HYPERMETRICS | SENSORY

Pt. 1

Developing a Modern Cannabis Aroma Lexicon

May 2023

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analytica

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Abstract

From cultivators to consumers, there is currently a significant unmet need for more scientific and unbiased communication of aroma profiles across the cannabis industry. Herein we present the largest formal sensory evaluation of cured cannabis flowers and the first steps towards development and deployment of a robust framework to accurately characterize their aroma profiles. First, a preliminary lexicon was created using a focus panel and administrated discussion of real cannabis bud samples. This preliminary lexicon then served as a CATA tool over 48 sessions by trained panelists to describe 36 randomly selected cannabis buds. Pooled data were then analyzed for associations between panel liking and specific aromas, employing a penalty analysis to reveal positive associations with fruit and food aromas and negative associations with agricultural aromas ($p<0.05$). Experimental reorganization of the lexicon promoted collection of more actionable data for cannabis marketers, growers, and salespeople. To the best of our knowledge, this study presents the first cannabis aroma wheel developed using methodology derived from the field of food science validated by trained human panelists. As the cannabis industry collectively grows, the approaches and aroma wheel presented here establishes a rigorous foundational scientific framework for advanced aroma character and consumer liking metrics.

Main Findings

- A comprehensive and reliable tool is needed for new and experienced cannabis users to navigate and describe the complex aromatic profiles of cannabis products.
- Citrus, tropical, and floral type odors yield higher liking scores, whereas certain biological, packaging and agricultural odors may penalize liking.
- In addition to traditional food aromas, nature, materials, and urban-type aromas contribute significantly to cannabis aroma character and their inclusion in the lexicon enables more adequate characterization.

Introduction

As the cannabis industry matures, there is an opportunity for brands and dispensaries to prove that "premium," top-shelf cannabis is more than mere theatrics. Whether you're a new cannabis user or an experienced consumer, you will inevitably face the fabled paradox of choice when purchasing cannabis flower from a dispensary. But the challenge extends beyond the consumer; Budtenders carry the critical responsibility of communicating differences between cultivars. While the Budtenders' own anecdotal experiences with cannabis are useful, a standardized approach to cannabis characterization would better serve the average consumer and the broader cannabis industry. Establishing a set of universally recognized quality attributes for cannabis flower will help new and experienced consumers navigate the labyrinth of strain names and incidental metrics, thereby improving their overall purchasing experience.

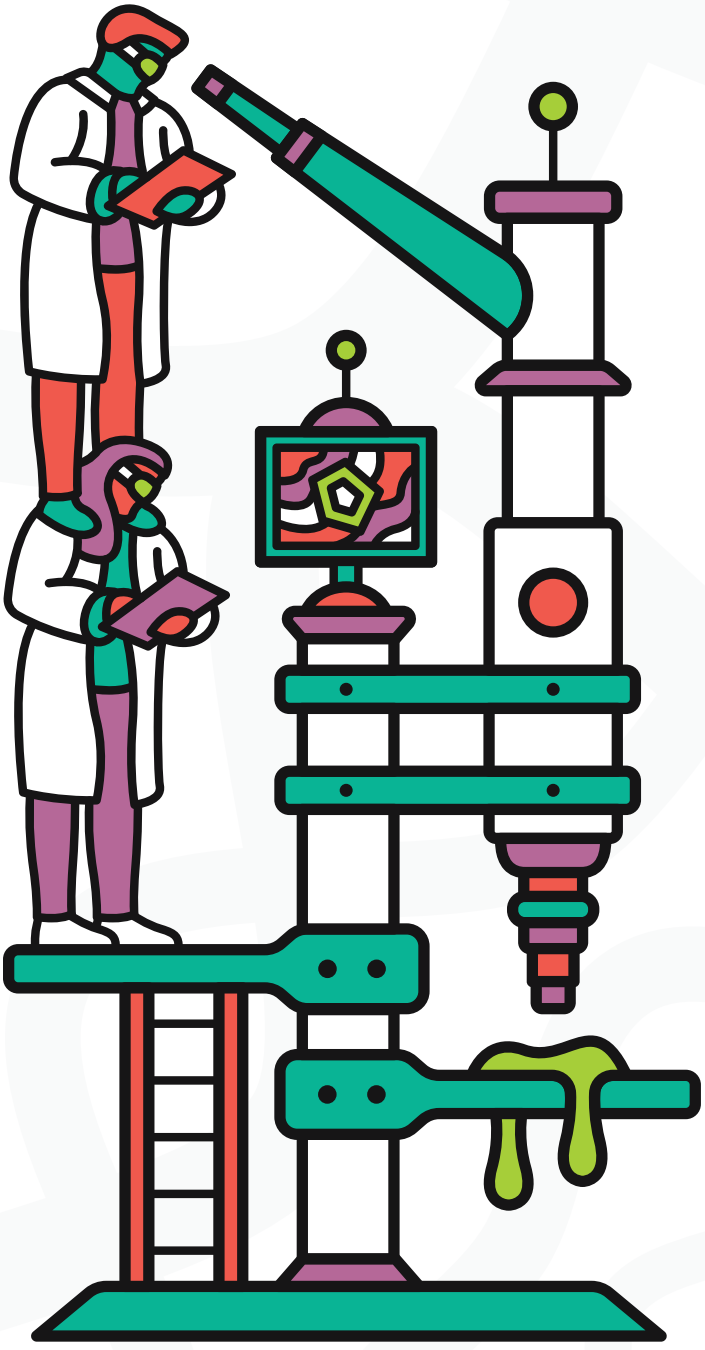
Historically, objective chemical measurements have been widely available and seem to govern the consumer market value of cannabis (i.e., potency of THC/cannabinoids and terpene content). While these metrics are useful, they alone are poor predictors of product quality and user experience. Research into food, tobacco, and other consumables suggests that sensory attributes like taste, appearance, aroma, and texture define the experience. Surprisingly, very little is known about sensory attributes of cannabis flower and their relationship with perceived quality. As such, there is an unmet need in the cannabis industry for reliable measurement of quality and sensory metrics. It is exceedingly likely that texture, aroma, and appearance all play a role in consumer perception of cannabis flower. Of the relevant attributes of cannabis, aroma is perhaps the most important, as it is thought to heavily impact the consumption experience [1] and has been associated with a consumer's evaluation of overall quality [2].

The current prevailing approach for communicating aromatic properties of cannabis flower to consumers is to list the most abundant aromas based on strain genealogy, the presence of certain terpene aroma compounds, and anecdotal reviews of the product by users. By visiting popular sites like Leafly.com, ConfidentCannabis.com, and Eaze.com, consumers can select strains by dominant flavor, such as vanilla or citrus. These categorizations tend to be based on inferences using terpene data and user reviews. It is commonly reported that terpenes provide the basis for cannabis aroma character given their relative abundance [3]. However, this has not been shown empirically despite being a widely held assumption and, given the significant impact that minor odorants can have and synergies between aroma compounds [4], more research is needed.

Outside of these aroma indications, the name of the cultivar itself is often an aroma descriptive (e.g., Garlic Mints) or blend of parent strain names (e.g., Kush Mints, a cross between Bubba Kush and Animal Mints). While these creative names are a cultural staple of the industry, the naming conventions are decoupled from the genomic origins of cultivars and are not universally adopted. As a result, names can be misleading for consumers seeking specific aroma profiles in their cannabis flower. Given the current market landscape, an aroma-inclined cannabis consumer must gamble on whether the indications above will align with their perception.

While this gamble is essentially present for any complex food product (e.g., wine, spirits), other mature markets have made a strong effort to classify products in meaningful ways so consumers can make an informed purchase. For example, red wines are described by species, terroir, and date, allowing consumers to identify personal correlates with specific aromas. Mature markets have the advantage

of years of research to associate expressed traits of ingredient inputs (such as grain, grapes, or fruits) to certain end-product attributes. The cannabis industry would equally benefit from rigorous standardized sensory research. As the cannabis market begins to mature, more robust approaches to sensory characterization must be adopted to engender consumer trust and promote more effective strains. To the best of our knowledge, there is currently no published literature that attempts to characterize how consumers experience and communicate cannabis aroma. As such, there is currently a significant unmet need of a framework for accurately describing and communicating cannabis aroma. Herein we present the first steps towards development and deployment of such a program.



Background

Possibly one of the earliest plants to be cultivate by ancient human civilizations with archaeological evidence dating back to 10,000 years ago, cannabis has grown and travelled the world alongside humans. No time in cannabis history has ever been more exciting (and volatile) than the present. While some countries (e.g., Canada, Mexico, South Africa, etc.) and many US states (California, Colorado, Michigan, etc.) have legalized cannabis, it has a rich international history as part of a robust illegal market.

In the latter half of the 20th century, during the early stages of the archaic revival, cannabis cultivators developed terminology to describe their product and position it as superior to competing products. Instead of "brands" in the traditional sense, different cannabis strains were named creatively to differentiate products from one another (e.g., Blue Dream or Garlic Cookies). At the time, these names were likely partially selected based on aroma properties of the flower strain—with a bias towards any differentiating aromas.

While the naming conventions were effective at the time, this approach has resulted in a muddied and confusing approach to aroma communication by brands in the present legal cannabis markets. If aroma is a major component of the experience, it should be considered early during branding— and play a significant role in describing the experience. Currently, brands commonly suggest the aroma based on largely unrelated evidence (terpenes, geneaology), and assume an associated experience will follow; rather, it may be beneficial to use the aroma to describe the experience, thus positioning the consumer to have that experience (Figure 1).

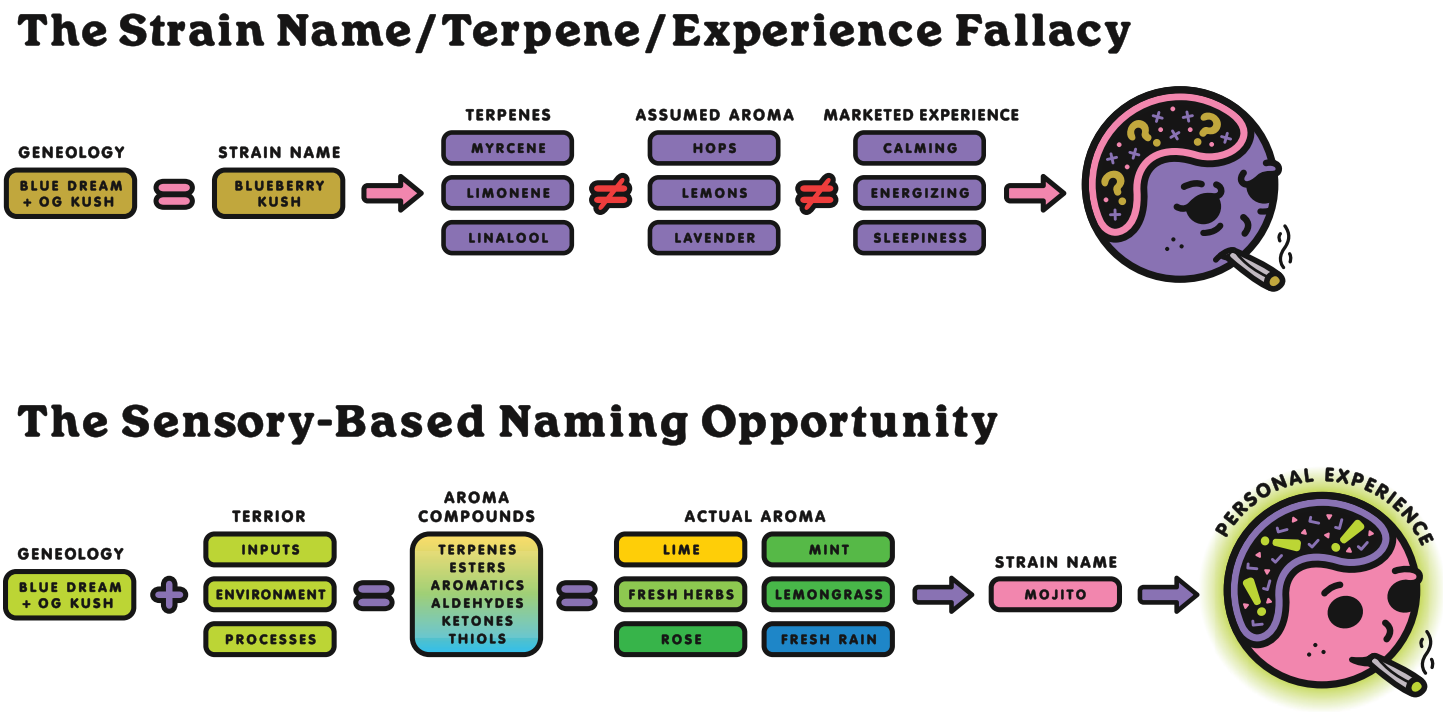


Figure 1. Illustration of the conventional approach to strain branding (top), a proposed evidence-based approach to branding cannabis bud (bottom)

Meanwhile, aroma descriptive techniques and practices have become robust and well-studied in legal consumer goods industries. From trained descriptive sensory panels to human measurement of fractionated headspace (i.e., gas chromatography-olfactory), consumer product industries such as food, automobiles, and hygiene now regularly utilize advanced aroma analysis tools. These tools enable them to make decisions about aroma optimization in products to promote greater pleasurable interactions between the consumer and the product. Being a nascent market, cannabis brands have yet to apply these tools and techniques to cannabis flower. To our knowledge, only a small number of studies are published examining human perception of cannabis aroma [2,5,6]. The result is a market landscape that requires more accurate, informed, and substantiated claims about cannabis aromas and their interactions with the physiological and psychoactive effects of the plant.

There are a great many factors that likely influence consumer cannabis purchase decisions; how are researchers to approach developing a framework for aroma communication that both captures existing norms and leaves room for new consumers to engage? Given the limited nature of the current peer-reviewed literature, there is a clear and critical need for a foundational understanding of cannabis aromas. For example, terpenes are commonly reported to contribute the primary cannabis aroma character, but other classes of compounds (aldehydes [7], ketones [7], sulfurous [8]) are likely to play a role as well [3]. One previous study used a similar approach to classify cannabis using available lexicography [2]. While these studies are useful in their own specific ways, a more holistic approach using both qualitative and quantitative methods is necessary to establish an unbiased foundational framework for effective aroma communication across the cannabis industry, from cultivators to consumers.

Methods

To gain a broad understanding of the varied nature of cannabis flower aroma, a two-phased approach was used. First, a focus panel including research team members, naïve cannabis users, and experienced cannabis users was conducted per the methods described in Meilgaard et al. [9]. The purposes of the focus panel were to elicit perceptions of cannabis flower quality, develop a cannabis aroma descriptor lexicon, and capture interactions between naïve and experienced cannabis users. In the second phase, a quantitative survey of cannabis flower using pool of eligible Cambium employees was conducted in a controlled setting. The purpose of the survey was to refine the qualitatively developed aroma lexicon for use in rapidly screening and characterization of cannabis flower. The methodology used for each phase is described in detail below.

Ethics Statement

All volunteer panelists provided informed written consent prior to participation in this exercise. Panelists did not consume cannabis in any form as part of the study. All panelists were lab employees who had been trained on appropriate handling of cannabis per Michigan state guidelines. Panels were conducted during normal work hours, and panelists were not compensated for their participation beyond their normal salaried earnings. Participation was fully voluntary, and panelists were able to withdraw at any time without penalty or repercussions. Cannabis was disposed of per Michigan state regulations at the conclusion of each session. All data were fully anonymized after collection and before data analysis. Given that only anonymous survey data were collected, and evaluation was limited to non-consumption sensory interaction, the study is exempt from IRB review per CFR 46.104 subpart D.

Focus Panel

Participants

A group of 10 mixed-demographic individuals with varying levels of experience interacting with cannabis were recruited from within Cambium to gain an understanding of how consumers perceive cannabis aroma. Over the course of 10 weekly sessions, the Cambium research team scientists administered discussions regarding the aroma of cured cannabis flower. During each focus panel, cannabis flower samples were provided to touch and smell (but not to consume). Cannabis samples were selected randomly from legally transferred lab samples that had previously passed compliance testing per all State of Michigan regulations. The focus panel was held in Traverse City, Michigan in an open office space with neutral decor.

Panel Sessions

During the first three sessions, panelists evaluated the aroma of randomly selected cannabis flower with the goal of developing a comprehensive list of relevant aroma descriptors. In the process of generating the initial list of aroma descriptors, it became clear that cannabis is not sufficiently described using exclusively traditional food and nature aromas. The panelists described the aroma of most strains presented as predominantly non-food, pungent, or "weedy," indicating that description of the aroma of cannabis flower would benefit from non-traditional descriptors. While considering what aromas to include in the initial lexicon, we encouraged panelists to use nontraditional aroma descriptors, such as memory-tied "nostalgic," [10] as well as more common descriptors, such as "berry." This inclusive approach was selected to encourage novel connections between the experienced cannabis users and the naïve users.

To help expand the lexicon beyond traditional aroma descriptors, three further sessions were held using the same group to probe additional descriptors with the aid of aroma references. These references, such as fresh and rotten fruit, fresh and dried herbs, fabrics, pungent "chemicals," and samples from residential and industrial settings were collected and discussed during each session. Panelists were asked to pay attention to aromas in their daily lives that reminded them of the random flower samples being presented each week.

Upon being provided with additional reference aromas, the Material and Urban categories were added to the lexicon by consensus. The complete list of generated descriptors is presented in Table 1, along with the consolidated aromas and categorizations developed by the research team and the wheel presentation that was employed for sensory evaluation.

Comments made throughout the focus panels were screened by the Cambium research team to consolidate overlapping terms. The result was a single list of hundreds of descriptive terms. The list was then split into digestible categories (tiers) and aligned with terms used in existing aroma literature surrounding known aroma compounds in cannabis flower [11]. Consolidation of highly specific aromas into categories is purported to be a necessary component of successful description of complex, multifaceted aromas by humans [12].

The consolidated list was translated into a multi-tiered donut chart ("wheel") format and participant feedback was utilized to inform future iterations. While participants responded positively to the wheel as a tool to help guide them in aroma description, new strains sampled at the panel continued to present unique aromas, resulting in addition of several further categories. Each session, the research team solicited feedback on missing categories and tracked categories and descriptors that were not commonly utilized.

Table 1. Inclusive Lexicon of Cannabis Flower Descriptors Collected During Focus Panel

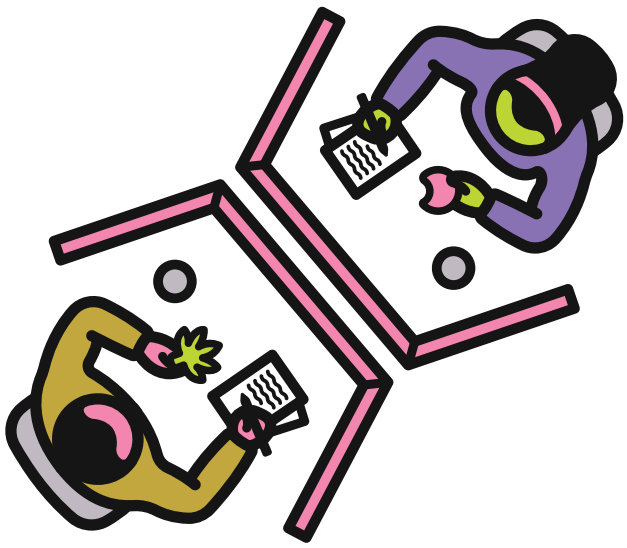
Fruit	
Berry	Strawberry, blueberry, blackberry
Citrus	Orange, lemon, lime, grapefruit
Tropical	Pineapple, ripe banana, mango, guava
Pomme	Apple, pear
Stone fruit	Peach, plum, apricot
Unripe fruit	Green Bananas
Rotting/fermented fruit	Spoilage or intentional fermentation
Dried fruit	Date, raisin, prune
Fat	
Butter	Cooked butter, popcorn, milky/creamy, soured
Oils	Rancid, cooked, canola
Nuts & Seeds	Peanut, sesame, cashew, hazelnut, almond
Meat	
Red meat	Gamey, savory, beefy
Poultry	Raw, savory, chicken, gamey
Fish	Raw, cooked, rotting
Cured meats	Bacon, sausage
Herbal	
Fresh herbs	Parsley, rosemary, basil, dill
Dried herbs	Oregano, basil, thyme
Tea	Dried green and black tea leaves
Spices	Clove, nutmeg, pepper, "spice cabinet"
Agricultural	
Barn	Animal feed, manure
Hay	Dry crops, hay, straw, agriculture
Soil	Damp, potting soil, fertilizers
Wild grasses	Prairie, dry native grasses (switchgrass, bottlebrush), tall weeds
Animal	
Pets	Pet store, pet food, caged animal bedding
Aquarium	Fish food, "domestic" algae & fishy (i.e., not outdoor fresh/saltwater)
Livestock	Horses, sheep, goats, cows—smells originating from the animals rather than their environment
Musk/gamey	Wild animals, scents used for hunting
Roadkill	Non-skunk, decomposing wild animals
Industrial	
Asphalt	Hot blacktop, pothole filler
Exhaust	Burned gasoline/diesel
Car oil	Mechanic, garage, auto grease
Gasoline	Gas station, "fresh" fuel
Burnt rubber	Tire skids, melting plastic/rubber
Metallic	Coins, nuts & bolts, machine shop
Lumber	Treated and processed wood, hardware store
Upholstery	
Fabric/textiles	Laundry, clean linen, "grandpa's couch"
Leather	Leather jacket, football, tanned hide
Vinyl	Flooring, siding, hardware store, rubber gloves, pool toys
Packaging	
Styrofoam	Burnt/melted Styrofoam
Plastic	Rubbermaid tub, melted plastic, cheap packaging
Cardboard	Cardboard box, pizza box, packing boxes
Legend	
Main Category	
Categorical Descriptors	Specific Descriptors

Vegetable	
Leafy green	Lettuce, spinach, kale
Cruciferous	Broccoli, cauliflower, Brussels sprout
Root	Carrot, potato, turnip
Stem	Asparagus, celery
Allium	Garlic, onion, shallot
Squash	Cucumber, pumpkin
Fermented	Pickle, sauerkraut
Grain	
Wheat	Processed wheat grain, any form
Corn	Fresh, canned, popped, cornmeal
Yeasty/fermented	Sourdough, beer
Soy/beany	Dried or canned beans, protein puffs
Condiments	
Mustard	Yellow, honey, whole grain, dried
Horseradish	Spread, fresh
Dressing/vinaigrette	Balsamic, vinegar-y, Italian dressing, ranch dressing
Forest	
Bark	Dry or wet, woody exterior tree parts
Pine	Pine needles, evergreen, Christmas tree
Moss	Wet earthy green, forest floor
Dirt	Dry earthy brown
Foliage	Leaves, bushes, vines, green parts of naturally-occurring vegetation
Fungi	Wild mushrooms, damp earthy
Aquatic	
Algae	Freshwater lakes, pond scum, swampy, surface aquatic vegetation
Seaweed	Underwater vegetation, fresh or saltwater
Sea air/briny	Iodine, salty briny sea breeze, fishy
Residential	
Petrichor	Smell of fresh rain
Sewage	Porta-potty, sewer, septic tank
Fresh-cut grass	Residential, fresh-cut lawn
Mulch	Landscaping, garden, woodchips
Biological	
Urine	Human urine, cat urine, urinal cake
Sweat	Body odor, armpit, sweaty gym sock
Feces	Non-agricultural feces—human, pet, public bathroom
Vomit	Butyric acid, baby barf, pungent stomach acid
Blood/wound	Metallic, pus-like
Mold/mildew	Damp basement, dirty bathroom, moldy refrigerator
Pungent	
Skunk	Skunk spray or skunk roadkill
Dumpster	Comingled trash, rotting food, unidentifiable rot, landfill
Sulfur	Rotten eggs, natural gas
Cheesy	Unpleasant/stinky cheese
Chemical	
Rubbing alcohol	Hand sanitizer, rubbing alcohol, antiseptic wash, nail polish remover
Cleaners	Pine Sol, bleach, ammonia, Windex, Pledge
Paint	House paint, nail polish, craft paint, spray paint
Adhesives	Super glue, Elmer's glue, duct tape adhesive
Developed by a panel of Cambium Analytical Employees over 5 focus panel sessions and categorized and consolidated by the Cambium Sensory Team	

Sensory Evaluation

Panelists

A cannabis sensory evaluation pool was formed internally at Cambium, and 80 employees over the age of 21 were initially recruited into the pool. Panelists were excluded if they were pregnant or currently lacked full olfactory function for any reason. Panelists were primarily young and varied in their cannabis usage rate and type. All panelists were screened for olfactory disfunction using threshold-discrimination-identification (TDI) testing [13]. All panelists were found to be normosmic (TDI > 30). No panelists were excluded for the reasons described above, but 27 employees chose to remove themselves from the pool for personal reasons. The stabilized pool included 53 total members. This pool of panelists was randomly sampled from for all the following evaluation sessions. The demographics of the 53 participant pool members are presented in Table 2.



Four to five panelists were randomly recruited from the Cambium pool for each session, with a maximum of two sessions occurring in a single day. Panelists were seated in booths consisting of a privacy wall, flower samples, and a web-connected device to record responses. Panelists were instructed not to speak to one another and were always monitored by a research administrator. Testing occurred in a segregated conference room with neutral décor in an aroma-free portion of the Cambium's testing lab in Traverse City, Michigan. Any odor build-up was managed using a hybrid HEPA/carbon filtration system (AirOasis, iAdaptAir Small) which was active throughout testing. Panelists were provided evaluation instructions through the survey software with additional clarification from the research administrator if needed. Panelists evaluated flower for six sessions prior to data collection to promote familiarity with flower, sensory testing protocols, and data collection software.

Samples

A total of 48 sessions were held for data collection, resulting in 402 individual observations of 36 different flower samples. Cannabis flower samples for the sensory evaluations were selected randomly from the total supply of flower that passed all state-mandated compliance testing.

A research technician identified viable bulk flower submissions to sample from and collected approximately 50 g of flower, which was then transferred to a secure location within the lab for further processing. The sampled flower was then distributed in 1-gram portions into 2-oz mylar bags with black exterior coating to prevent visual biases. The sample bags were then labeled with three-digit blinding codes and stored in a secure refrigerator for no more than 3 days prior to testing. Panelists evaluated three total flower samples, one at a time, during each 20-minute session.

Table 2. Sensory Evaluation Pool Demographics

Category	Options	Frequency (n=53)
Age	20-30	37
	31-40	15
	41+	1
Sex	Female	23
	Male	30
Frequency of use of cannabis flower, smoked (joint, pipe, waterpipe/bong)	Once a day or more	19
	Once a week	10
	Once a month or less	17
	Never	7
Frequency of use of cannabis flower, vaporized (volcano)	Once a day or more	9
	Once a week	6
	Once a month or less	18
	Never	20
Frequency of use of cannabis oils and extracts (vaporized, vape pens)	Once a day or more	8
	Once a week	10
	Once a month or less	20
	Never	15
Frequency of use of cannabis tinctures for oral use	Once a day or more	2
	Once a week	1
	Once a month or less	22
	Never	28
Frequency of use of cannabis-infused confections (lollipops, gummys, mints, etc)	Once a day or more	3
	Once a week	14
	Once a month or less	27
	Never	9
Frequency of use of cannabis-infused baked goods (brownies, cakes, bars, etc)	Once a day or more	0
	Once a week	6
	Once a month or less	27
	Never	20
Frequency of use of cannabis-infused beverages (seltzers, teas, etc.)	Once a day or more	0
	Once a week	1
	Once a month or less	16
	Never	36
Frequency of use of topical cannabis products (lotion, soaps perfumes, etc	Once a day or more	1
	Once a week	3
	Once a month or less	18
	Never	31
Frequency of use of CBD/ non-psychoactive cannabinoid products	Once a day or more	5
	Once a week	8
	Once a month or less	22
	Never	18
Reasons for cannabis use (all that apply)	To have a fun experience	43
	To alleviate chronic pain	18
	To manage a mental health condition	19
	To focus on important tasks	12
	To improve or initiate sleep	35
	To prevent illness	4
	To improve performance in physical activities	11
	To improve my ability to socialize with others	9
	To enhance my experience with media such as TV, video games, etc.	27
	To unwind after stressful activities such as work	40
	To improve my creativity for art, design, writing, or other creative endeavors	28

Aroma Wheel

The wheel (Figure 2) was printed and laminated for use by all panelists during evaluation. Aroma descriptors were presented in the form of a tiered check-all-that-apply (CATA) format within the data collection software. The inner wheel comprised the four broadest categories— "Food," "Nature," "Urban," and "Material"—and acted as "gateways" to a middle tier of the wheel, which further branched into the most specific tier around the edge of the wheel. The broad gateway categories contained an exit option (e.g., No Food Aroma Present), allowing panelists to disregard that category in any given aroma evaluation. After this gateway, panelists could choose to go as "deep" as they wanted into the wheel, stopping at the gateway itself, or on either of the next two deepest tiers. In other words, panelists could choose to report very granular aromas or "exit" the wheel at broader, unspecified aroma. Panelists also scored their overall aroma liking using 100pt scale.

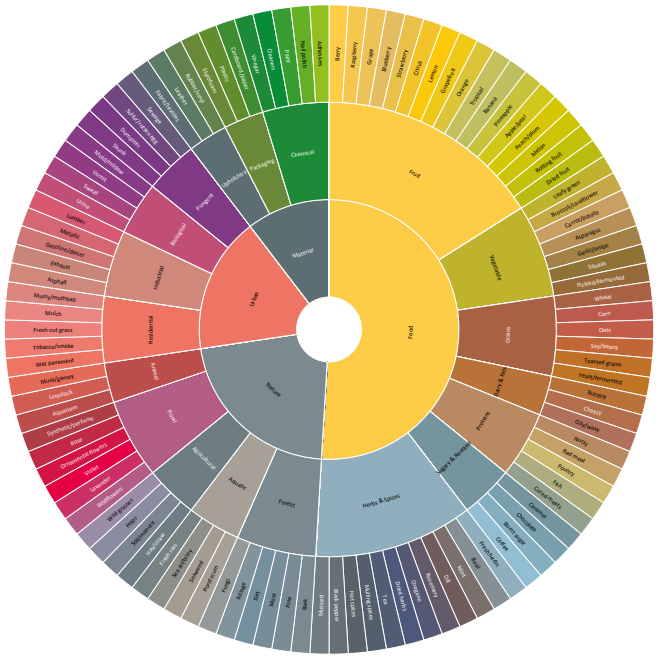


Figure 2. Aroma Wheel

Analysis

All statistical analysis was conducted using either R[14] or XLSTAT Sensory[15]. R was used for large datasets and XLSTAT Sensory was used for specialized sensory data analysis. Data collection was performed using RedJade Sensory Data Management Software [16]. Penalty analyses, frequency analyses, principal component analysis (PCA), and descriptive statistics were calculated using XLSTAT Sensory. $P<0.05$ confidence level was used for all statistics unless stated otherwise. Observation thresholds were reduced to 8% of panelists instead of the traditional 20% given the data from wide range of cannabis flowers samples was pooled. Given the nascent nature of this research, we felt it was important to consider aromas that may be differentiators but were not widely present in the sampled cross-section. For future single sample characterization, a 20% threshold or greater should be used.

Results

During the initial three focus panel sessions, several classes of descriptors were used more often than others: "Greenery," "Wild Grasses," "Fresh-Cut Grass," "Dried Herbs," "Citrus," and "Cleaners." The frequency analysis performed using the formal sensory evaluation data roughly reflected these initial descriptors, with "Hay," "Herbs," "Forest," and "Agriculture" being the most commonly used terms. The frequency count for the categories evaluated are presented in Table 3.

There were three types of CATA selections; gateway categories, subcategories, and terminal aromas. Gateways acted as broadest pools of aromas and were selected to split the total lexicon to make it easier for panelists to find their perceived aroma using the wheel. The subcategories (middle tier of the wheel) are unique in that they do not require great specificity from the panelist while still capturing differentiating aromas between cannabis samples. Terminal aromas are the most specific aromas and are found on the outermost tier of the wheel. If a panelist selects a terminal aroma, no additional subcategories are presented.

The four gateway categories were utilized in different amounts (Table 3); however, given the varying size branches and number of terminal aromas within each, these differences are not indicative of any pattern of common aromas. It is

Table 3. Frequency of CATA responses to cannabis buds

Aroma Descriptor	Number of Panelists Observing (402 total evaluations)	% of panelists observing
Agricultural	213	53.0
Herbs & Spices	208	51.7
Forest	188	46.8
Hay/straw	134	33.3
Fruit	133	33.1
Grains	126	31.3
Residential	121	30.1
Dried herbs	116	28.9
Vegetable	114	23.4
Floral	111	27.6
Industrial	89	22.1
Wild grasses	87	21.6
Packaging	87	21.6
Pungent	86	21.4
Pine	82	20.4
Upholstery	77	19.2
Animal	76	18.9
Dairy & Fats	74	18.4
Dirt	69	17.2
Foliage	67	16.7
Skunk	67	16.7
Wheat	62	15.4
Citrus	60	14.9
Hops	59	14.7
Mulch	59	14.7
Cardboard/paper	59	14.7
Chemical	54	13.4
Toasted grains	52	12.9
Oregano	51	12.7
Moss	51	12.7
Wildflowers	49	12.2
Leafy Green	48	11.9
Garlic/onion	46	11.4
Tea	46	11.4
Black pepper	46	11.4
Biological	46	11.4
Leather	46	11.4
Oats	45	11.2
Proteins	43	10.7
Soil/manure	43	10.7
Livestock	41	10.2
Musk/gamey	40	10.0
Cheesy	39	9.7
Fresh-cut grass	37	9.2
Bark	36	9.0
Gasoline/diesel	36	9.0
Lemon	35	8.7
Tropical	35	8.7
Sugary & Roasted	34	8.5
Lumber	34	8.5
Aquatic	33	8.2
Berry	31	7.7
Nutty	30	7.5
Fresh herbs	30	7.5
Broccoli/cauliflower	28	7.0
"Ornamental flowers"	27	6.7
Musty/mothball	26	6.5
Buttery	24	6.0
Basil	24	6.0
Mold/mildew	24	6.0
Yeast/fermented	22	5.5
Orange	21	5.2
Fungi	21	5.2
Plastic	21	5.2
Asparagus	20	5.0
Oily/waxy	20	5.0
Rose	20	5.0
Cleaners	20	5.0
Dried Fruit	19	4.7
Carrot/potato	19	4.7
Exhaust	19	4.7
Rubber/vinyl	19	4.7
Grapefruit	17	4.2
Sweat	17	4.2
Tobacco/smoke	17	4.2
Adhesives	17	4.2
Blueberry	16	4.0
Dill	16	4.0
Fabric/textiles	16	4.0
Coffee	15	3.7
Rosemary	15	3.7
Lavender	15	3.7
Mint	14	3.5
Mulling Spices	14	3.5
Synthetic/perfume	14	3.5
Pineapple	13	3.2
Corn	13	3.2
Soy/beany	13	3.2
Melon	12	3.0
Burnt sugar	12	3.0
Violet	11	2.7
Wet pavement	11	2.7
Grape	10	2.5
Vinegar	10	2.5
Apple/pear	9	2.2
Squash	9	2.2
Fresh rain	9	2.2
Dumpster	9	2.2
Metallic	9	2.2
Asphault	9	2.2
Paint	9	2.2
Strawberry	8	2.0
Peach/plum	8	2.0
Chocolate	8	2.0
Hot spices	8	2.0
Nail polish	8	2.0
Styrofoam	8	2.0
Cured meats	7	1.7
Raspberry	6	1.5
Red meat	6	1.5
Caramel	6	1.5
Mustard	6	1.5
Aquarium	6	1.5
Pond scum	6	1.5
Sulfur/rotten egg	6	1.5
Sewage	5	1.2
Banana	4	1.0
Rotting Fruit	4	1.0
Pickled/fermented	4	1.0
Sea air/briny	4	1.0
Poultry	3	0.7
Seaweed	3	0.7
Vomit	3	0.7
Urine	2	0.5
Fish	0	0.0

worth noting that while over 90% of samples evaluated were perceived as presenting "Nature" and "Food" aromas, a significant portion (>45% of flower samples evaluated) also presented "Urban" and "Material" aromas. This corroborates the need for diverse aroma categories when characterizing cannabis flower.

The most frequently utilized gateway category was "Food," with "Fruit" and "Herbs & Spices" being the most common branch categories (Table 3). A summary of the impact of the presence or absence of an aroma is presented in Table 4. Presence of "Fruit" aroma was associated with significantly greater overall aroma liking scores (present = 7.04, absent = 5.59, $p<0.0001$). Presence of "Herbs & Spices" was not significantly differentiating ($p>0.05$).

The second most utilized gateway category was "Nature," with "Agriculture," "Forest," and "Floral" being the most commonly utilized branch categories. "Agriculture" was the most used branch category, and its usage was associated with a significantly lower overall liking (present = 5.83, absent = 6.33, $p<0.01$). Presence of "Floral" aroma was associated with greater overall aroma liking scores (present = 6.87, absent = 5.77, $p<0.001$, Table 4). Presence of "Forest" was not significantly differentiating ($p>0.05$).

The third most utilized gateway category was "Urban," with "Residential" being the most utilized branch category. However, presence of "Residential" odors was not associated with overall liking ($p>0.05$), nor was the "Urban" gateway category itself ($p>0.05$). Finally, the "Material" gateway category was the least utilized. However, two branch categories were found to be significant contributors to liking: "Packaging" and "Biological." Presence of "Packaging" was associated with significantly lower overall liking scores (present = 5.64, absent = 6.18, $p>0.05$). Presence of "Biological" was also associated with significantly lower overall liking scores (present = 6.18, absent = 5.66, $p<0.0001$, Table 4).

Several terminal aromas were also associated with overall liking mean changes. The most significant terminal aromas for mean gains were "Lemon," "Tropical," "Citrus," "Pine," "Wildflowers," and "Lumber." The most significant terminal aromas for mean penalties were "Soil/Manure," "Musk/Gamey," and "Dirt." The overall liking mean impact for both category and terminal aromas are visually summarized in Figures 3 and 4, respectively.

Table 4. Relationships between aroma categories and overall aroma liking

Attribute	Level	Mean Overall Liking (100-point scale)	Mean impact	p-value
Floral	Absent Present	63.5 75.3	12%	<0.0001
Fruit	Absent Present	61.5 77.4	16%	<0.0001
Agricultural	Absent Present	69.7 64.1	-6%	0.007
Packaging	Absent Present	68.0 62.0	-6%	0.016
Biological	Absent Present	68.2 55.7	-13%	<0.0001

Green shading represents a significant mean gain when the attribute is present, red shading represents a significant mean drop when the attribute is present ($p<0.05$). Non-significant aromas that fell below the observation threshold for mean comparisons (10%) are not shown. Overall liking was evaluated on a scale from 0 (dislike extremely) to 100 (like extremely).

Discussion

Aroma Usage

In the cannabis industry, there is a strong bias toward describing cannabis aroma in terms of food. Out of the 47 "flavors" used to describe cannabis aroma on "Leafly.com," only six are non-food aromas. The initial construction of our wheel was not immune to this bias; our "Food" category comprised nearly 50% of our wheel, and the "Fruit" branch category alone was larger than the entire Material category. Humans experience some of our most memorable and pleasant odors through food in the form of aromas and flavors. However, in practice, food-like aromas are only a partial constituent of the aroma of cannabis [2]. Thus, the tendency to describe cannabis in terms of food may be a barrier to communication between brands and consumers, which can lead to consumer confusion and even distrust in the cannabis industry. Food aromas, when used to describe non-food items, tend to have a positive connotation. It's much easier to develop branding and advertising around "garlic" than "sulfurous." Therefore, more research is needed to understand how non-food aromas can be used in marketing of cannabis flower.

The prevalence of "Agricultural" and "Hay/straw" type aromas suggests that processing or growing techniques used widely in the cannabis industry may be insufficient at preventing development of "off" aromas. These types of aromas are commonly cited as oxidative degradative compounds in wines [17] driven by the development of aldehydes and furanones during processing. "Hay/straw" was not associated with consumer dislike (despite being observed in over a quarter of the samples) in our data sample, while "Agricultural" was. This suggests that "fault" or "off" aromas associated with food should not be assumed to apply in cannabis. This is further supported by the positive association with "Lumber," which would generally be seen as an "off" aroma in foods, such as coffee.[18]

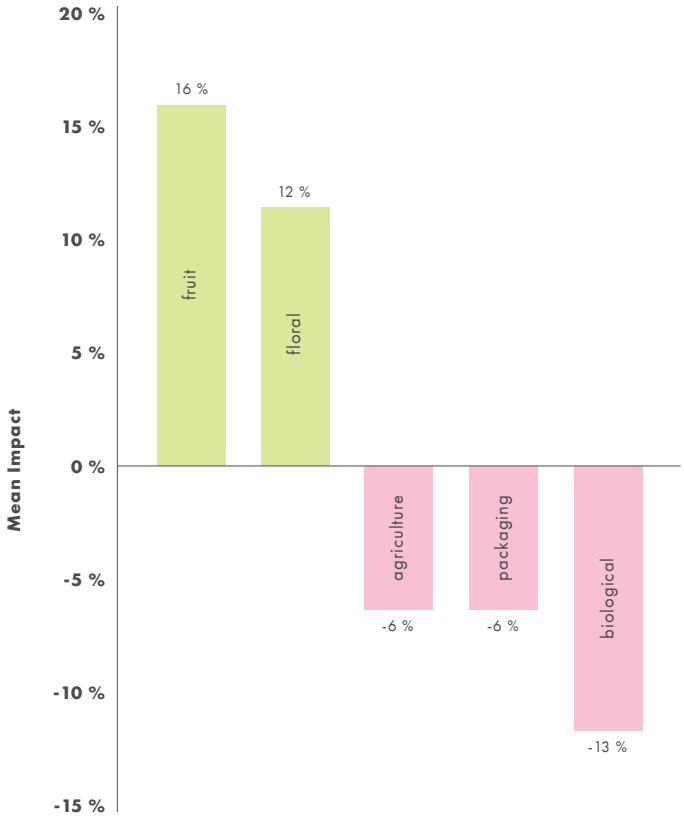


Figure 3. Mean impacts of aroma categories on overall aroma liking.

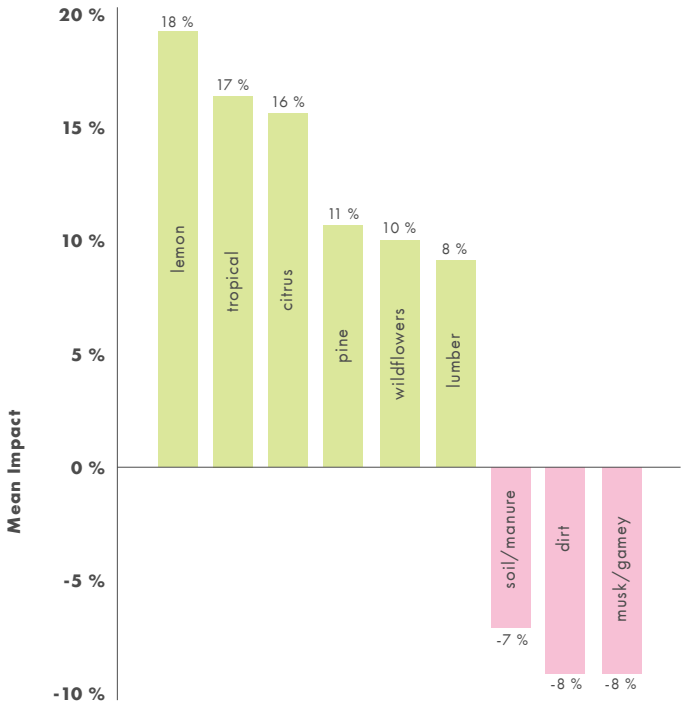


Figure 4. Mean impacts of specific aromas on overall aroma liking.

Post-hoc wheel update

Several factors were considered while refining the initial wheel. Modifications were made considered to the wheel to improve usability, align more closely with existing literature, and further balance tier usage. PCA plots were used to identify certain attributes that may have been redundant and combine them into a single category [19]. A brief literature review of terpene aromas was conducted to improve alignment of existing aroma descriptors in literature and our lexicon. Finally, comments collected throughout testing were reviewed and applied through consensus discussion amongst the research team. The intention for future use of this tool is as a standard for characterization of cannabis strain aroma, and thus the lexicon will continue to evolve as more knowledge is gained regarding cannabis aroma.

A list of 36 relevant terpenes was selected based on frequency of detection in lab analyses. Using a variety of internet references—both scientific [11] and cannabis consumer-centric [20]—an expected aroma profile was developed for each terpene. The current leaders in dissemination of cannabis information for consumers uses these aroma descriptors for each terpene to misguidedly generate expected aromas for cannabis strains based on their terpene content. The terpene aroma descriptors were cross-referenced with the items on our aroma wheel to determine if any relevant descriptors were missing from our wheel. While the majority of the literature-based descriptors were adequately represented on our wheel, we did identify key places where improvements could be made to improve repeatability and promote comparisons across disciplines in cannabis research.

When considering places to add the new terpene-derived aroma descriptors, it was challenging deciding between equally applicable branch categories; for example, "Cedar" would fit into "Forest" if it were being evaluated in its natural state, but as a processed wood it would be more suited for the "Industrial" branch category. Additionally, panelists expressed a need to differentiate even further within "Food" branch categories, such as distinguishing fresh from dried herbs and raw from cooked vegetables. For these reasons, we felt it would be more appropriate to restructure the categories and tier structure of the wheel rather than recategorize new aromas arbitrarily. When building the new wheel, we abandoned the rigid structure in favor of allowing each category to segment itself more organically. As a result, some categories developed two or more branch categories, while others did not have any. While there is a risk of misrepresentation of samples as a collection of independent "notes" (which is generally not the case due to synergistic sensory effects) [12], we wanted to strike a balance between encouraging participants to specify aroma while not forcing them to commit to erroneous specifics.

One frequently referenced aroma descriptor that we had difficulty placing in our wheel was "camphor," as camphor itself is the name of one of the prominent terpenes in cannabis. To say that the terpene camphor (as well as camphene) smell like camphor is meaningless. Both of the aforementioned terpenes contribute to the characteristic aroma of mothballs; however, this aromatic reference would also be meaningless to a person who has never smelled mothballs. In the interest of inclusivity, "Camphor/Mothball" was included under the "Organic" branch category within the "Pungent" category.

Finally, we added an "exit" option to all categories. This option is used when a specific aroma cannot be determined with confidence within a category. For example, if a panelist identified citrus, but could not confidently say "Lemon" or "Orange," they could choose to exit at the gateway cateroys, thus terminating at "Citrus (General)". This will promote differentiation between cannabis which present clearly as with an existing, familiar aroma and those that are more unique and novel (thus likely requiring different branding techniques). The revised and refined wheel is presented in Figure 5.

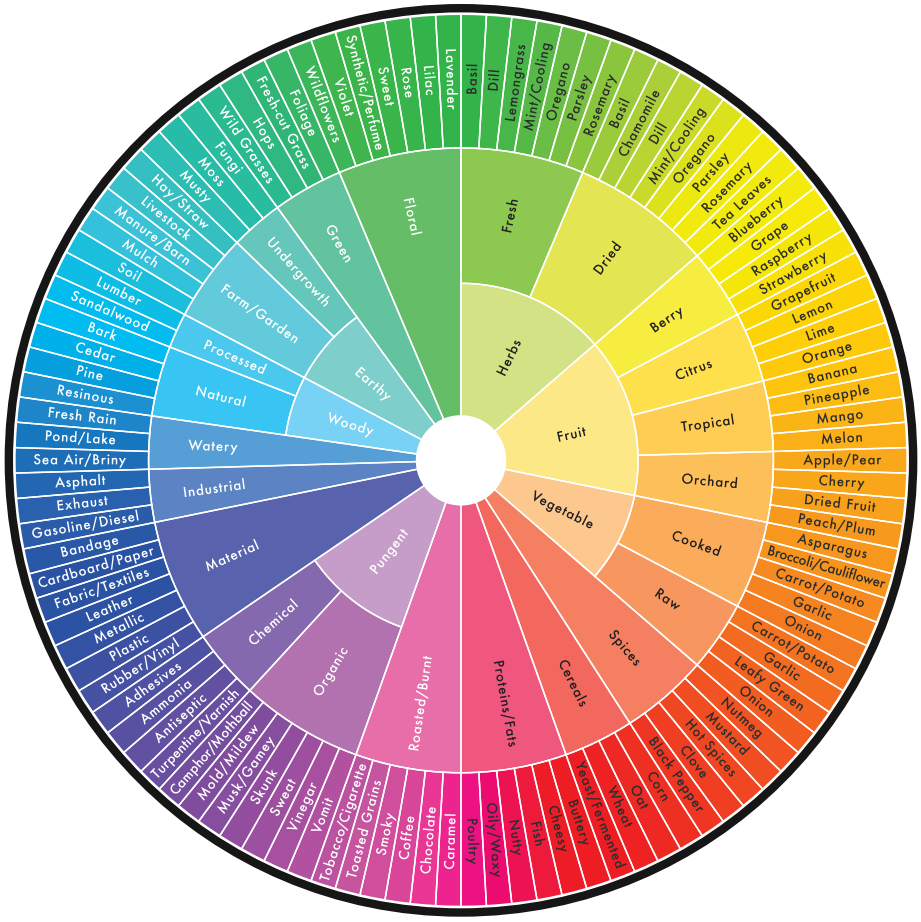


Figure 5. Revised and refined aroma wheel.

Conclusions

The current study is, to our knowledge, the largest formal sensory evaluation of cured cannabis flower. The large sample size, wide variety of strains evaluated, and the robust change-log approach to improving the lexicon are the primary strengths of this study. Nevertheless, some limitations exist; for instance, our panelists (who work with and analyze cannabis daily) may not have been representative of the diverse populations that consume cannabis flower. Generalizations of our findings to the broader cannabis market, particularly those related to hedonics, should be made with caution. Future studies will elucidate differences in language that non-users and experienced users employ to describe cannabis flower as the research will benefit from evaluating these populations independently. Further studies are needed regarding the contexts, methods, and sophistication of cannabis aroma evaluation by consumers to apply findings most effectively in the industry.

To our knowledge, this is the first attempt to develop a cannabis aroma wheel using trained human panelists and a methodology derived from the field of food sensory science. Therefore, it should be expected that modifications be made over time to better capture differences in aroma of cannabis cultivars. As our collective understanding of the biochemical constituents and perceived aromas grows, some categories may need be removed and others added to refine the tool. The functional evolution of the holistic approach presented herein calls for an industry-wide effort to establish an unbiased foundational framework for effective aroma communication across the cannabis market, from cultivators to consumers. We look forward to stewarding the application of this aroma wheel tool and are excited to collect feedback from industry, academic and consumer representatives.

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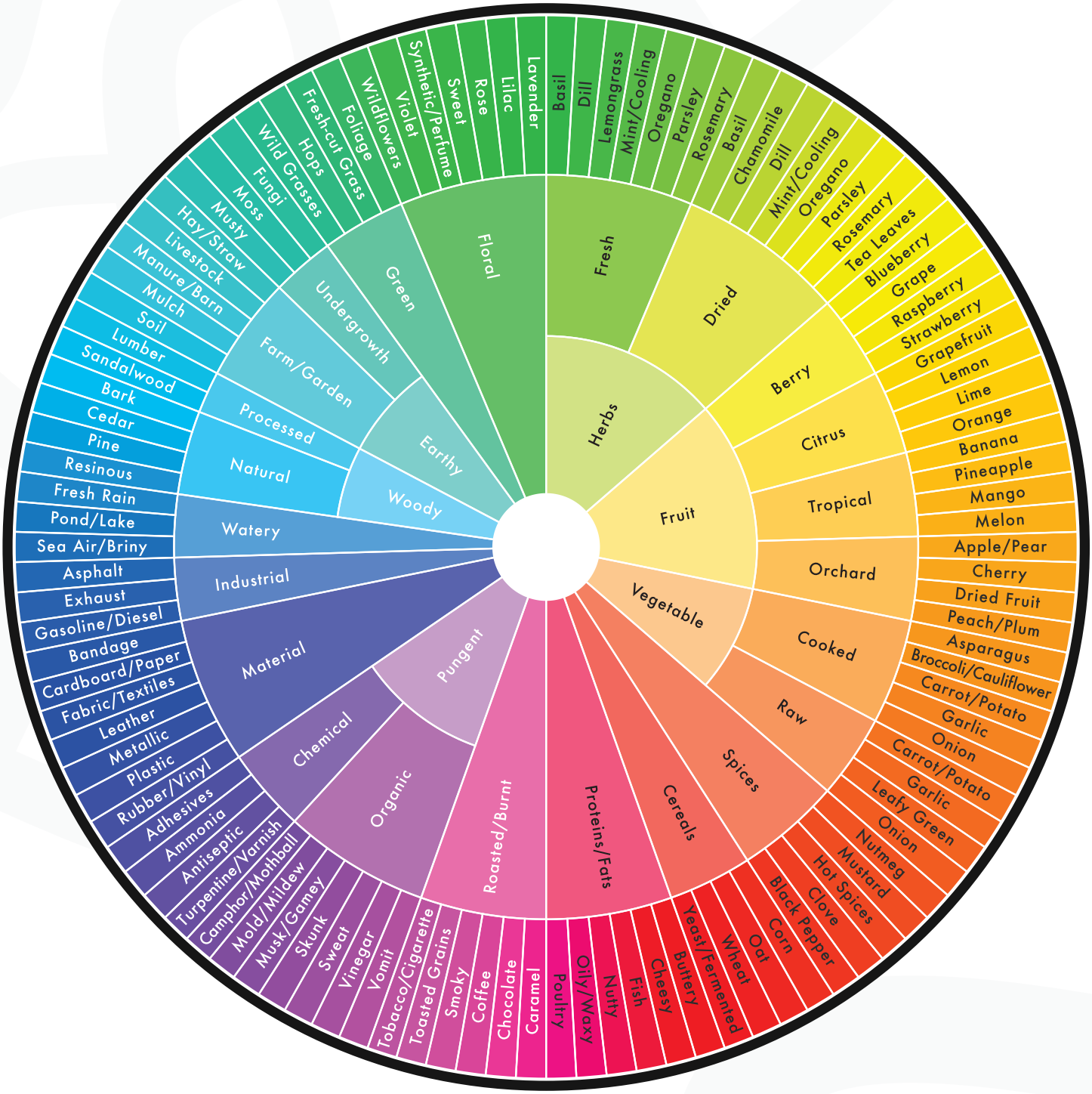

HYPERMETRICS | SENSORY

Pt. 1

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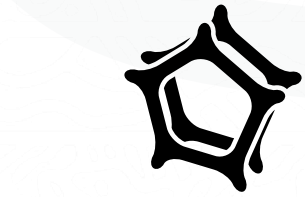

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