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Development of sensory lexicon for aromas of espadin mezcal (*Agave angustifolia*) based on Analytical Hierarchy Process with trained panellists and mezcal masters

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Abstract

The aim of the present work was to develop a sensory lexicon for representative aromas of espadin mezcal using the Analytical Hierarchy Process (AHP) technique. The present work included the participation of 15 panellists and 59 mezcal masters. A profile analysis was performed to compare weights assigned to attributes by these both groups. Following a consensus, a list of 42 aroma descriptors for espadin mezcal was established. The aroma attributes for main criteria (process stage) with the highest hierarchy based on their importance within the process were raw material (agave and herbaceous), cooking (smoky and cooked agave), and fermentation (fruity and alcohol). The profile analysis (parallel, flat, and level profile) indicated a similarity in hierarchies (from AHP) assigned by both groups, panellists and mezcal masters. The AHP technique proved to be a reliable tool for prioritising attributes for the development of a sensory lexicon for mezcal aromas. It allowed for the understanding of how panellists and mezcal master's associated and hierarchised aromas on each process stage.

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Introduction

Mezcal is a distilled alcoholic beverage primarily produced in Mexico from the agave plant (*Agave angustifolia*). Its sensory characteristics, such as smoky flavour, come from the traditional method of roasting the agave hearts in underground pits, lined with hot rocks and wood, before fermentation and distillation (Figure 1). International demand for mezcal in 2021 generated a total of 5.1 million L for the international market, with the United States as the primary export destination (83.78%), followed by the Netherlands (1.93%), the United Kingdom (1.90%), Australia (1.60%), Italy (1.46%), Canada (1.37%), Germany (1.06%), Spain (1.16%), and France (1.46%). In the national market, mezcal consumption reached 3.6 million litres, a 54% increase over 2021. Oaxaca (78.8%) and Puebla (14%) states of Mexico were the main producers. In total, 8,099,591.00 L of mezcal were produced, marking a 3.2% increase in production volume compared to the previous year (COMERCAM, 2022). Mezcal's growing popularity is associated to its reputation, exclusivity, and authenticity (López-Rosas and Espinoza-Ortega, 2018), where aroma and flavour reflect quality and differentiation among mezcals (Barrera-Rodríguez *et al*., 2019). However, current tools for assessing the sensory quality of the final product are limited.

Sensory research in mezcal focuses on its characterisation, consumer acceptability, and relationship between sensory and instrumental measurements (Gschaedler-Mathis *et al*., 2008; Villanueva-Rodriguez and Escalona-Buendia, 2012; García-Barrón, 2012; 2017; García-Barrón *et al*., 2013; Mozqueda *et al*., 2018). However, the need for a cohesive framework, such as a sensory lexicon, to communicate and standardise the evaluation of sensory characteristics of mezcal remains (Meilgaard

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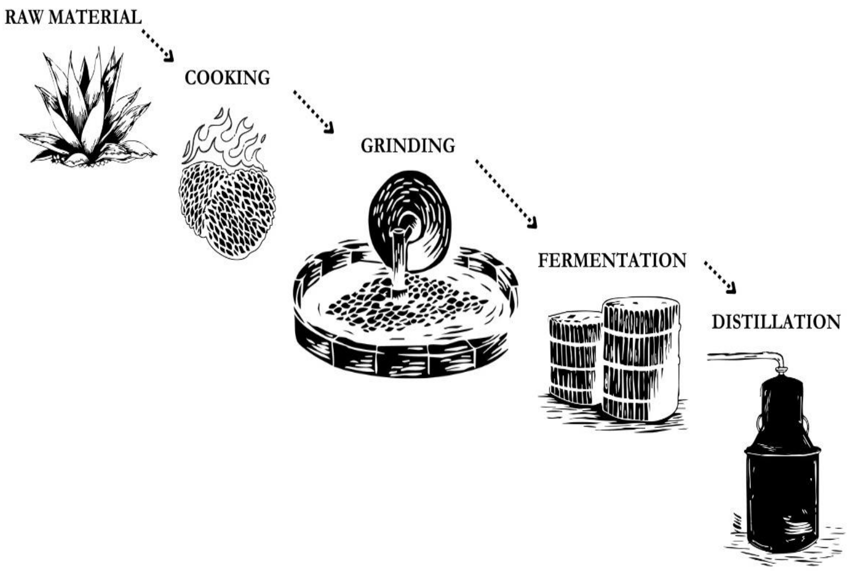

Figure 1. Mezcal production process.

et al., 1982; Noble *et al*., 1987; Lurton *et al*., 2012; Lawless and Civille, 2013; Suwonsichon, 2019). Such measurements are vital to demonstrate the effects of the artisanal production, authenticity, and aromatic quality of the final product (Álvarez-Ainza *et al*., 2017).

A lexicon provides a scientific vocabulary of defined descriptors and standardised evaluation procedures, enabling consistent and accurate information on a product's sensory properties. A sensory lexicon is a guiding tool for research and product development (Lawless and Civille, 2013; Suwonsichon, 2019) that must be organised and validated to faithfully represent the sensory space. A sensory lexicon can be visualised through a sensory wheel, which is largely representative of the sensory attributes of specific food products (Lawless and Civille, 2013; Asih *et al*., 2021).

In sensory science, panellists' judgement is crucial for product analysis. Multi-criteria decision-making techniques offer more accurate characterisation than conventional alternatives. The Analytical Hierarchy Process (AHP), for instance, has been used to select optimal aromas (vanilla, strawberry, and cocoa) in a prebiotic pudding (Gurmeric *et al*., 2013), quality attributes in coffees (Tapiero *et al*., 2017), and sensory quality of ice cream, tea, and chocolates (Karaman *et al*., 2014; Ren and Liu, 2015; Dogan *et al*., 2016). Ramírez-Rivera *et al*. (2020) demonstrated that AHP was effective for the generation of a reliable sensory vocabulary, yielding results similar to the ISO standard 11035. AHP allowed for a higher certainty regarding the judgement of the participants in the selection of attributes when supported by the values of weight (W), Consistency Index (CI), and Consistency Rate (CR). The AHP technique supports experts and consumers by prioritising the sensory attributes based on their food-related experiences.

The objective of the present work was, therefore, to construct a hierarchical sensory lexicon for mezcal aromas using the AHP technique, and to compare responses from a sensory panel versus a group of mezcal masters (experienced mezcal producers). Finally, the construction of a mezcal aroma wheel was proposed as a tool for the sensory lexicon that represents the hierarchy of sensory attributes, divided by category based on their importance from the centre outwards (Koch *et al*., 2012; Larssen *et al*., 2018; De Pelsmaeker *et al*., 2019; Li *et al*., 2019; Mendes Da Silva *et al*., 2019; Swegarden *et al*., 2019; Croijmans *et al*., 2020; Du Preez *et al*., 2020; Silvello *et al*., 2020).

Materials and methods

Panellists and mezcal masters

The recruitment and selection of participants was carried out using a Google® forms questionnaire. Participants were provided with written instructions regarding their participation in the present work. A total of 89 subjects (15 panellists and 74 mezcal masters) participated in three different phases of the present work. The average age of the participants ranged between 26 and 45 years. In line with the Declaration of Helsinki, all participants were fully informed and consented to the study's ethical principles, ensuring respect for their rights, integrity, dignity, and privacy. To prevent any response bias or health risks from alcohol consumption, no samples were ingested during the study. The ISO 8586 (ISO, 2012) standard emphasises that experience allows expert panellists to recognise specific attributes, and make rigorous judgements. For the selection of mezcal masters, a minimum of five years of experience in the evaluation of the sensory properties of mezcal or in the production of mezcal was required. The sensory panel was recruited from the Colegio de Postgraduados community in Campus Córdoba.

Mezcal samples

Certified white or young artisanal mezcals with 45° alcohol by volume were chosen for the study. Mezcal products were produced using ancestral techniques, with no post-distillation process, and met the specifications outlined in the Official Mexican Standard NOM-070-SCFI-2016 (NOM, 2016). Due to their historical and economic importance, espadin (*Agave angustifolia*) mezcal samples were sourced from Oaxaca and Puebla states (the main producers in the national market). The selected mezcals for developing the lexicon were from the brands: (1) Nits-Dov (DOV) from Ejutla de Crespo, Oaxaca; (2) Urakan (KAN); (3) Xochiteco (ECO) from Xochitlán Todos Santos, Puebla; and (4) Las Ruinas (NAS) from the Tepeaca region, Puebla.

Mezcal evaluation protocol

No specific glass for the evaluation of agave distillates has been formally established yet in mezcal official evaluation protocols. However, glass volume and shape can significantly influence aromatic perception of mezcal. Increasing the ratio between the maximum diameter and the opening diameter can enhance aromatic characterisation (Fischer and Loewe-Stanienda, 1999; Cliff, 2001; Delwiche and Pelchat, 2002; Bai *et al*., 2023). In the present work, a Rioja-type glass (capacity: 318 mL; height: 19.8 cm; and opening diameter: 5.5 cm) was used. Aromas were evaluated by holding the glass approximately 2 cm from the nose, aligning the centre with the nasal cavity, and inhaling slowly for 4 sec through the nose, then exhaling slowly through the mouth for another 4 sec. This action was repeated twice by each subject.

Generation of sensory lexicon

The construction of the sensory lexicon must contain specific reference words to adequately describe the mezcal aromas. Affinity and judges' experience play an important role in delimiting the sensory space. A multi-criteria consensus approach was developed to build, refine, select, and rank the attributes.

Phase 1: Preliminary list of terms

An initial term bank was created using a collection of words describing mezcal aromas through a two-stage process; (1) mezcal producers (45) attending the Expo-Mezcal Orgullo de Puebla 2022, were surveyed. Based on their experience in the production and tasting of mezcal, the participants provided information on characteristic aromas for young espadin mezcal. This feedback formed the first list of terms. (2) The sensory panel generated a second list of terms in alignment with the ISO 11035 (ISO, 1994) standard. Together, these lists constituted the full preliminary list of terms.

Phase 2: Descriptor refinement and selection

The preliminary list of terms was reduced based on the frequency of appearance, and the identification of inappropriate terms for product description. Hedonic, quantitative, irrelevant, confusing terms, or terms not associated to the product were eliminated in consensus with the panel (ISO 11035; ISO, 1994). Using these criteria, a first list of refined terms was obtained. Subsequently, 15 panellists and 16 mezcal masters participated in a second refinement process using the Check All That Apply (CATA) technique, by selecting the more representative product descriptors. CATA has high discriminatory power, effectively reducing large term lists (under 50 words), and eliminating less relevant terms (Jaeger *et al*., 2015). This final list was used as a basis to define and hierarchise the descriptors for the mezcal aromas' sensory lexicon.

Phase 3: Descriptor hierarchisation

The AHP was used as a multi-criteria decision-making technique to establish descriptor prioritisation levels. The main criteria matrix was based on the mezcal production process, and included five criteria: raw materials, cooking, grinding, fermentation, and distillation. The sub-criteria corresponding to each criterion were assigned from the final list generated with CATA. These were assigned based on each criterion's relevance within the process, and under participants' consensus.

Hierarchy data were collected using the SCD-AHP-V1 software, a proprietary online data acquisition tool for AHP from Colegio de Postgraduados, Campus Cordoba (registration no.: 03-2023-112712020100-01, Mexico). Participants (eight panellists and 13 mezcal masters) assigned importance levels for pairs of terms using the Saaty scale (Saaty, 2008). Each criterion was individually evaluated by each participant. Weight (W), Consistency Index (CI), and Consistency Rate (CR) were compared between both groups. Based on the CR, the final descriptor hierarchy was determined. Responses of both groups were averaged and organised to construct an aroma wheel for espadin mezcal.

Data analysis

To obtain the relative weight, the comparison matrix was normalised by dividing the individual values in the table by the sum of each column (Vargas, 2010; Ramírez-Rivera *et al*., 2020). After normalisation, row sums were divided by the number of elements (arithmetic mean) to create a priority vector or eigenvector indicating the weight for each criterion or sub-criterion (Vargas, 2010; Ramírez-Rivera *et al*., 2020).

Consistency was assessed using the CI = (λmax - n) / (n - 1), with n representing the matrix size. The maximum eigenvalue or maximum priority value (λmax) was calculated by summing of each element in the eigenvector, and dividing it by its column total in the original comparison matrix.

The CR was then calculated by dividing the CI by the Random Consistency Value (RI) based on matrix size (number of criteria). The RI values were drawn from the Random Consistency Indices Table. The procedure and data were deemed reliable when the CR was within 0.1 to 0.2 (10 - 20%) (Saaty, 2008; Vargas, 2010). Calculations for W, CI, and CR were processed in XLSTAT version 2020 (Addinsoft, New York, NY, USA). The espadin mezcal aroma wheel was constructed using the R programming language version 4.2.3 (R Core Team, 2023) with the RStudio Integrated Development environment (version 2023.06.0), and plotted using the plotly package (Sievert, 2020).

Results and discussion

Sensory lexicon

A total of 570 words were collected as a preliminary list of terms. Initially, synonyms and adjectives were discarded, reducing the list to 59 terms. Next, confusing terms were also excluded, reducing the list to 54 terms. Further refinement using the CATA methodology allowed panellists to select terms most representative of mezcal aromas, resulting in a final list of 42 descriptors, each with an appearance frequency above 2% (Table 1). These terms were defined as the aroma descriptors for espadin mezcal.

Aromas such as agave, herbaceous, floral, smoky, cooked agave, burnt, sour, palm, floral, sweet, caramel, ash, humidity, wood (cedar), leather, citrus, lemon, rancid, alcohol, and irritation have been reported as mezcal descriptors in previous research (Villanueva-Rodriguez and Escalona-Buendia, 2012; García-Barrón, 2012). However, other descriptors such as agave nectar, honey, mineral, toasted, firewood, charcoal, earthy, mud, spices, pepper, seeds, fermented, pulque, apple, peach, plum, oak, petrichor, lactic, balsamic, mint, lemon, and orange have not been reported in previous research, and represented novel descriptors unique to this lexicon.

The agave, smoky, and sour attributes allow mezcals to be differentiated when their sensory attributes are compared (Gschaedler-Mathis, *et al*., 2008; Mozqueda-Balderas *et al*., 2018). Even though trigeminal sensations are not properly aroma attributes, they can be associated with the content of ethanol and other alcohols in mezcal. Also, the term irritation in the nose is worth to consider as it is the first sensory perception when evaluating mezcal, and can help to determine the strength and quality of mezcal (Villanueva-Rodriguez and Escalona-Buendia, 2012).

Importance of terms based on Analytical Hierarchical Process technique

Comparison of weights between panellists and mezcal master's for main criteria

Based on the profile analysis, the *p*-values when testing for parallel profile (0.3641), flat profile (0.1881), and level (0.749) indicated that the responses between both groups (panellists and mezcal masters) were not significantly different, confirming there was homogeneity regarding the hierarchy of the weights assigned by the two groups (Figure 2).

Table 1. Frequency of appearance per term.

Attribute	Proportion (%)	Attribute	Proportion (%)	Attribute	Proportion (%)
Alcohol	21.89	Firewood	5.62	Black pepper	2.32
Sweet	15.30	Spices	5.62	Seeds	2.32
Fruity	14.72	Peach	5.42	Mexican hawthorn	1.16
Sour	12.98	Oak	5.23	Peppermint	1.16
Agave	12.78	Toasted	4.84	Tepache	1.16
Smoky	11.81	Balsamic	4.65	Clove	1.16
Citric	10.07	Agave honey	4.65	Plastic	1.16
Floral	9.88	Irritation	4.45	Cheese	0.97
Rancid	9.68	Petrichor	3.49	Chocolate	0.97
Humidity	9.30	Honey	3.29	Sider	0.39
Apple	9.30	Ash	3.10	Cocoa	0.39
Wood	8.91	Mineral	3.10	Coffee	0.39
Fermented	8.33	Plum	2.91	Bread	0.39
Cooked agave	8.13	Burned	2.71		
Leather	7.94	Charcoal	2.71		
Herbaceous	7.55	Mint	2.52		
Lemon	7.17	Lactic	2.52		
Orange	6.00	Palm	2.32		
Earthy	5.81	Mud	2.32		
Caramel	5.62	Pulque	2.32		

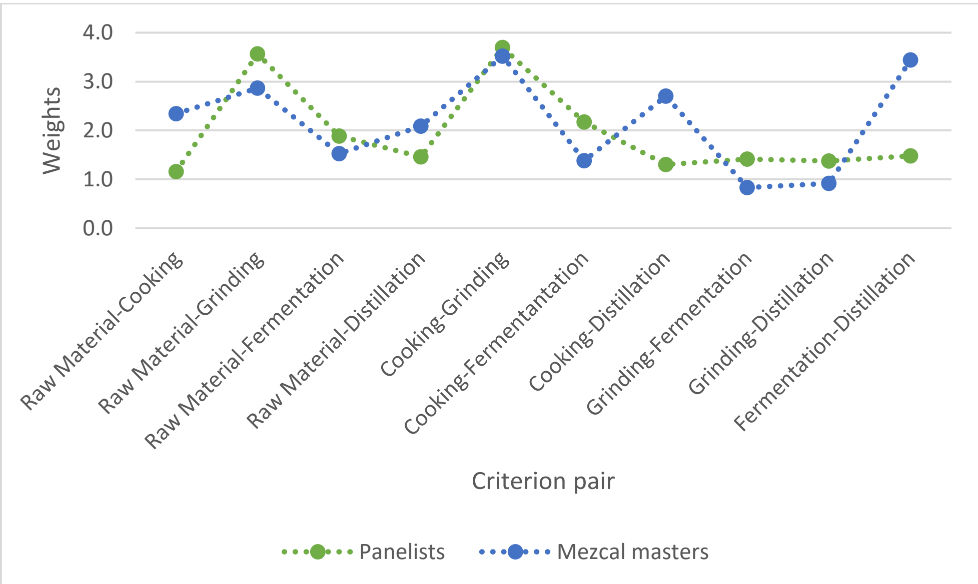

Figure 2. Profile analysis plot comparing panellists' and mezcal masters' weights (W).

Hierarchy of aroma attributes in mezcal

Weights for aromas in main criteria (mezcal processing)

The resulting weights for the main criteria matrix are shown in Table 2. A similar hierarchy was observed in the responses from the panellists and mezcal masters for natural, cooking, and fermentation criteria. A difference was found in the hierarchy for the grinding criteria evaluated by the mezcal masters. Likely, this difference in the weight value for grinding (11.92) was due to the familiarity of mezcal masters with the mezcal production (González Seguí *et al*., 2019).

Table 2. Weights (W) from AHP for main criteria.

Main	Panellist (%)	Mezcal master (%)
Raw material	30.44	32.56
Cooked	25.66	26.48
Fermentation	19.85	18.05
Distillation	12.40	11.00
Grinding	11.65	11.92

Weights for aromas associated to natural agave as raw material

Both panellists and mezcal masters showed similar weight distributions for raw material attributes (Table 3). These aromas included attributes such as agave, herbaceous, floral, and mineral, which are characteristic aromas of mezcal, and usually associated with compounds such as fructans, terpenes, saponins, metals, and minerals naturally present in the raw material. Among the different species of agave, the concentrations of these compounds vary.

The mineral attribute of agave appeared associated to raw material, with weight values of 3.27 for panellists and 3.62 for mezcal masters (Table 3). Minerality is a rare and complex attribute in sensory research. However, phosphorus, sodium, potassium, calcium, magnesium, copper, manganese, zinc, cadmium, and lead have been identified in raw agave. During cooking, fermentation, and distillation, up to 99.3% of these compounds are lost (Velasco, 2017).

Table 3. Weights (W) for natural agave as raw material.

Aroma	Panellist (%)	Mezcal master (%)
Agave	11.76	12.55
Herbaceous	9.82	10.16
Floral	5.58	6.23
Mineral	3.27	3.62

Weights for aromas associated to cooking process

Results for aromas associated to the cooking process are presented in Table 4. A similar trend in weights was found when comparing panellists and mezcal masters. The attributes with the relevant weights were smoked (3.44 and 3.69), cooked agave (2.85 and 3.13), toasted (2.61 and 2.52), palm (2.31 and 2.30), and burnt (2.06 and 2.18) for panellists and mezcal masters, respectively. It was also observed that the attribute weights had a logical order corresponding to the cooking process. The production of aromatic compounds during cooking occurs when fructans undergo hydrolysation, releasing fermentable sugars such as fructose, glucose, xylose, and maltose. Sugars exposed to temperatures higher than their melting point undergo pyrolysis or caramelisation. The interaction of sugars with proteins through the Maillard reaction generates characteristic aromatic volatile compounds in mezcal (Vera-Guzman *et al*., 2009; 2010; 2018; Chavez-Parga *et al*., 2016). The volatile compounds generated in these reactions can evoke attributes such as cooked, toasted, palm, burnt, and caramel agave. However, the caramel attribute (one of the main attributes generated during cooking) obtained the lowest value in the category (1.05 and 1.10).

Attributes such as smoky, firewood, charcoal, ash, spices, pepper, and seeds derive from the thermolysis of cellulose, hemicellulose, and lignins contained in the agave and the wood used for cooking. Depending on the type of wood and the concentration of compounds (phenols and aldehydes), the sensory properties usually vary (Zhang *et al*., 2020).

Table 4. Weights (W) for aromas associated to cooking process.

Aroma	Panellist (%)	Mezcal master (%)
Smoky	3.44	3.69
Cooked agave	2.85	3.13
Toasted	2.61	2.52
Palm	2.31	2.30
Burned	2.06	2.18
Wood	1.99	2.08
Charcoal	1.93	2.07
Earthy	1.89	1.70
Ash	1.62	1.69
Spices	1.45	1.60
Black pepper	1.27	1.25
Seeds	1.19	1.18
Caramel	1.05	1.10

Weights for aromas associated to grinding process

The attributes included in the grinding criterion were agave honey, honey, and sweet. The contribution of this criterion to the impact of mezcal aroma is significant due to the weights of its sub-criteria. The weights of the attributes were higher than others due to the number of sub-criteria in the category. Similar weights were observed between the agave honey (5.18 and 5.42) and honey (4.42 and 4.46) attributes for panellists and mezcal masters, respectively. These attributes come from the extraction of juices from cooked freckles. In this part of the process, the grinding method is carried out with a mallet, knife mill, or stone mill. The sugar contents in the must vary, and affect the production of volatile aromatic compounds (Durán-García *et al*., 2007; Caballero *et al*., 2013).

Weights for aromas associated to fermentation process

Table 5 shows the attribute weights for the aroma category associated to fermentation process. There was a variation in the hierarchy of attributes obtained by the panellist and the mezcal masters. The difference was mainly observed in the responses for the attributes associated to ethanol, methanol, and higher alcohols. The alcohol attribute is directly related to the amount of ethanol in mezcal, which is the major volatile compound previously reported (Vera-Guzmán *et al*., 2010; González Seguí *et al*., 2019).

The fruity attribute had similar values between both groups. The weight for the alcohol attribute indicated higher relevance for the sensory panel (1.82) compared to the response of the mezcal masters (1.44). For mezcal masters, alcohol and fermented attributes had no difference in weight. However, for the sensory panel, the alcohol attribute had a higher hierarchy than the fermented attribute. The volatile compounds that intervene in the perception of attributes such as alcohol and fermented are usually complex. They correspond to major compounds such as ethanol, propanol, 1-propanol, 1-butanol, isoprenol, amyl alcohol, among others (De León-Rodríguez *et al*., 2006). Even though the volatile compounds associated with an attribute may be complex due to their quantity or concentration, there are attributes detectable due to their familiarity in other products. This is the case of the apple and peach attributes related to ethyl acetate. This compound is present in distilled agave drinks, and affects the perception of fruity aromas. However, other esters and terpenes may be involved. Among the esters with an impact on this type of aromas are the ethyl ester of octanoic acid, ethyl ester of decanoic acid, and ethyl ester of dodecanoic acid. Terpenes such as linalool, α-terpineol, citronellol, and geraniol can also influence the perception of some floral, fruity, or sweet notes (Vera-Guzmán *et al*., 2010; 2018).

While major compounds can serve as quality indicators, in mezcal, artisanal techniques introduce a higher variability in minor compounds, contributing to mezcal's authenticity (Lachenmeier *et al*., 2006). Some attributes within this criterion corresponded to minor compounds within mezcal. In contrast, drinks such as tequila have little variability in the generation of volatile compounds due to the process standardisation (Villanueva-Rodriguez and Escalona-Buendia, 2012).

In mezcal, some volatile and non-volatile chemical compounds have been identified as quality attributes, attributing some notes that can be perceptible such as organic acids, alcohols, ketones, aldehydes, esters, phenols, and terpenes. However, the notes and intensities (sensory attributes) will depend on the fermentation batch as particular organisms may predominate. Therefore, the generation of chemical compounds from each process may also originate in the raw material, and vary between species and climatic conditions (Chavez-Parga *et al*., 2016; Vera-Guzmán *et al*., 2010; 2018).

Table 5. Weights (W) for aromas associated to fermentation process.

Aroma	Panellist (%)	Mezcal master (%)
Fruity	1.54	1.52
Alcohol	1.82	1.44
Fermented	1.68	1.44
Apple	1.22	1.21
Peach	1.22	1.17
Humidity	1.37	1.10
Wood	1.23	1.04
Oak	1.15	0.93
Pulque	0.98	0.96
Plum	0.91	0.97
Leather	1.07	0.94
Petrichor	0.99	0.87
Lactic	0.97	0.87
Balsamic	0.79	0.74
Citric	0.67	0.64
Rancid	0.71	0.65
Mint	0.55	0.54
Lemon	0.52	0.54
Orange	0.47	0.47

Weights for aromas associated to distillation process

The distillation criterion included only three attributes: irritation, mud, and sour. The weight values assigned by the panellists and the mezcal masters for the irritation attribute were 6.59 and 5.29; the mud attribute obtained values of 3.11 and 4.47, and the sour attribute obtained values 2.71 and 2.25, respectively.

Distillation conditions (copper stills and clay pot distillation) and rectification (distillation cuts) influence the content of volatile compounds, particularly ethanol and methanol contained in mezcal. The irritation attribute can likely be associated to the concentration of methanol and higher alcohols. Generally, in the second distillation, "cuts" are made; from which three fractions are obtained (tips, body, and tails). The body and tips are mixed to obtain an alcohol content of 45° or higher. Distillation can remove up to 99% of methanol (Lachenmeier *et al*., 2006; González Seguí *et al*., 2019; Arellano-Plaza *et al*., 2022). In rectification, a significant percentage of methanol is added to reach the desired sensory properties of mezcal.

The clay attribute may have its origin in clay pot distillation. Similarly, distillation with copper stills may increase the copper concentration in mezcal due to the release of particles (Velasco, 2017). The sour attribute corresponds to the acetic acid contained in mezcal. Sometimes it is part of the majority compounds, and its presence has been attributed to *Acetobacter* bacteria (Vera-Guzmán *et al*., 2009).

Consistency Index (CI) and Consistency Rate (CR)

The CI and CR indicated high reliability in the responses from both panellists and mezcal masters (Table 6). Overall, the CI and CR values for both groups were similar. However, values from the distillation criterion evaluated by the mezcal masters were slightly different. The CI (0.056) was close to the random CI (0.058). The CR had values close to 10, which suggested potential inconsistencies. Values for the CI close to the value of the random CI (RI) can be considered unreliable. When the CR is adequate, its value is maintained between 0 and 10%. On the contrary, higher values indicate inconsistency. The CI and CR values suggested that responses from both groups were homogeneous and adequate for most criteria.

The responses of both groups were combined to improve the performance of the obtained values. This generated new weight values for the criteria: natural (34.46), cooking (26.93), fermentation (16.52), distillation (12.23), and grinding (11.86). The consistency indices and global Consistency Rates are shown in Table 7. A decrease in the IC and TC values was observed for the main criteria, cooking, fermentation, and grinding. The distillation criterion was maintained with a CR value close to 10%.

Table 6. Consistency Index (CI) and Consistency Rate (CR) by group.

Criterion	Panellist CI	Mezcal master CI	Panellist CR	Mezcal master CR
Main	0.054	0.062	4.80	5.48
Natural	0.037	0.040	4.15	4.50
Cooked	0.074	0.059	4.74	3.76
Fermentation	0.084	0.081	5.19	5.0
Distillation	0.009	0.056	1.6	9.63
Grinding	0.009	0.002	1.52	0.43

Table 7. Global Consistency Index (CI) and Consistency Rate (CR).

Criterion	Consistency Index (CI)	Consistency Rate (CR)
Main	0.041	3.65
Natural	0.039	4.33
Cooked	0.059	3.75
Fermentation	0.080	4.94
Distillation	0.053	9.06
Grinding	0.002	0.37

Judgement scales have been shown to play an important role in AHP. The use of new scales has been suggested to achieve better judgements based on hierarchy and consistency of data. Consistency is increased when the square root or logarithmic judgement scale is applied to improve consistency measures. The power or geometric judgement scale can also be adopted to find differences between the criteria and sub-criteria. The judgement scale applied by Saaty remains adequate for a reliable approximation (Franek and Kresta, 2014).

Hierarchy of aroma attributes for espadin mezcal

Table 8 shows the weights obtained by AHP through the average response of both groups (panellists and mezcal masters). The distillation and grinding criteria contributed to the attributes: irritation (5.90), mud (4.00), agave nectar (5.45), and honey (4.44). Cooking provided the attributes smoked (3.76) and cooked agave (3.17). The attributes agave (12.37), herbaceous (10.29), floral (6.16), and mineral (3.63) belonging to the raw material criterion were part of the highest positions in the hierarchy. The fermentation criterion did not provide any attribute in the first ten positions of the table. Fermentation attributes had the lowest position in the hierarchy. Particularly, hierarchisation allowed us to understand the effect of the production process on each attribute in the sensory profile of espadin mezcal.

Table 8. Weights (W) for espadin mezcal aromas.

Attribute	Weight (%)	Attribute	Weight (%)
Agave	12.37	Alcohol	1.37
Herbaceous	10.29	Fermented	1.33
Floral	6.16	Black pepper	1.27
Irritation	5.90	Seeds	1.27
Agave honey	5.45	Caramel	1.13
Honey	4.44	Apple	1.07
Mud	4.00	Peach	1.06
Smoky	3.76	Humidity	1.05
Mineral	3.63	Wood	0.95
Cooked agave	3.17	Oak	0.87
Toasted	2.55	Pulque	0.87
Sour	2.33	Plum	0.86
Palm	2.27	Leather	0.86
Burned	2.16	Petrichor	0.81
Firewood	2.13	Lactic	0.78
Charcoal	2.07	Balsamic	0.69
Sweet	1.97	Citric	0.58
Earthy	1.82	Rancid	0.57
Ash	1.72	Mint	0.49
Spices	1.61	Lemon	0.49
Fruity	1.39	Orange	0.42

Overall, research on mezcal has focused on characterising the fermentation process, attributing a direct impact on sensory properties, and suggesting that most of the aromatic volatile compounds are closely linked to the action of microorganisms within the fermentation (Vera-Guzmán *et al.*, 2010; González Seguí *et al.*, 2019). However, recent evidence suggested that the generation of relevant aromatic volatile compounds may also have a different origin (pyrolysis, hydrolysis, esterification, among others) (Zhang *et al.*, 2020).

Through the AHP technique, the attributes with the highest impact on the sensory properties of espadin mezcal were found. It was identified that the attributes with the highest position belonged to minor compounds (39). The major compounds were represented in five attributes (irritation, sour, alcohol, fermented, and fruity). To illustrate the results of AHP, an aroma wheel of espadin mezcal was constructed (Figure 3). The distribution of attributes was carried out by semantics based on their weights. The aroma wheel includes four levels. The first level in the centre of the aroma wheel contains the stages of mezcal production. The second level of the wheel contains attributes that represent the highest-ranking major and minor compounds. The third and fourth levels of the wheel include attributes that belong to the minor compounds.

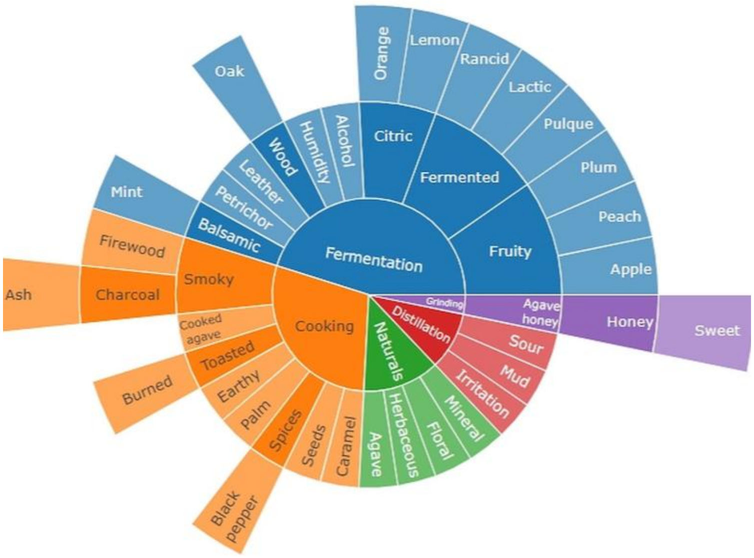

Figure 3. Proposed aroma wheel for espadin (*Agave angustifolia*) mezcal.

Conclusion

The Analytical Hierarchy Process technique proved to be a reliable tool for prioritising attributes. The responses of the panellists and the mezcal masters were similar. It was determined that the responses were homogeneous, thus a consensus was reached between the groups. The ranking showed that the main attributes with an impact on the aroma of mezcal were agave, herbaceous, floral, irritation, agave honey, honey, mud, smoky, mineral, and cooked agave. These attributes are indicators of the aromatic quality in the mezcal, and can be used in the monitoring, control, or design of mezcals with specific characteristics The aroma attributes for main criteria (process stage) with the highest hierarchy based on their importance within the process were raw material (agave and herbaceous), cooking (smoky and cooked agave), and fermentation (fruity and alcohol). The aroma wheel was made up of 44 attributes that are part of the sensory lexicon generated in the first stage of research. This tool could help the mezcal industry to control the sensory quality at each stage of the mezcal production process and final product.

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