.6% sucrose (sweet), 0.02% caffeine (bitter), 0.13% sodium chloride (salty), and 0.03% monosodium glutamate (umami). The odor samples were 1 ppm vanillin (vanilla), 0.1 ppm γ-nonalactone (coconut), 5 ppm benzaldehyde (bitter almonds), and 25 ppm butyric acid (rancid butter) absorbed in odorless cotton wool. The QDA panel of nine individuals (six women and three men) was composed of six staff members of the Food Industry Research and Development Institute (Hsinchu City, Taiwan), two graduate students, and a recent college graduate of National Tsing Hua University (Hsinchu City, Taiwan). The panelists for the CATA/acceptance/ideal product tests ($n = 80$) were recruited from naïve staff of the Food Industry Research and Development Institute. They were not screened for taste/odor sensitivity. Their ages ranged from 20 to 65 years old, and the demographic information is provided in Supporting Information (Table S2).

2.3 | Quantitative descriptive analysis

A QDA panel was assembled to create sensory terms for the 12 milk coffee samples following the method of Kuo and Lee (2017). The members of the panel underwent 33 training sessions and 4 test sessions (1 h per session). The training included term generation, reference refinement, term finalization, and group scoring. The panel also developed the following rinsing protocol to be used between samples: rinsing with warm (45°C) and then room temperature water. During the test sessions, each panelist completed triplicate evaluations of the sensory attributes of each sample. Analysis of variance (ANOVA) and calculation of the adjusted F-value (F_{adj}) for each QDA term were performed as described in Kuo and Lee (2017). Table S3 lists the finalized terms and the corresponding F_{adj} for each term. The 20 sensory attributes in the CATA questionnaire (Table 1) were selected and modified from the 38 terms generated by the QDA panel. The selection was made by discussing with the QDA panel on how to combine similar terms for different modalities and remove the terms with lower degrees of differentiation among samples.

2.4 | Consumer tests: CATA, consumer acceptance test, and ideal product survey

The CATA/acceptance testing was conducted in standard sensory booths (ISO 8589) in the Research Hall at the Food Industry Research and Development Institute. Compusense Cloud (Guelph, ON, Canada) was used for data

TABLE 1 Selection frequencies (%) of sensory attributes for the plant-based milk coffee samples, the dairy milk coffee sample, an ideal dairy milk coffee, and an ideal plant-based milk coffee

	Studied samples																								Ideal products			
	Oat milk coffee												Soy milk coffee				Almond milk coffee		Coconut milk coffee				Dairy milk coffee		Plant-based or dairy milk coffee		Plant-based milk coffee	
Attributes	P1		P2		P3		P4		P5		P6		P7		P8		P9		P10		P11		P12					
Flavor																												
Milky	44	bc	39	bcd	31	bcd	38	bcd	19	d	16	d	28	bcd	18	d	21	cd	46	b	21	cd	81	a	83	A	60	B
Bitter	50	abc	68	a	50	abc	53	ab	66	a	65	a	55	ab	50	abc	39	bc	28	c	50	abc	48	abc	23	A	25	A
Roasted	49	ab	50	ab	48	ab	59	a	33	bc	38	abc	39	abc	36	abc	30	bc	21	c	21	c	34	bc	31	A	30	A
Sweet	20	cd	9	d	29	cd	35	bc	11	d	9	d	18	cd	19	cd	50	ab	63	a	28	cd	23	cd	53	A	53	A
Bitter chocolate	23	ab	34	a	10	b	20	ab	25	ab	16	ab	14	b	13	b	16	ab	14	b	15	b	23	ab	31	A	20	B
Sour	16	a	33	a	55	b	31	a	23	a	21	a	33	a	26	a	19	a	16	a	53	b	20	a	13	A	5	B
Beany	24	abcde	18	cde	20	bcde	26	abcde	31	abcd	33	abc	39	ab	41	a	8	e	11	de	8	e	10	e	10	A	15	A
Walnut	16	a	20	a	11	a	14	a	24	a	18	a	21	a	16	a	9	a	13	a	9	a	10	a	11	A	21	A
Rice bran	25	abc	20	abcd	19	abcd	21	abcd	23	abcd	38	a	29	abc	30	ab	11	bcd	3	d	11	bcd	9	cd	4	A	9	A
Rancid oil	19	abc	6	c	26	ab	15	bc	25	abc	24	abc	10	bc	28	ab	11	bc	6	c	35	a	6	c	0	A	0	A
Oat	24	abc	18	bcd	16	bcd	20	bcd	31	ab	41	a	20	bcd	18	bcd	8	cd	14	bcd	4	d	5	cd	15	B	46	A
Coconut	1	b	1	b	0	b	6	b	1	b	3	b	0	b	0	b	1	b	66	a	64	a	5	b	4	A	6	A
Cereal	9	a	9	a	10	a	8	a	19	a	18	a	13	a	13	a	5	a	10	a	9	a	4	a	6	A	13	A
Almond tea	1	b	4	b	3	b	6	b	3	b	5	b	3	b	4	b	85	a	8	b	11	b	0	b	5	B	14	A
Peanut	9	ab	5	ab	15	a	11	ab	13	ab	14	ab	5	ab	9	ab	4	ab	6	ab	9	ab	0	b	1	A	8	A
Salty	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		1	A	0	A
Buttery	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		21	A	18	A
Hazelnut	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		43	A	49	A
Caramel	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		35	A	24	A
Seaweed	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		0	A	0	A
Texture																												
Smooth	53	abcd	53	abcd	55	abcd	63	abc	34	d	41	cd	46	bcd	40	cd	68	ab	71	a	33	d	69	ab	98	A	94	A
Thick	56	ab	48	abcd	26	d	59	a	35	bcd	36	abcd	48	abcd	33	cd	35	bcd	46	abcd	36	abcd	51	abc	80	A	65	B
Astringent	23	bc	34	abc	38	abc	23	bc	54	a	48	a	43	ab	41	ab	20	bc	14	c	40	ab	21	bc	1	A	0	A
Greasy	20	ab	14	b	23	ab	16	b	16	b	24	ab	21	ab	21	ab	9	b	18	b	39	a	11	b	1	A	0	A
Grainy	6	b	5	b	5	b	4	b	19	a	4	b	1	b	4	b	5	b	4	b	5	b	0	b	5	A	6	A
Refreshing	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		28	A	36	A
Mouth coating	NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		8	A	5	A

Note: The letters indicate the results of significance tests for differences in the frequency of panelists' selection of an attribute between samples. Statistical tests were performed for each attribute, and samples marked with the same letter are not significantly different ($p > 0.05$). The lower-case letters are from comparisons among the twelve studied coffee samples, while the upper-case letters are from comparisons between the ideal milk coffee (including dairy and plant-based milk coffees) and the ideal plant-based milk coffee. NA means the attributes were not listed in the CATA questionnaire.

collection. The samples were evaluated in a monadic series with a Williams Latin square design (Williams, 1949). The Thermos flasks were labeled with three-digit random numbers. There was a waiting period of at least 30 s in between samples and a break of at least 6 min after tasting six samples. Warm (45°C) and then room temperature water was used for rinsing between samples. The panelists were instructed to take approximately two sips of each sample. After the first sip, the panelists were asked to score their overall liking and liking for the aroma, flavor, and texture of a sample using a 9-point hedonic scale with three verbal anchors: "dislike extremely" (1), "neither like or dislike" (5), and "like extremely" (9). After the second sip, they completed a CATA questionnaire to indicate whether they perceived any of the 20 attributes listed. Finally, the panelists were asked to write down any additional sensory attributes they perceived in the 12 samples. The CATA terms of the 12 samples were presented to the panelists grouped by modalities. The flavor modality terms were presented first, followed by the texture modality terms. Within each modality, the terms were generally presented in randomized order. However, due to a software operation error, 10 flavor terms were presented in a fixed order (i.e., cereal, peanut, walnut, almond tea, coconut, beany, rancid oil, roasted, milky, and bitter chocolate). Nevertheless, the resulting selection frequencies of these terms appeared to be independent of the presentation order. In addition, as discussed in more detail in the Results and Discussion, terms such as almond tea and coconut significantly differentiated the samples. Hence, we believe that the CATA results provide valuable information about the sample sensory qualities despite the fixed order of presentation for some of the terms.

The ideal product survey was conducted online and Compusense Cloud was used for data collection. The same group of panelists (80 people) participating in the CATA/acceptance test were asked to complete this survey. The sensory attributes that were perceived by the CATA/acceptance panel but were not present in the CATA/acceptance questionnaire were salty, buttery, hazelnut, caramel, refreshing, mouth coating, and seaweed. The 27 descriptive attributes (Table 1) including the seven attributes added by the panelists were used for the ideal product survey. The panelists were asked to check all the attributes they considered appropriate to describe the flavor and texture properties of an ideal milk coffee product (coffee containing a plant-based milk or a dairy milk) and an ideal plant-based milk coffee product (coffee containing a plant-based milk only). CATA terms in the ideal product survey were divided into two modalities: flavor and texture. The terms for each modality were randomized.

2.5 | Statistical analyses

The data were analyzed using XLSTAT (Paris, France) software, and the analytical methodology was modified from Liou et al. (2020). Cochran's Q test and multiple pairwise comparisons with critical difference (Sheskin) were conducted to compare differences in the attribute selection frequencies among the samples. Correspondence analysis was performed on the sensory attributes checked by ≥20% of the panelists to measure similarities among the samples and attributes. Agglomerative hierarchical clustering (AHC) analysis with Euclidean distance, Ward's method, and automatic truncation based on entropy were used to classify the samples based on the attribute selection frequencies. Consumer's liking scores (9-point hedonic scale) for the samples were compared by one-way ANOVA with Fisher's least significant difference (LSD) test. AHC analysis with Euclidean distance, Ward's method, and automatic truncation based on entropy were used to classify the panelists based on their overall liking scores for the samples. Finally, partial least squares regression (PLSR) analysis was performed on the sensory attributes checked by ≥20% of consumers to understand the relationships among overall liking, sensory attributes, and samples.

3 | RESULTS AND DISCUSSION

3.1 | Sensory profiles of the plant- and dairy-based milk coffee samples

The QDA in this study was used for generating important sensory terms for plant-based milk coffee samples to be used in the subsequent CATA questionnaires. There were 38 terms generated by the QDA panel for describing and differentiating sensory attributes of milk coffee samples (Table S3). For all 38 terms, there were significant differences among the 12 milk coffee samples ($F_{adj} > F_{critical}$, Table S3).

Table 1 lists the selection frequencies for the 20 CATA attributes of the 12 coffee samples (11 plant-based milks [P1–11] and one dairy-based milk [P12]). Among the 20 attributes, only cereal and walnut did not show any significant differences in selection frequency across the samples ($p > 0.05$). This suggested that the panelists perceived differences in the sensory characteristics of the 12 samples and that the differences were effectively captured by the CATA questionnaire.

According to penalty analysis, the attributes that are selected by fewer than 20% of the panelists in either of the two not-JAR (just about right) categories (too little and too much) are generally eliminated because they have less impact (Schraidt, 2009). In this study, the attributes selected by fewer than 20% of panelists, cereal, peanut, and grainy were not recognized as important characteristics of the plant-based milk coffees, while the other 17 attributes were considered essential. For the 11 plant-based milk coffee samples (P1–11), the major sensory perceptions were sweet, sour, bitter, roasted, almond tea, coconut, smooth, thick, and astringent (selected by ≥50% panelists), and milky, oat, rice bran, walnut, bitter chocolate, beany, rancid oil, and greasy were moderately important attributes (selected by 20–50% of panelists) (Table 1). On the other hand, the major sensory perceptions of the dairy milk coffee sample (P12) were milky, smooth, thick, and bitter.

Vidal et al. (2021) analyzed the empirical data from five consumer studies (each with 159–209 participants) and concluded that the differences in citation proportions in CATA questionnaires could be used as a proxy for the differences in the perceived intensity of sensory attributes under certain criteria (i.e., moderate differences among samples, ≥50 panelists, and no involvement of complex terms). There was a significant difference in the selection frequency for milky flavor between plant- and dairy-based milk coffees (Table 1). P10 (coconut) had the highest selection frequency for sweet and the lowest for bitter, while P2, P5, and P6 (oat) had the lowest for sweet and the highest for bitter. This may imply that the perception of sweetness can suppress the perception of bitterness. P3 (oat) and P11 (coconut) had the highest selection frequencies for sour. The selection frequency for roasted flavor for P4 (oat) was significantly higher compared with those for P5 (oat), P9 (almond), P10 and P11 (coconut), and P12 (dairy). Coconut flavor was only perceived in P10 and P11 (coconut). In terms of texture, P10 (coconut), P4 (oat), and P5 (oat) received the highest selection frequencies for smooth, thick, and astringent, respectively.

The selection frequency of almond tea flavor was the highest for P9 (Table 1). Almond tea, also called Chinese almond tea, or Chinese almond milk in Taiwan, is a common traditional beverage made of apricot kernel flour and sugar, and it does not contain tea. The QDA panel identified almond tea as a reference to describe the almond flavor of P9 (Table S3), even though the milk of P9 is made of almond instead of apricot kernel flour. The CATA/acceptance panel was naïve to the identity of the milk used in the coffee samples but still identified the almond tea flavor in P9 as did the QDA panel. This suggested that either the almond milk used for P9, or the combination of almond milk and coffee, bore a flavor profile resembling that of what general consumers would recognize as "almond tea."

Based on the results of cluster analysis using 17 CATA attributes selected by ≥20% of the panelists, the 12 milk coffee samples were sorted into two groups using cluster analysis (Figure 1). Group 1 contained P1–8 (oat and soy) and P12 (dairy), while Group 2 contained P9 (almond) and P10 and P11 (coconut). Group 2 featured almond tea and coconut flavors (Table 1 and Figure S1). Overall, the sensory properties of the plant-based milk coffees were primarily determined by the plant variety. Compared with Group 2 coffees, the oat (P1–6) and soy milk (P7–8) coffees in Group 1 possessed flavor characteristics closer to those of dairy milk coffee (P12), and they may be closer to the consumers' expectation of "typical" milk products. P9, P10, and P11 in Group 2 possessed distinctive flavor profiles of almond and coconut milks, which are easily differentiated from the profiles of dairy milk and closer to those of "flavored" milk products.

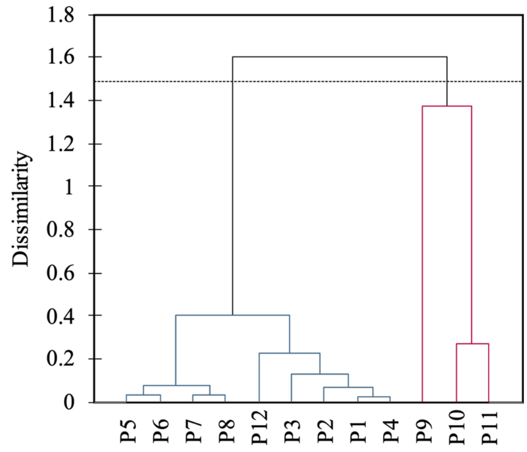

FIGURE 1 Cluster analysis of the 12 milk coffee samples in association with the 17 sensory attributes selected by ≥20% of participants.

As shown in Figure 1, the nine samples in Group 1 were further classified into two groups, Group 1a containing the oat coffees P5 and P6 and the soy coffees P7 and P8, and Group 1b containing the oat coffees P1–4 and P12 (dairy). Figure 2 shows the correspondence analysis biplot of the CATA attributes of these nine samples. The F1 (57.52%) and F2 (18.50%) axes together accounted for 76% of the total variance. Group 1a samples were in the region featuring the attributes astringent, beany, rice bran, bitter, oat, greasy, and rancid oil. Group 1b samples were in the region featuring the attributes milky, smooth, sweet, thick, roasted, sour, and bitter chocolate. The two groups were separated mainly by the perceptions of milky, smooth, astringent, and beany attributes (Figure 2 and Table 1). According to Wang et al. (2021), the key compounds responsible for the beany flavor of soybean are short-chain aliphatic carbonyl compounds, which are produced by PUFA degradation. Blanching and grinding with hot water were found to significantly reduce the lipoxygenase activity and beany flavor in soy milks

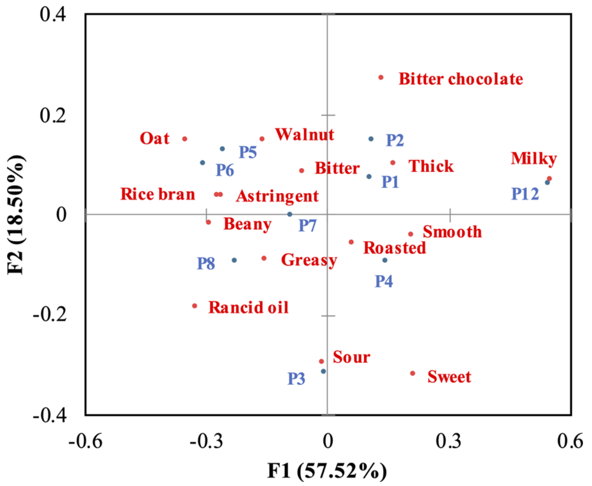

FIGURE 2 A correspondence analysis biplot of the nine milk coffee samples of Group 1 in association with the 15 CATA sensory attributes selected by ≥20% of panelists.

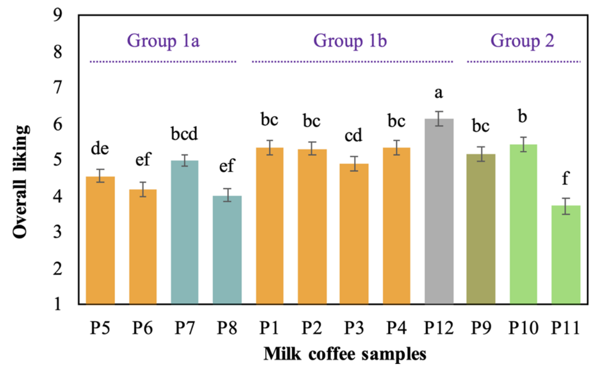

FIGURE 3 The overall liking of the 12 milk coffee samples. The same letters indicate that there is no significant difference between the samples, as determined by Fisher's least significant difference ($\alpha = 0.05$) test.

(Lv et al., 2011). Molteberg et al. (1996) found that more volatile lipid oxidation compounds were formed during the storage of raw oat flour compared with heat-treated oat flours; one of these compounds was 1-octen-3-ol, a key compound responsible for beany odor. Furthermore, plant phenolic compounds are responsible for the perception of astringency (Drewnowski & Gomez-Carneros, 2000). The manufacturing process used for different plant-based milk products may be one of the key factors responsible for the different perceptions of astringency and beany flavor in plant-based milk coffees.

Among the six oat milks (M1–6) used to make the coffee samples in this study, the compositions of M1 and M6 were the most similar compared with those of the other four (Table S1). However, the sensory characteristics of P1 and P6 were distinguishable. P1 was clustered into Group 1b, and not into Group 1a with P6, which had a higher selection frequency for the milky attribute and lower frequency for astringent (Figure 2 and Table 1). In addition, there was no significant difference in texture attributes between P1 and P4 even though M4 had no added oil and its fat content was lower (0.4%) than that of M1 (2.6%). The above comparisons between sample compositions and sensory characteristics showed that the manufacturing process of plant-based milks may influence their flavor and texture properties. Grinding, enzymatic treatments, roasting, and ultra-high temperature pasteurization are conventional processes used for the production of plant-based milks (Aydar et al., 2020). Combining these treatments with optimized parameters can transform the components of the primary ingredients and create targeted flavors or mouthfeel without adding artificial additives.

3.2 | Consumer acceptance of the plant and dairy-based milk coffee samples

As shown in Figure 3, the overall liking scores for the 12 milk coffee samples ranged from 3.7 to 6.1. Significant differences in the overall liking scores among the samples were found ($p < 0.0001$). P12 (dairy) had the highest overall liking score (6.1), whereas P6 (oat), P8 (soy), and P11 (coconut) were the least liked (3.7–4.2).

When comparing the samples by their CATA groupings (Figure 1), Group 1b had the highest average overall liking score (LSD; $p < 0.05$) and possessed flavor and texture characteristics related to dairy or coffee products. For example, P1 possessed a milky flavor, P2 a bitter chocolate flavor, and P4 a roasted flavor and smooth texture. These familiar features not only surprise consumers (e.g., there is no chocolate added but there is a chocolate flavor) but also bridge the sensory gap between plant-based milk and coffee. Among the samples in Group 1b, the overall liking score for P3 was the lowest. This might be related to the perception of a stronger sour taste by consumers (Table 1 and Figure 2).

As shown in Figure 3, the overall liking scores for P10 (5.4) and P11 (3.7) were significantly different ($p < 0.05$), even though P10 and P11 were clustered together in Group 2. Consumers preferred coconut milk coffee (P10) with a sweet taste and smooth texture, but not coconut milk coffee with a sour taste (P11) (Table 1). According to the listed ingredients (Table S1), both M10 and M11 contained added sugar. The sugar contents of P10 and P11 were 3.3% and 2.6%, respectively. The higher sugar content of P10 evidently increased the sweetness perception and consumer acceptance of the coconut milk coffee. Previous studies have also found sweetness to be an important factor in consumer acceptance. Felberg et al. (2010) investigated the influence of the concentration of instant coffee, soymilk powder, and sugar on consumer acceptance of soy milk coffee. They found that sugar was the most influential factor and that an increase in sugar concentration contributed to a higher acceptance of the beverage (Felberg et al., 2010). Gorman et al. (2021) also reported that sweetness increased consumers' liking for plant-based milk coffees, while sourness decreased it. This is probably because our sensory system evolved to detect and prefer specifically crucial nutrients such as the once rare energy (carbohydrate)-rich plants that taste sweet (Mennella et al., 2016). Cotter et al. (2021) reported that sourness was a positive sensory driver of liking for some consumers who were attracted to extreme sensory profiles for black coffee. We speculate that sourness may have a positive or negative effect on consumer preference, depending on the food system and consumer cluster. Fat is also another important component. The fat contents of P10 and P11 were 1.4% and 3.7%, respectively. The higher fat content of P11 might be responsible for its rancid oil flavor and greasy texture (Table 1). The different liking and perceptions of P10 and P11 suggest that consumer preference for plant-based milk coffee is not solely dictated by the plant variety and emphasize the importance of enhancing desirable attributes and reducing undesirable attributes for various types of raw materials.

Cluster analysis of overall liking scores identified of two consumer segments with different preference patterns. Cluster 1 was composed of 43 panelists who clearly preferred the dairy milk coffee (P12) and disliked P6, P8, and P11 (Table 2). On the other hand, the remaining 37 panelists (Cluster 2) preferred various milk coffees, and there were no significant differences in ratings between the plant-based milk coffee samples P1–2, P4, and P9–10 (6.1–6.6) and the dairy milk coffee sample P12 (6.4). Overall, the panelists of Cluster 2 enjoyed plant-based milk coffee much more than those of Cluster 1, except that P11 and P3 were equally preferred by the two clusters. This implied that Cluster 2 panelists accepted milk coffees with a wider range of sensory attributes and appreciated the unique flavors of plant-based milks. This group of consumers was recognized in this study as "plant-based milk coffee lovers." Cluster 1 panelists on average rated all of the plant-based milk coffee samples between "dislike moderately" and "neither like or dislike" and significantly preferred the dairy milk coffee sample over the others. This cluster was considered to be "dairy milk coffee lovers." Clusters 1 and 2 did not differ significantly in general demographic characteristics including gender, age, consumption pattern, and purchase intent (Table S2, Chi-square test; significance level of 0.05). This suggests that future studies to explore other consumer information such as educational background, income, or plant-based milk consumption pattern may help to identify demographic factors that drive the liking for plant-based milk coffees.

TABLE 2 Mean values for overall liking by the two clusters of panelists classified by hierarchical clustering analysis

		Milk coffee samples											
		Group 1a				Group 1b					Group 2		
	Number	P5	P6	P7	P8	P1	P2	P3	P4	P12	P9	P10	P11
Consumer	(percentage)	Oat	Oat	Soy	Soy	Oat	Oat	Oat	Oat	Dairy	Almond	Coconut	Coconut
Cluster1	43 (53.8)	3.93 Bcde	3.7 4 Bdef	4.47 Bbc	3.21 Bf	4.56 Bbc	4.53 Bbc	4.58 Abc	4.67 Bb	5.86 Aa	4.02 Bbcde	4.40 Bbcd	3.42 Aef
Cluster2	37 (46.2)	5.27 Acd	4.73 Ade	5.59 Abc	4.97 Acd	6.24 Aab	6.19 Aab	5.27 Acd	6.08 Aab	6.43 Aa	6.49 Aa	6.65 Aa	4.08 Ae

Note: Significant differences were determined by Fisher's least significant difference (α= 0.05) test. The mean values followed by the same upper-case letters are not significantly different within each sample column, while the mean values followed by the same lower-case letters are not significantly different within each consumer cluster row.

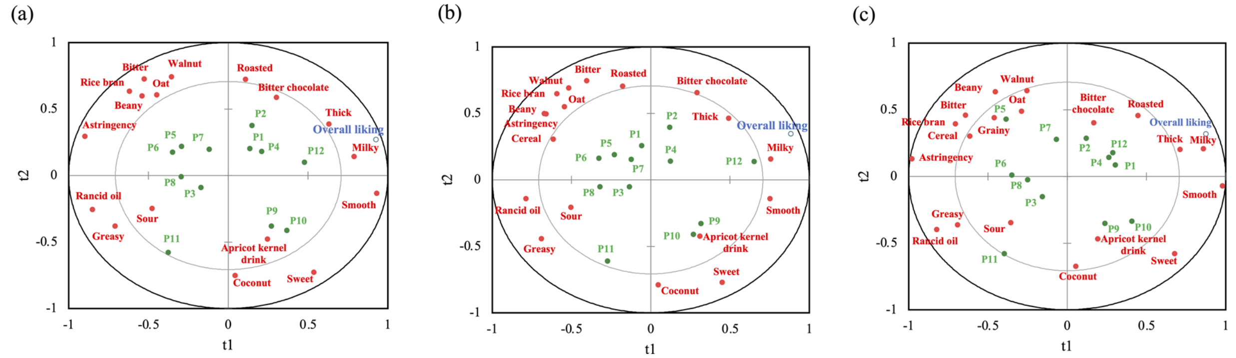

FIGURE 4 Partial least squares regression correlation loading plots of sensory attributes and overall liking of the 12 milk coffee samples assessed by all (a), Cluster 1 (b), and Cluster 2 (c) panelists. The model was derived from attributes as the X-matrix and overall liking as the Y-matrix. The default values for radii correspond to 70% and 100% explained variance. The coefficients of determination (R^2) for (a), (b), and (c) are 0.929, 0.898, and 0.866, respectively.

There were no significant differences between the two clusters in terms of available demographic data including gender, age, pattern of consumption of coffee, milk coffee, and plant-based milk coffee, and purchase intent (Table S2). Felberg et al. (2010) also reported that there were no differences among three clusters of consumers when analyzing demographic data such as income, education level, and gender. However, they found differences in soy beverage and coffee consumption patterns between the three clusters of consumers. It is worth noting that in our study the over half of the panelists (51%) had never had a plant-based milk coffee and that the consumption frequency of plant-based milk coffees for 48% of the panelists was less once per week. On the other hand, many consumers (50%) consumed dairy milk coffees more than twice per week and only 1% of consumers had never had a cup of dairy milk coffee. Since Cluster 2 panelists are high-potential customers for plant-based milk coffees and most of them (44%) had never had a cup of plant-based milk coffee, we propose that increasing the exposure of the Cluster 2-type consumers to plant-based milk coffee will be beneficial for creating new business opportunities for these coffees. Furthermore, our results showed that taste was the primary factor motivating consumers in both Clusters 1 and 2 to purchase a food product. These consumers might be a close match to the "indulgent consumers" mentioned in Jervis et al. (2012), for which the types of milk and sweetener added to latte-style coffee beverages are important attributes.

3.3 | Sensory drivers of liking for plant-based milk coffees

The selection frequencies of CATA attributes and overall liking for the 12 milk coffee samples were analyzed by PLSR, and the results were expressed as a correlation loading plot (Figure 4). In the plot, the attributes between the two circles are important factors, while the attributes inside the inner circle are less influential in determining the panelists' acceptance of the milk coffees (Fauser et al., 2010). PLSR analysis based on the pooled panelist data revealed that smooth, milky, and thick were important drivers of liking for the milk coffee samples (Figure 4a and Figure S2). On the contrary, rancid oil, greasy, astringent, and rice bran were the major sensory attributes lowering the panelists' acceptance of the milk coffee samples (Figure 4a and Figure S2). According to a study by Gorman et al. (2021) conducted in Canada, the sweet attribute was the key driver of liking for plant-based milk (oat, soy, and almond) and dairy coffee samples, while pungent, grassy, earthy, beany, and sour negatively affected consumer liking. The differences between our results and those of Gorman et al. (2021) may be due to the differences in consumer preferences between Eastern and Western countries. It might also imply that texture attributes (smooth, thick, greasy, and astringent) are more important to product design in the Asian market. For the panelists in Cluster 1, bitter chocolate was a more important positive characteristic, while roasted flavor and thick texture were more important positive attributes for the Cluster 2 panelists (Figure 4b,c and Figure S3).

After tasting the 12 milk coffee samples, the panelists were asked to complete the CATA questionnaire to describe their ideal milk (including dairy milk and plant-based milk) coffee and plant-based milk coffee products. As shown in Table 1 and Figure 5, smooth, thick, milky, and sweet were selected by ≥50% panelists to describe the sensory characteristics of the ideal plant-based milk coffee. Three of these ideal attributes (smooth, thick, and milky) matched the perceived desirable attributes identified by PLSR of the 12 samples evaluated, further confirming these attributes as the main drivers of liking for plant-based milk (Figure 4a and Figure S2). Hazelnut, oat, refreshing,

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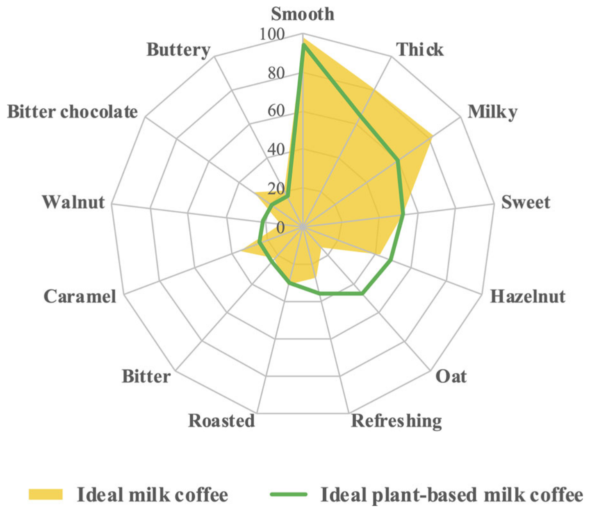

FIGURE 5 Sensory attributes of an ideal milk coffee and plant-based milk coffee. The 13 sensory attributes were selected by ≥20% of participants.

roasted, bitter, caramel, walnut, and bitter chocolate were considered moderate sensory drivers of liking for an ideal plant-based milk coffee as these attributes were selected by 20–49% of panelists. Lastly, sour, mouth coating, grainy, coconut, peanut, rice bran, cereal, almond tea, beany, buttery, and seaweed were not considered drivers of liking for an ideal plant-based milk coffee as they were selected by < 20% of panelists.

Among the 27 attributes in the CATA questionnaire, six of them showed significant differences ($p < 0.05$) in selection frequency between an ideal milk coffee and plant-based milk coffee (Table 1). Compared with an ideal milk (including dairy and plant-based milks) coffee, an ideal plant-based milk coffee was expected to possess fewer milky, bitter chocolate, thick, and sour flavors and more oat and almond tea flavors. It is interesting that many panelists (46%) considered oat flavor to be an important sensory attribute for an ideal plant-based milk coffee (Figure 5). However, the oat flavor in the 12 milk coffee samples was not an important attribute driving overall liking scores for both Clusters 1 and 2 (Figure 4). The results of the ideal products survey revealed the expectations consumers had for milk coffees, while the results of the taste testing revealed the performances of the milk coffee samples presented to consumers. The different results from the ideal products survey and taste testing may imply that the panelists were not satisfied with the current oat flavors in the samples and that there is room for improvement of the oat flavor profiles in the products.

Numerous research efforts are underway to improve the organoleptic, nutritional, and functional properties of the plant-based milks. Stability, removal of off-flavor, inactivation/removal of inhibitors, and shelf-life improvement are four major areas for product improvement mentioned in the current literature (Paul et al., 2020). To the best of our knowledge, there are no research reports investigating the enhancement of the perceptions of dairy in plant-based milks even though dairy attributes are key drivers for persuading a broader segment of the population to accept plant-based milk coffee products. The milk-related flavors and mouthfeels such as milky and creaminess are contributed by short chain fatty acids, fatty acid ethyl esters, lactones, somatosensory compounds, milk fat, and milk protein (Maga & Katz, 1976; Parat-Wilhelms et al., 2005; Potts & Peterson, 2019; Zhang et al., 2016). The milky flavor compounds originate from the feed, cow's metabolism, rumen fermentation, and the degradation of milk constituents during processing (Nursten, 1997). Adding plant-based ingredients and using processing technology to create milk-related perceptions will be critical to the development of successful plant-based milks.

4 | CONCLUSIONS

In this study, the important positive drivers of liking for plant-based milk coffee samples were smooth, milky, and thick. The important negative drivers of liking were rancid oil, greasy, astringent, and rice bran. For all consumers, the more similar a plant-based milk coffee was to dairy milk coffee, the more positive sensory experiences were perceived. The majority of consumers (53.8%) were "dairy milk coffee lovers," who had a strong preference for dairy milk coffees over plant-based milk coffees. There was also a group of consumers (46.2%) classified as "plant-based milk coffee lovers." They enjoyed coffees containing a wide range of milks (both dairy and non-dairy milks) and accepted the plant flavors present in coffee samples. Developing formulas or processing technologies for creating dairy flavors (i.e., milky flavor) and textures (i.e., smooth, thick, and lower astringency) would be beneficial to increasing the popularity of plant-based milks with the general public. Product developers also need to pay attention to the prevention of lipid oxidation and control of emulsification during processing to reduce the sensory perceptions of rancid oil flavor and greasy texture. Lastly, the sensory attributes of oat and soy milk products may be closer to those of "typical" milk products, while those of almond and coconut milk products are closer to those of "flavored" milk products.

AUTHOR CONTRIBUTIONS

Yi-Lin Chung: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Writing – original draft.

Wan-Yuan Kuo: Conceptualization; Formal analysis; Investigation; Methodology; Supervision; Writing – review & editing. **Bo-Kang Liou**: Formal analysis; Investigation; Methodology; Supervision. **Po-Chuan Chen**: Data curation; Investigation; Methodology. **Yu-Chuan Tseng**: Data curation. **Rui-Yu Huang**: Data curation. **Mei-Chu Tsai**: Data curation

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CONFLICTS OF INTEREST

There are no conflicts of interest to be declared in this study.

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