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Liking and sensory determinants of perceived naturalness and healthiness. A study on pizzas with young adults in a natural eating environment

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ABSTRACT

This study aims to determine the sensory drivers of liking, perceived naturalness, and healthiness of pizzas in an ecological setting. The approach consisted in evaluating beliefs, perceptions, and liking by consumers of a large range of 16 pizzas representative of the French commercial market and selected on environmental and nutritional criteria. Sixty-four pizza consumers were invited to take 16 different meals in real-setting conditions of consumption at a university restaurant with pizza as the main course. Pizzas were also characterized by a trained sensory panel. This study confirms a positive link between liking and healthiness and naturalness, even though individual differences were evident, with some consumers prioritizing naturalness while others favored healthiness. Frozen pizzas are perceived as highly processed but were well liked when evaluated in the dining condition. Overall, preferences were mainly driven by the presence of multiple pieces of vegetables, sauce, and color. Drivers of dislike were mostly related to texture (*stickiness* and *difficulty to cut*). Although preference, naturalness, and healthiness mappings are relatively similar, our models show a discrepancy in the way texture drives preferences and perceived healthiness. This suggests that texture may play a critical role in the trade-offs between liking and healthiness, and that there may be a fine line between what is considered a desirable texture and a healthy texture. Individual regressions provided insights into consumer diversity, while combining sensory profiling with consumer-based methods offered a comprehensive understanding of product perception.

1. Introduction

In recent years, there has been a significant increase in the demand for natural food products and beverages worldwide (Talwar et al., 2021; Willer and Lernoud, 2018). More and more products are sold with various claims such as “all natural”, “100 % natural”, “from natural origin”, etc. This trend can be attributed to beliefs that natural foods are healthier, tastier, and more sustainable. Although there is no single formal definition for a natural food, nor any evidence that “natural” is healthy or sustainable, naturalness is clearly associated with a very positive image.

According to a systematic review by Román et al. (2017), food naturalness can be defined based on three criteria that matter most to consumers. These include the origin of the food, the elaboration of the food product (including ingredients and technology used), and the properties of the final product (such as being healthy, eco-friendly, tasty, and fresh).

While it might be relatively easy to anticipate what consumers consider to be natural vs. less natural food categories (likewise, healthy vs. unhealthy), assessing the perception of such qualities within a category may be more challenging. This is particularly important because consumers often make choices within a food category. It is thus crucial to understand how they perceive differences among products that are more directly comparable to each other.

The information printed on the packaging is the most likely source from which consumers form their opinion about the naturalness of a food product (Aschemann-Witzel et al., 2019). Interestingly, Román et al. (2017) found that consumer perception of naturalness is focused more on the lack of negative features, such as additives, than the presence of positive features. This echoes the current appeal for “cleanliness” and clean labels (Asioli et al., 2017; Hartmann et al., 2018).

However, despite these insights, there is still limited understanding

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of how consumers form their perception of food naturalness. The same goes with the perception of healthiness, which may have critical consequences on food choices and eating behaviors (Faulkner et al., 2014; Provencher et al., 2009). In this study, we hypothesized that when consumers are eating food without having access to explicit information or claims provided on the packaging, their perception of naturalness and healthiness would be very subjective and primarily influenced by personal preference. The objective of this study was thus to investigate how the perception of food naturalness and healthiness relate to preferences using pizza as a case study. We expected consumers to primarily form their judgments based on the sensory characteristics of the food they are consuming, as suggested by Asioli et al. (2014). Therefore, we also aimed to identify the sensory determinants of perceived naturalness and healthiness.

Pizza is a specially interesting food category that is often cited as a typical highly processed and energy-dense "junk food" and it is a popular meal choice for many people. Pizzas are indeed high in calories, sodium, and carbs, but their nutritional properties can vary widely depending on the type and ingredients used to compose the pizza. Presumably, most pizzas would also rank poorly on sustainability indices with their usually high animal protein content because of such ingredients as mozzarella cheese (or other types of cheeses) and meat or delicatessen toppings. However, this category comprises a wide diversity of products and not all pizzas are equivalent on those criteria (Cortesi et al., 2022a). In other words, some pizzas are healthier and more sustainable than others. As an alternative to drastically change their diets, consumers may thus achieve small steps improvements by choosing different pizzas. The question is whether consumers perceive these variations in healthiness and sustainability. Accordingly, it would be insightful to understand which sensory cues drive consumers towards more sustainable and healthy pizza consumption. Such information could indeed help them make informed choices, but it could also be used to entice food companies to reformulate healthier versions of their products without risking losing consumer preference.

To this end, we conducted a consumer and a sensory study of a variety of pizzas that were served to young adults for dinner at a university restaurant. Tested pizzas were selected to span across that category with varying types of crust and selection of toppings so that they would cover a wide range of nutrition properties and environmental impact.

2. Materials and methods

2.1. Study design

The study involved both consumers and trained panelists as presented in Fig. 1. The consumer test was conducted in the University restaurant on the AgroParisTech campus. A different pizza was served every two days over an eight-week study campaign. In total, sixteen different pizzas were tested, and all consumers evaluated each pizza once over that period. They were asked to give their liking for each pizza, if they perceived it to be healthy and natural, and to evaluate other subjective criteria. This allowed us to explore how these dimensions relate to each other. Before the in-restaurant test, participants had filled an online survey about their beliefs regarding pizzas.

Parallel to this, a sensory descriptive analysis of the 16 pizzas was performed with a trained panel in the objective of identifying sensory determinants of consumer responses using the external preference mapping approach (Danzart, et al., 2004; Schlich and McEwan, 1992). However, pizzas are challenging products to describe. They constitute a food of their own, but they are composite, heterogeneous, multicomponent products (Wilkinson et al., 2022). For that reason, only the sensory attributes that could be quantified and compared across pizzas (such as the crust properties) were evaluated using conventional Descriptive Analysis. Besides, a Check-all-that-apply (CATA) questionnaire was added to the in-restaurant test to better capture consumer experience and to include those attributes that could be very specific to a single pizza type (e.g., "presence of vegetable toppings").

2.2. Selection and description of the samples

The sixteen commercial pizzas were selected to represent the nutritional diversity of pizzas of the French market. For that purpose, we investigated the ingredients and nutritional composition of 387 fresh (sold in the refrigerated section at 4 °C) and frozen pizzas sold in large and medium-sized French grocery stores and supermarkets. The products belonged to different families (delicatessen, cheese, cheese ham, veggie, margherita, meat), fresh and frozen retail and covered all range segments (entry-level, private labels, national brands and specialized retailers) (Cortesi et al., 2022b). Ingredients and nutritional composition data of these 387 pizzas, as provided on their labels, were extracted from the OQALI database ("OQALI - Observatoire de la Qualité de l'Alimentation - Accueil," n.d.), and consolidated with nutritional data from CIQUAL database for mean ingredients ("Ciqual Table de composition nutritionnelle des aliments," n.d.) when composition was not available.

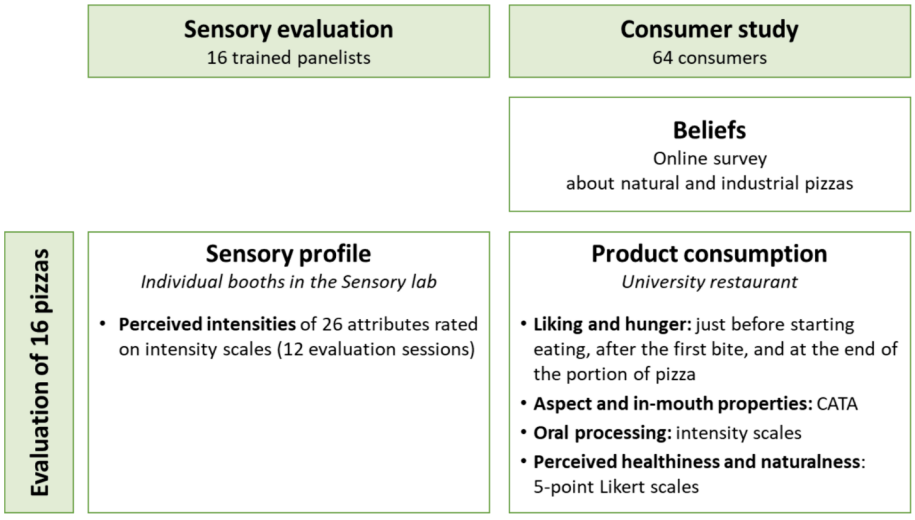

Fig. 1. Overview of the approach used in the study involving trained panelists and consumers.

From these data, a Hierarchical Cluster Analysis (HCA, Euclidean distance, Ward's criteria) was performed and allowed to identify 16 different classes of pizzas. A solver analysis was then applied so that one pizza was selected in each class, under the constraint that the final selection included all main pizza types (e.g., margherita, cheese, veggie, etc.), and 50 % of frozen pizzas. Nutritional, environmental, degree of processing indices and ratio animal proteins to plant proteins were calculated for the 16 selected pizzas and presented in Table 1 (Cortesi et al., 2022a). Large differences were observed between the pizzas across all variables, indicating a broad range of intra-category products based on environmental, nutritional, and processing criteria.

2.3. Consumer study

Sixty-four participants were recruited among university students on the AgroParisTech campus in the Paris area (mean age: 21-year-old). They were all regular consumers of pizza (i.e., they ate pizza at least two times a month) and had no food allergies nor dietary restrictions. They were recruited about two weeks prior to the test by means of online and printed flyers and were screened for their pizza consumption frequency. They gave their free and informed consent and received compensation for their participation. Upon recruitment, participants received a link to a brief online survey about their consumption habits and their beliefs regarding pizzas. They were notably asked to give their agreement (using 5-point Likert scales) for several statements about natural pizzas and industrial pizzas (e.g., *"is made of local ingredients"*, *"is high in calories"*, etc.).

The consumption study took place at a university restaurant on campus during regular opening time for dinner. Pizzas were served as part of an evening meal, two days a week. The participants were sitting together while eating. The evaluation was conducted in a monadic way (one pizza per meal). Sixteen evening meals were thus served over two months. Each meal lasted about 40 min. The study could not follow a complete balanced design because of the limited number of ovens, and priority was given to limiting the risk of mistakes when dealing with many different pizzas on the same sitting. To account for potential order effects, participants were split into two groups that each received a different presentation order. Although not perfect, this design allowed limiting to two different pizzas served per sitting. To check for possible differences in participants' state on different days, we measured hunger levels before and after each meal. No differences were found between testing days.

At the start of each meal, participants were offered a 200 g piece of pizza (about half a pizza) as the main course. They could choose any side normally included in the meal price (vegetables, potatoes, rice, noodles…), as well as three choices of starters and dessert. Bread and tap water were available for free and ad libitum.

On each test day dinner, participants were asked to fill in a questionnaire about their consumption and attitudes toward the pizza that they ate during the meal. All data were collected using a paper and pencil questionnaire form. Participants rated their hunger sensations, as well as their liking for the pizza (on a 7-point hedonic scale) just before starting eating, after the first bite, and at the end of the portion of pizza. While they were eating, they were also asked to evaluate visual and in-mouth sensory properties of the pizzas using a check-all-that-apply (CATA) questionnaire (see the complete list of attributes in Supplementary Table 2). Four attributes linked to food oral processing (heterogeneity while masticating, formation of a sticky bolus, salivation while chewing, difficulty to chew and swallow) were also evaluated with intensity scales. Eventually, participants were asked for their agreement on seven statements concerning the pizza that they just ate using a 5-point Likert scale. These questions were intended to evaluate how healthy and natural they perceived each pizza (Table 2). Note that, unlike naturalness that could be translated directly, several items relate to the concept of healthiness which has no simple French equivalent in this context. For the analyses presented in article, we chose to retain

Table 1
Values of the objective criteria characterizing the 16 selected pizza (nutritional, environmental, technological criteria). The 5C score, called NutriScore, is based on Rayner's score, which was developed for the UK's Food Standards Agency to divide the foods into five classes relating to nutrition.

Pizza code	Retail	Family	Number of additives	Number of ingredient**	Energy (kcal/100 g)	Proteins (g/100 g)	Fat (g/100 g)	Sodium (g/100 g)	Carbohydrates (g/100 g)	5C score	toppings / crust w/w	Prot Anim. / Prot Veg.	Processing score *	Carbon footprint (CO2 g eq)
P1	refrigerated	delicatessen	12	13	280	12.00	12.00	0.56	30.00	4	1.22	1.88	38	0.45
P2	frozen	cheese	5	11	254	10.90	10.80	0.52	28.20	3	1.08	1.37	37	0.45
P3	frozen	ham cheese	19	18	203	9.70	6.10	0.66	27.30	3	1.44	0.91	43	0.48
P4	frozen	margherita	8	12	199	5.20	3.20	0.44	36.20	2	0.83	0.15	47	0.18
P5	refrigerated	delicatessen	9	15	243	11.00	11.00	0.72	25.00	4	1.33	1.62	44	0.49
P6	frozen	bolognese	8	14	354	18.10	16.60	0.40	33.10	3	1.44	1.18	44	0.34
P7	frozen	veggie	8	15	199	6.60	8.90	0.40	22.00	3	1.56	0.82	34	0.35
P8	refrigerated	ham cheese	9	14	227	6.80	7.40	0.46	31.80	3	0.82	0.56	39	0.20
P9	frozen	meat	6	10	235	8.90	11.00	0.40	25.00	3	1.22	1.17	31	0.30
P10	frozen	cheese	1	9	264	11.60	12.00	0.44	26.10	3	1.00	1.58	39	0.57
P11	refrigerated	ham cheese	11	15	200	11.00	6.50	0.65	25.00	3	1.63	1.66	32	0.49
P12	frozen	ham cheese	10	10	196	9.00	5.80	0.48	25.80	2	1.12	1.05	39	0.33
P13	refrigerated	cheese	2	9	240	14.00	10.00	0.59	23.00	4	1.63	2.46	34	0.60
P14	frozen	veggie	4	8	193	6.70	5.00	0.35	29.00	3	1.22	0.46	27	0.31
P15	refrigerated	margherita	6	6	244	10.60	8.90	0.54	29.70	3	0.69	0.74	28	0.35
P16	refrigerated	cheese	21	21	252	11.70	10.90	0.53	26.80	4	2.57	2.65	57	0.48

* Processing score proposes a robust and universal classification system for foods according to the level of food processing (Maurice et al., PhD thesis, 2022).

**that are not additives.

Table 2
Subjective items evaluated by consumers using a 5-point Likert scale for the statement: "In your opinion, the pizza that you just ate is…". (Nota: for nutritional quality, the question was asked both in a positive and a negative way as a control check for internal consistency).

Subjective perception (in French)	Subjective perception (in English)
Equilibrée	Nutritionally balanced / healthy
Calorique	Energy dense
Rassasiante	Satiating
Mauvaise qualité nutritionnelle	Poor nutritional quality
Bonne qualité nutritionnelle	Good nutritional quality
Naturelle	Natural
Artificielle	Artificial

"*équilibrée*" (≈ nutritionally balanced) deemed the best proxy for perceived healthiness.

2.4. Sensory evaluation

The sensory evaluation of the 16 selected pizzas was performed using conventional descriptive analysis (DA). Selected pizzas belong to different subcategories and thus each had very specific features. Therefore, all attributes deemed too specific to be evaluated quantitatively (e.g., presence of herbs, lardons, vegetable pieces) were left out of the DA and included in a CATA questionnaire for direct evaluation by the consumers (Ares and Jaeger, 2015).

For the sensory study, 16 volunteers (9 women and 7 men) were recruited (different from the participants to consumer study). They gave their free and informed consent and received compensation for their participation. They were asked to not eat or drink for at least 1 h before the study sessions. While independent, these sensory sessions were performed during the same period as consumer study.

Sensory evaluation was carried out in an air-conditioned room (20 °C), in individual booths, under white light. Pizzas were baked in domestic ovens just before consumption, following the recommendations suggested in each packaging. Samples of pizza (50 g) were presented at 60 °C in isothermal plastic boxes labeled with randomly selected three-digit numbers. During profile evaluation, the samples were balanced following a Williams' Latin square experimental design order across panelists taking care to avoid carry-over effects. Panelists were provided with mineral water (Evian, Danone, France) to rinse their mouths between samples.

First steps of DA consisted in four sessions dedicated to generation and selection of attributes common to the set of pizzas, then in training for the use and quantification of these attributes on intensity scales Panelists agreed on a reduced list of 26 common attributes with definition and evaluation protocols (Table 3). The 16 samples were evaluated for each of these attributes on a 10-point unstructured intensity scale using Fizz Acquisition software (Version 2.47A, Biosystemes, France). Samples were presented in monadic sequential mode in triplicate. Panelists evaluated four pizzas per session, leading up to a total of 12 evaluation sessions. Panel performances were validated in terms of homogeneity, discrimination ability and repeatability.

2.5. Data analysis

Liking scores, and ratings for hunger sensation and subjective items (perceived healthiness and naturalness) were all analyzed using two-way Analyses of Variance (ANOVA) with products and consumers as main effects, followed by Tukey HSD test ($p < 0.05$) to determine differences between pizzas. For all subjective items, ratings on Likert scales were converted to scores ranging from "1″ (strongly disagree) to "5" (strongly agree). When appropriate, Pearson correlation coefficients on average data are provided to indicate linear relationships between two variables. Relationships between liking and perceived healthiness and naturalness were further explored at the individual level using simple

Table 3
List of the 26 sensory attributes. their definitions and intensity scales used for profile evaluation of pizzas.

	Sensory attributes (in French)	Sensory attributes (in English)	Scale	Definition
Appearance	Intensité globale	Overall flavor intensity	low to high	Overall flavor intensity
	Epaisseur pâte	Crust thickness	low to high	Crust thickness
	Couleur pâte	Crust color	light to dark	Crust color
	Légèreté pâte	Crust lightness	dense to airy	Crust lightness
	Dureté pâte	Crust hardness	soft to hard	Force necessary to press the crust with fingers
	Pâte imbibée par sauce	Crust soaked in sauce	low to high	Crust soaked in sauce
	Abondance garniture	Abundance of toppings	low to rich	Abundance of toppings
	Couleur garniture	Topping color	monochrome to multicolor	Topping color
	Ingrédients identifiables	Identifiable toppings	low to high	Identifiable toppings
	Garniture liquide	Liquid filling	low to high	Amount of water or juice released by the topping
	Intensité tomate	Tomato flavor intensity	low to high	Tomato flavor intensity
	Ratio pâte/ garniture	Crust / toppings ratio	low to high	Percentage of crust compared to that of the toppings
	Difficulté à couper	Difficulty to cut	easy to difficult	Force needed to cut a bite-size piece with a knife
In-mouth	Croustillant pâte	Crust crispness	low to high	Crust crispness (between teeth)
	Salé	Salty	low to high	Perceived saltiness intensity
	Sucré	Sweet	low to high	Perceived sweetness intensity
	Acide	Sour	low to high	Perceived sourness intensity
	Piquant	Spicy(hot), pungent	low to high	Percevied spiciness (hot), pungent intensity
	Epicé	Spicy	low to high	Perceived spiciness intensity
	Aromates	Herbs	low to high	Perceived herb intensity
	Huileux, gras	Oily, fatty	low to high	Oily, fatty
	Homogénéité	Homogeneity	low to high	Homogeneous distribution of pieces in saliva as a result of mastication
	Bol collant, pâteux	Sticky, pasty bolus	low to high	Tongue force needed to take off bolus that adheres to the inside of the oral cavity
	Salivation	Salivation	low to high	Quantity of saliva needed to form a bolus

(*continued on next page*)

Table 3 (*continued*)

	Sensory attributes (in French)	Sensory attributes (in English)	Scale	Definition
	Difficulté mastication	Difficult to chew	easy to difficult	Force needed to completely chew until bolus can be swallowed into esophagus
	Morceaux après	Chunks after	low to high	Presence of remaining chunks or food pieces after swallowing

linear regression. Thus, two regression models were calculated for each participant: one for liking and healthiness, and one for liking and naturalness.

Data from descriptive analysis with the trained panel were submitted to an ANOVA for each attribute, with products, panelists, and replicates as main effects and first-order interactions to assess panelist performance. Post-hoc multiple comparison tests were performed to interpret pair-wise differences between pizzas (Tukey HSD test, $p < 0.05$). Descriptive data from the consumer test (CATA) were analyzed for the significance of between-product differences using a Cochran test for each attribute ($p < 0.05$). In addition to this, overall CATA counts were standardized attribute-wise and plotted as a heat map with pizzas and attributes clustered separately using ascendant hierarchical clustering (Euclidian distances, complete linkage) via the ComplexHeatmap R package (v2.15.4; Gu, 2022). A Multiple Factorial Analysis (MFA) was then performed using FactoMineR (v2.10; Husson et al., 2024) to simultaneously examine sensory intensities evaluated by the trained panel and frequency quotations determined by consumers for the 16 pizzas. Analyses of Variance were performed using XLSTAT (Addinsoft, 2017, Paris, France). Analyses requiring R packages were performed using R Statistical Software (v4.3.2; R Core Team 2023).

The effects of pizza sensory properties on liking, perceived naturalness, and perceived healthiness were then explored by applying the external preference mapping approach to individual modeling and response surface aggregation, as described by Danzart et al. (2004). As a basis for this analysis, we used the sensory map provided by the MFA of combined descriptive data from the trained panel (DA) and the consumers (CATA). Each consumer's liking score was thus regressed on the first two dimensions of the MFA as explanatory variables, using the coordinates of the centroids for each product. As usual for quadratic model preference mapping, the scores were normalized for each consumer. An individual model was thus computed for each consumer and all models were then discretized and aggregated using Matlab R2017 (The MathWorks Inc., Natick, MA, USA). Discretization was performed according to the individual preference threshold set at each consumer's average score (Delarue et al., 2010). The aggregated response surface was obtained by summing all discretized models and was plotted on the sensory map. For any point of the map, the surface indicates the percentage of preferences, that is to say the estimated number of consumers who would give the corresponding product a higher score than their average score.

3. Results

3.1. Beliefs for a healthy, natural and industrial pizza

Criteria for defining healthy, natural, and industrial (i.e. processed)

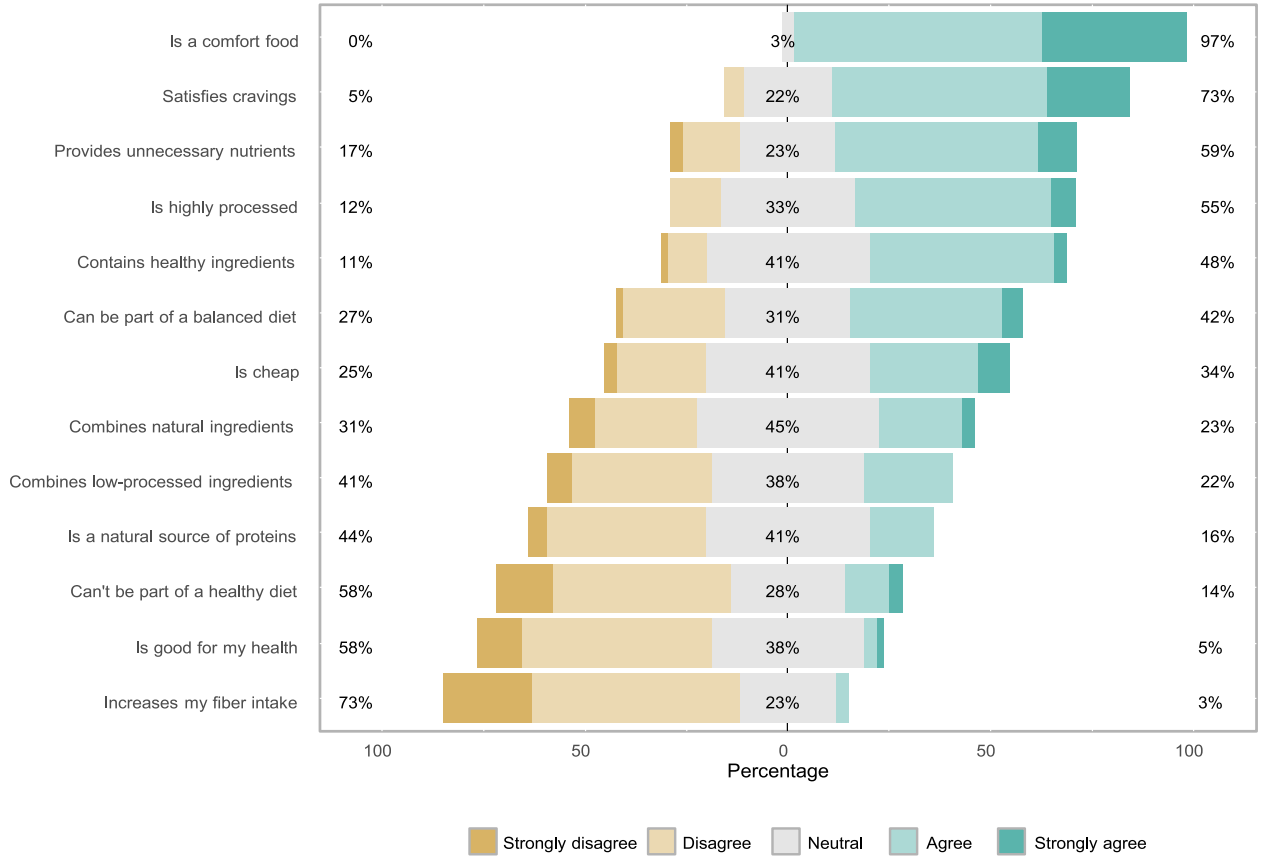

Fig. 2. Beliefs associated to a 'healthy pizza' (percentages of respondents are indicated for strongly disagree, disagree, neutral, agree, strongly agree response categories).

pizzas are given in Figs. 2 and 3. As for their beliefs, participants unanimously express that a healthy pizza is a comfort food, and a large majority agrees that it satisfies cravings, provides unnecessary nutrients and is highly processed. In addition, participants don't perceive healthy pizzas as good for health, as a fiber intake or a part of a healthy diet (Fig. 2).

Besides, a natural pizza was described by a majority of respondents (>65 %), as homemade, without additives, with minimally processed ingredients, and with identifiable toppings. They said it can be found in the refrigerated aisle of grocery stores (*fresh* or "*rayon frais*"). Conversely, 85 % of participants described industrial pizzas as frozen pizzas. More than 65 % of participants think that industrial pizzas cannot be made without additives, nor with minimal processed ingredients, cannot be home-made, nor baked in a wood fire oven. Likewise, they think that industrial pizzas cannot be organic nor locally produced (Fig. 3).

3.2. Liking of the 16 pizzas

As described in the methods section, once the participants had expressed their general beliefs about pizzas, they were invited to take the 16 different meals during which they evaluated their liking and perception at different steps of pizza consumption (before eating, just after the first bite and at the end of the slice). Results show that all the pizzas, except the pizza P04 were well appreciated, with an overall mean liking score of 5 on a scale ranging from 1 to 7 (Fig. 4). But some differences in liking could be observed between the 16 pizzas as shown by the ANOVA ($F_{(15,\ 945)} = 24.73$, $p < 0.001$) for liking evaluated after the consumption of the first bite, with average liking scores varying between 3.5 and 6. Remarkably, the six most appreciated pizzas (P03, P12, P14, P02, P09, P06) were frozen pizzas. In addition, a significant decrease in pizza liking after consumption was observed for the four least liked pizzas (P06, P10, P08 and P04) (Fig. 5). This effect was expected and likely results from sensory specific satiety (Rolls et al., 1981). However, it was not observed for the most liked pizzas (P14 and P03) that even show an increase in liking after consumption.

Hunger ratings confirm that pizzas induced satiation (as estimated from the difference in hunger before and after the meal), although that effect was less important for some of the less liked pizzas P04, P05, P07, P15. No clear link could be established between the nutritional composition of the pizzas and their differing satiating effect, which suggests that sensory properties, particularly texture, influenced oral processing and thus the cascade of satiation and satiety. It might also be possible that participants did not eat the full portion.

3.3. Perceived healthiness and naturalness

After consumption, participants rated their level of agreement with the fact that the pizza they just ate was natural and/or healthy (Fig. 6). Overall, most participants did not find pizzas to be natural (notably, eight participants did not rate any of the pizzas as natural (disagree or neutral)). However, large differences were observed between pizzas. Ten out 16 pizzas were found not to be natural by a majority of participants, with the pizza P04 perceived as being the least natural (more than 80 % of participants). Conversely, five pizzas (P14, P09, P07, P03 and P12) were evaluated to be natural by more than 40 % of the participants, with pizza P14 (veggie pizza) reaching 73 % of agreement.

Equilibrée (French for "balanced") was strongly correlated with

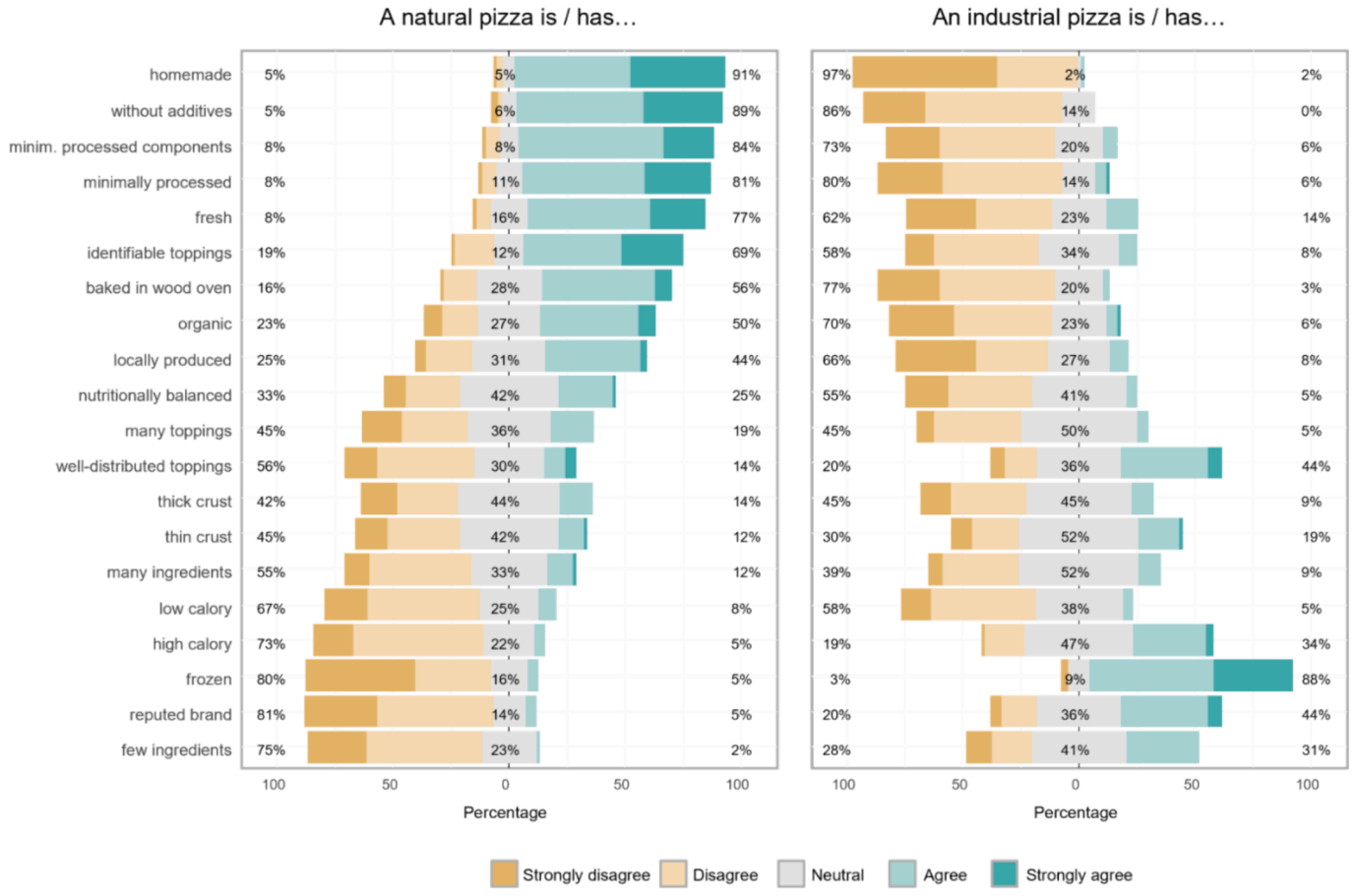

Fig. 3. Beliefs associated to a 'natural pizza' and to an 'industrial pizza' (percentages of respondents are indicated for strongly disagree, disagree, neutral, agree, strongly agree response categories).

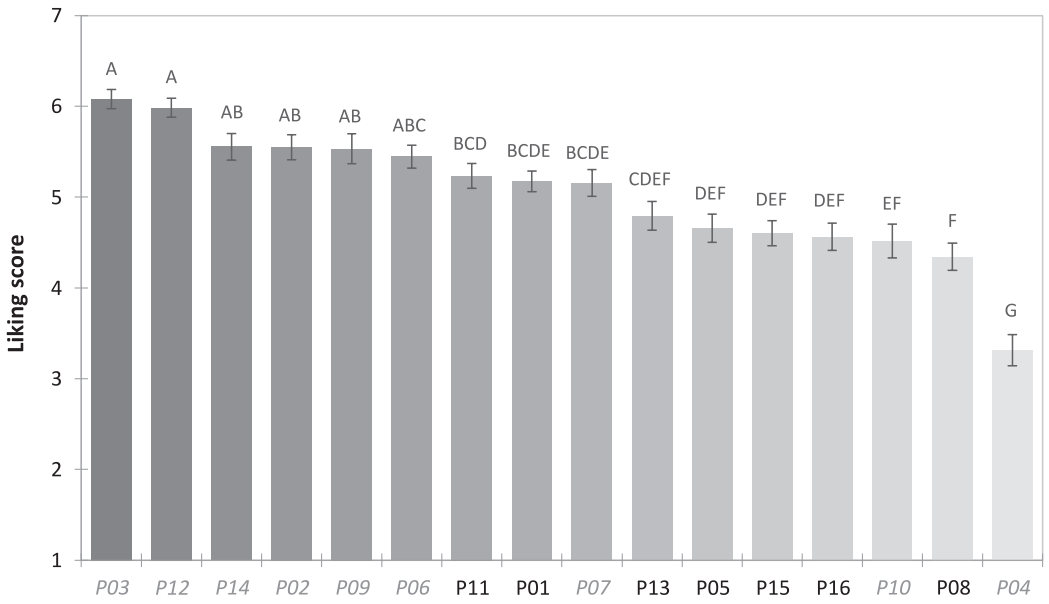

Fig. 4. Mean liking scores (on a 7-point scale ranging from "dislike a lot" (1) to "like it very much" (7)) of the 16 pizzas evaluated at t1 after the consumption of the first bite of pizza. Error bars represent SEM and letters represent non-significantly different groups (Tukey HSD test). Frozen pizzas codes are in italic.

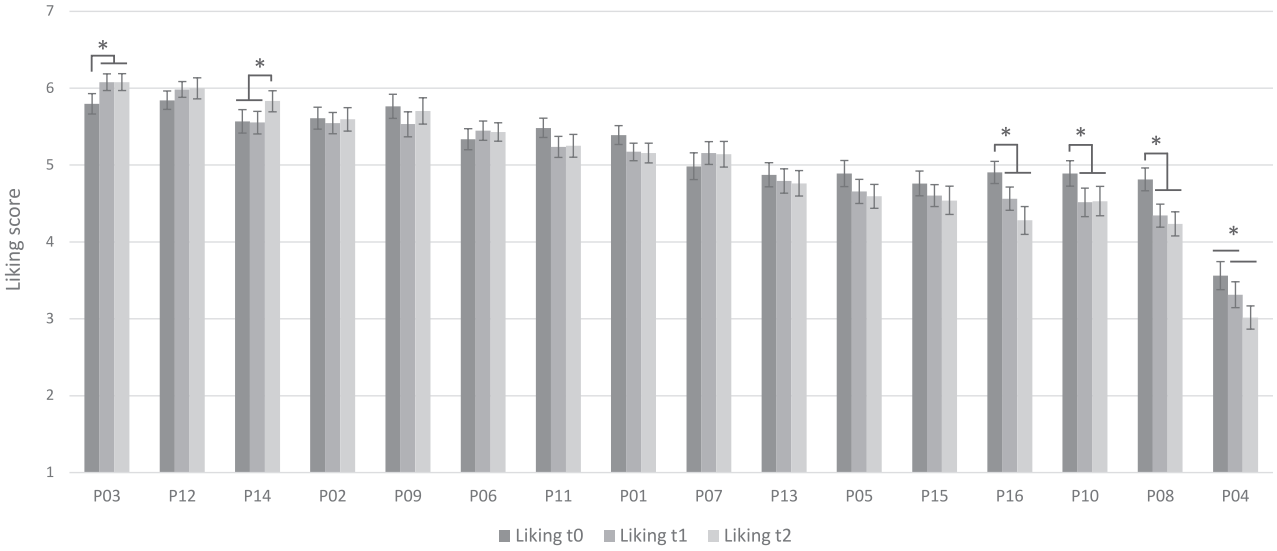

Fig. 5. Evolution of liking scores (on a 7-point scale) for the 16 pizzas, prior to the meal, after the first bite, and at the end of the portion of pizza. Error bars represent SEM and – for each pizza – letters indicate different groups (Tukey HSD test, $p < 0.05$) when a significant difference was found between the three evaluation points.

"good nutritional quality" ($r = 0.956$, $p < 0.0001$) and will be considered the best proxy for 'perceived healthiness' in English. On average, perceived healthiness and perceived naturalness are correlated ($r = 0.932$, $p < 0.001$), but perceived healthiness ratings are lower than perceived naturalness (notably, nine participants did not rate any of the pizzas as healthy). Half of the pizzas totaled more than 75 % of disagreement for "Nutritionally balanced", but three pizzas (P14, P07 and P09) were rated positively. Responses to other questions ("good nutritional quality", "poor nutritional balance", "artificial", "energy dense", "satiating") are provided as Supplementary Fig. 3. Notably, for this set of pizzas, we observed a weak but significant link between "satiating" and liking ($r = 0.579$, $p = 0.02$), but not between "satiating" and perceived healthiness ($r = -0.024$, $p = 0.928$). In addition, there is a negative (but nearly significant) correlation between pizzas' actual energy density (in Kcal) and their perceived "nutritionally balanced" ratings ($r = -0.490$, $p = 0.053$). More generally, "nutritionally balanced" doesn't correlate significantly with any of the compositional variables.

On average, liking is strongly correlated with perceived naturalness ($r = 0.745$, $p < 0.001$) and less so with perceived healthiness ($r = 0.562$, $p < 0.05$). This said, detailed results show a large variability between the participants. Individual scatter plots and regressions of liking (evaluated at the end of consumption) vs naturalness illustrate the diversity of consumers' responses (Fig. 7). For some participants, the perceived naturalness hardly varies between pizzas (e.g., participant #56), while others display large differences and a strong positive relationship between liking and perceived naturalness (e.g., participants #26 or #27). Similarly, the range of perceived healthiness ratings varies a lot between individuals (supplementary Fig.1).

To get a clearer view of these interindividual differences, we separately regressed perceived naturalness and perceived healthiness against liking for each individual and plotted the resulting paired R-squared values as shown on Fig. 8. This scatterplot allows identifying, for each participant, the strength of the relationship between liking and perceived healthiness, and perceived naturalness, respectively. Some

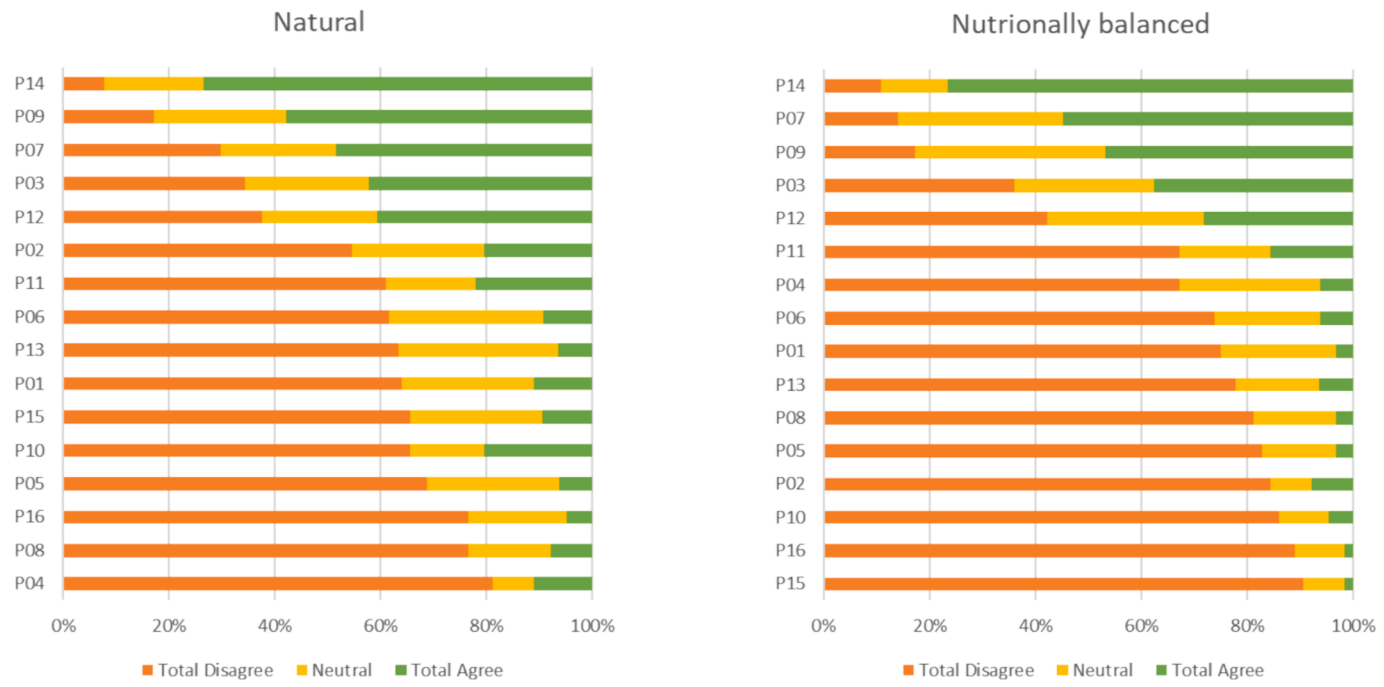

Fig. 6. Perceptions of "natural" and "nutritional balanced" evaluated by the 64 participants of the study for the 16 pizzas (Likert scale).

participants (like participant #10) clearly show a stronger link between their perceived healthiness and liking ratings, whereas others (like participant #27) show a stronger link between naturalness and liking. Other individuals (like participant #42) had equally balanced link to naturalness and healthiness. Eventually, it is worth noting that a number of participants have low R-squared values, indicating a poor degree of fit with either dimension. Overall, the participants were split equally on each side of the diagonal.

3.4. *Drivers of liking, naturalness, and healthiness for pizzas*

In the light of those inter-individual differences in perceived healthiness and naturalness, we aimed to identify the key drivers of liking, healthiness and naturalness using the individual modelling approach of external preference mapping for these three responses taken separately. The mappings relied on sensory data derived from both descriptive analyses conducted by the 16 trained panelists and CATA evaluations performed by consumers, offering supplementary descriptions.

First, the descriptive analysis revealed large differences between the 16 pizzas (see Supplementary Table 1 for ANOVAs and post hoc tests). Largest differences were found for crust thickness, filling color, intensity tomato, difficulty to cut, spicy, oily and bolus homogeneity. In addition, consumers' CATA evaluation in the restaurant setting also indicate large differences between pizzas on topping (variety of ingredients), crust, or sauce (Cochran test, $p < 0.05$) (supplementary Table 2).

As observed on the heat map (Fig. 9), three clusters of pizzas were identified, supported by different groups of sensory properties. Pizza P04 was the most different from others, characterized mainly with high selection frequencies for chewy, soft, sticky crust, pale, tomato, and thick crust attributes. Pizzas P03, P12, P14, P06, P09, and P07 were grouped together and mainly characterized, as example, by multicolored characteristic, the presence of vegetable pieces, light crust, juicy, mellow crust, thick sauce, and garnished properties. Differently, the pizzas P02, P08, P13, P16, P01, P11, P05, P10, and P15 are grouped together and illustrated with oily, shiny, and dry crust sensory perceptions. No link based on the type of pizza (fresh or frozen) could be observed. Likewise, there seems to be no obvious link between overall liking and pizza families. Notably, the least liked pizza, P04, is a Margherita, while P15, also a Margherita, has a much higher average liking score. Although they belong to the same family, they have widely different sensory characteristics, in particular their texture (see Supplementary Table 1). This highlights the specific challenge of defining the study domain (i.e. the studied food category and the selected product set within this category). This result further stresses the risk of considering 'the average food product' in dietary recommendations when very different versions of the same product may actually coexist.

Descriptive analysis and CATA data were then combined using MFA to provide a sensory map, with the first two dimensions of the compromise accounting for 55 % of total inertia (Fig. 10). It revealed a relatively high RV coefficient of 0.73 between the CATA and profile data, indicating a good level of consistency between consumers and trained panelists despite the different nature of their evaluation tasks. Consensus was particularly good for the description of texture.

Furthermore, pizzas are widely spread along the two dimensions of the sensory map. The first axis opposes oily and fatty pizzas (P15 and P13) with soaked crust (on the left) to pizzas with crispier crust and more toppings on the right (P09, P07 and P14). The second axis relates mainly to the thickness of the crust, which is especially high for P04.

Overlaying consumer preferences on this sensory map from MFA allows to identify drivers of liking (Fig. 10). This preference mapping approach can also be used to compare the drivers of liking, of perceived naturalness, and of perceived healthiness (Fig. 11). First, the analysis of liking data showed that preferences for pizzas are driven by the presence of multiple ingredients, the amount of filling, some color, and the presence of pieces of vegetables, whereas a thick dough appears to be a barrier to liking (Figs. 10, 11). It was observed that the P04, P02, P08, P10 pizzas are the least appreciated pizzas among the participants and are perceived as fatter, soaked dough, sticky in the mouth, and homogeneous in terms of ingredients. Thus, stickiness and difficulty to cut out stand out as drivers of dislike among consumers.

Second, based on the same product description map, one can notice a progressive shift of the maximum preference values towards the right when switching from liking to perceived naturalness and healthiness (Fig. 11). The pizzas perceived as the most natural are those that were perceived as the most colorful, abundant in vegetables and laden with

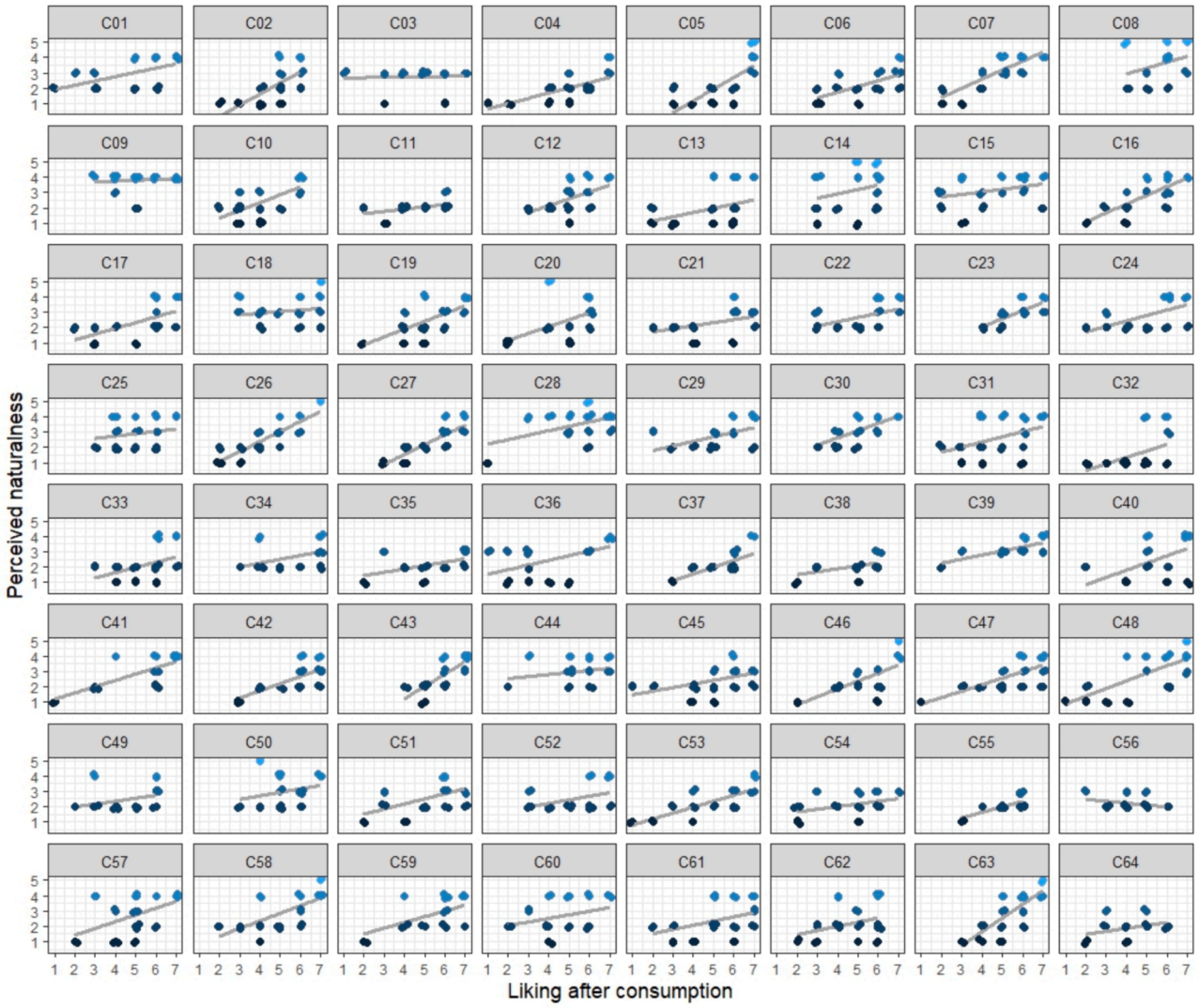

Fig. 7. Individual regressions between liking (after consumption) and naturalness scores for the 64 consumers.

numerous toppings. In contrast, attributes such as fat, homogeneity and stickiness in the mouth emerged as drivers of unnatural pizzas. Concerning healthiness mapping, analogous trends to those observed in naturalness were noted, but with more pronounced differences in identified drivers. Interestingly, the properties of the crust did not affect the perceived healthiness of the pizza. Instead, the ratio of filling to paste emerged as a significant factor affecting healthiness perception (axis 2). Moreover, the influence of sweet and salty perceptions on healthiness was slightly less pronounced compared to their impact on naturalness.

To finish, and interestingly, we observed variations in the evaluated pizzas: while P05 and P16 were deemed acceptable in terms of liking (zone of preference with approximately 50 % of consumers), they received low ratings for both healthiness and naturalness.

4. Discussion

As expected, we observed a clear and positive link between liking and perceived naturalness on average, and a somewhat weaker link between liking and perceived healthiness. The most appreciated pizzas were generally judged to be both natural and good for health. This result is in line with findings from other studies showing that the perceived naturalness is an important factor influencing consumer acceptance of food products (Román et al., 2017; Rozin, 2005). According to Román et al (2017), foods considered to be natural by consumers tend to encompass products that are generally deemed healthier (i.e., fruits, vegetables, whole grains). Alternately, ultra processed food products are often perceived as nutritionally deficient or unnatural (Ares et al., 2016; Machín et al., 2020; Varela et al., 2022). In the present study, the presence of identifiable toppings, especially non-processed vegetable pieces (such as basil leaves, or bell pepper pieces) contributed to increase the perception of naturalness. Conversely, we observed that the least appreciated pizzas were also perceived as poor for health. This finding contradicts the common belief that “healthier foods are less tasty” (Chan and Zhang, 2022), at least within this specific product category. It should be noted however that the present study, which was conducted in blind conditions, departs from other studies on the “tasty = unhealthy” assumption. Indeed, those studies investigated consumers’ reactions to health messages or to information conveyed on front packaging but did not involve food consumption nor tasting (Elliott, 2009; Horgen and Brownell, 2002; Pettigrew et al., 2024). It should also be noted that the general food context has changed a lot in the past 20 years. Many diet food products on the market have improved. As a result, it is possible that healthy (or healthier) foods are less negatively perceived nowadays.

However, despite the general trend in our data, some of the well-liked pizzas were perceived to be neither very natural, and nor very healthy (P16, P11 and P05). Interestingly, we observed a stronger link

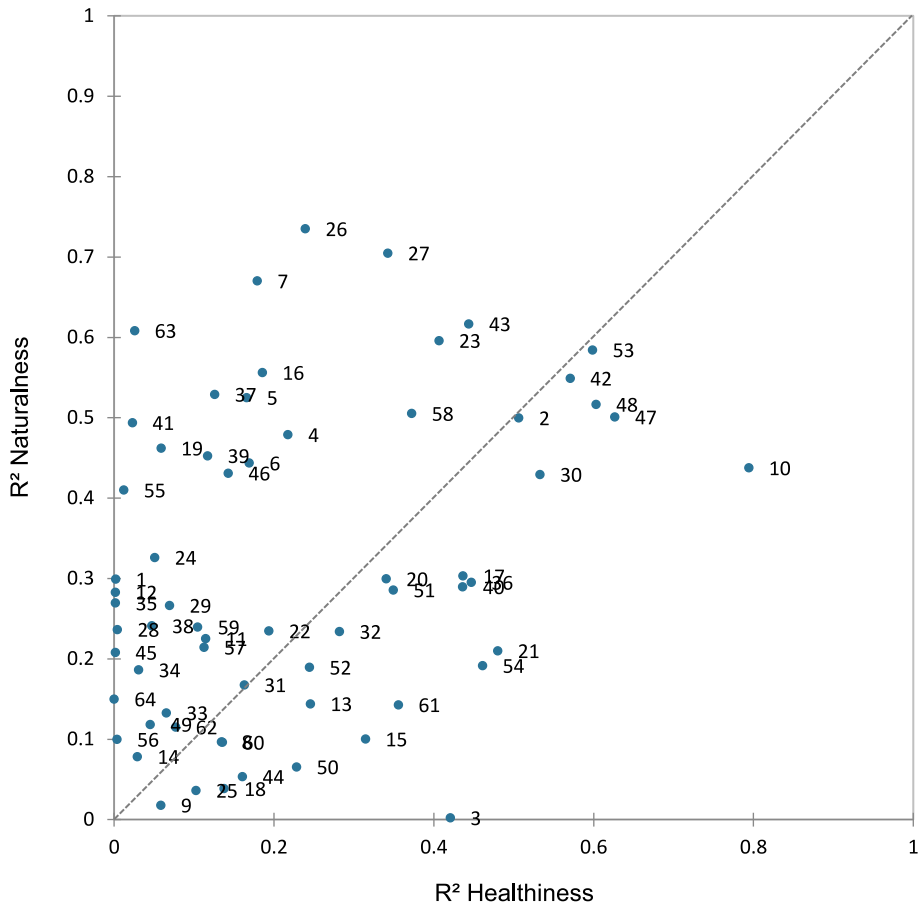

Fig. 8. Individual degrees of fit (R^2) between liking (evaluated after portion consumption) and healthiness and naturalness (from individual simple linear regressions).

between naturalness and liking than between healthiness and liking. The greater correlation between naturalness and liking could be explained by the fact that naturalness is a more complex and subjective notion than healthiness, which would lead consumers to rely more on their intuition and hedonic appraisal to make a judgment about naturalness. The definition of naturalness is indeed open to various consumer interpretations (Battacchi et al., 2020; Román et al., 2017). Besides, consumers may more easily associate healthiness (or unhealthiness) with their perception of quantifiable sensory attributes such as fattiness or saltiness.

Most strikingly, we observed a large variability between participants in their perception of naturalness and healthiness. Our data especially show that the link between these percepts and liking greatly differs at the individual level. Indeed, some consumers tend to associate liking with naturalness more, whereas others seem more sensitive to healthiness. Although causality cannot be inferred from our data, this result may indicate that part of the consumers value naturalness more, which may relate to a greater and increased concern about sustainability that also reflects in food choices (Aschemann-Witzel et al., 2020; Hoek et al., 2017). Such individual regressions of subjective dimensions on liking scores offer valuable insights into consumer diversity. Overlooking this diversity of response patterns would risk misunderstanding the drivers of consumer behaviors.

Furthermore, to explore the link between these dimensions and pizza sensory properties, we applied external preference mapping analysis (with individual modelling) to naturalness and healthiness responses. Overall, our results show that, for this product category, preferences were mainly driven by the presence of multiple ingredients and pieces of vegetables, the amount of filling, and color. Drivers of disliking were mostly related to texture (*stickiness* and *difficulty to cut*). Although preference, naturalness, and healthiness mappings are relatively similar, the models show a discrepancy in the way texture drives preferences and perceived healthiness. Crunchier pizzas are indeed perceived to be healthier but would tend to be less liked. This suggests that texture may play a critical role in the trade-offs between liking and healthiness, and that there may be a fine line between what is considered a desirable texture and a healthy texture. Whether or not a hard or crunchy texture is accepted is likely to depend on personal eating traits (Jeltema et al., 2016) and may have even further nutritional consequences because harder textures affect eating pace and reduce hunger sensations and energy intake (Wallace et al., 2023). For pizza specifically, Zhu et al. (2013) showed that the number of masticatory cycles before swallowing may reduce eating speed, increase satiation, and facilitate glucose absorption. This underscores the potential impact of sensory experiences on dietary choices and highlights the relevance of ongoing research in this field (Heuven et al., 2023). Similarly, perceived healthiness can be an important factor influencing portion size decisions (Labbe et al., 2017), even if some individuals may be more driven by hedonic considerations in their portion size selection. On a positive note, our models show that texture could be optimized in order to help consumers opt for healthier options.

Given the current emphasis on reducing animal protein consumption, it is interesting to note that we did not find any direct correlations between the animal / plant protein ratio and liking, nor with perceived naturalness or healthiness. Some pizzas with high ratios were well appreciated (e.g., P12, P01, P07), while others were not (e.g., P13 or P16). Interestingly, pizzas with low ratios were all highly depreciated (e.g., P04, P08, or P15), although it is worth noting that Pizza (P14), labelled as 'vegetarian' was highly appreciated and perceived as natural and nutritionally balanced. These findings suggest that the quantity of

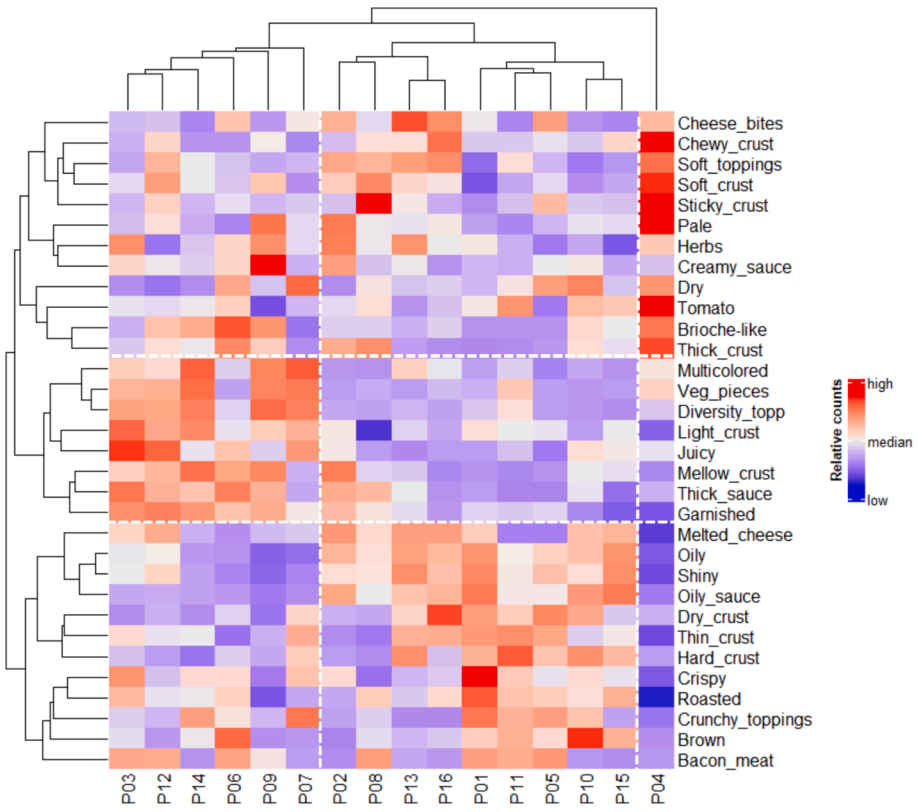

Fig. 9. Heat map on contingency data provided from CATA test. The features dendrogram was displayed vertically (the 16 pizzas in rows) and the individuals dendrogram is displayed horizontally (the sensory variables in columns).

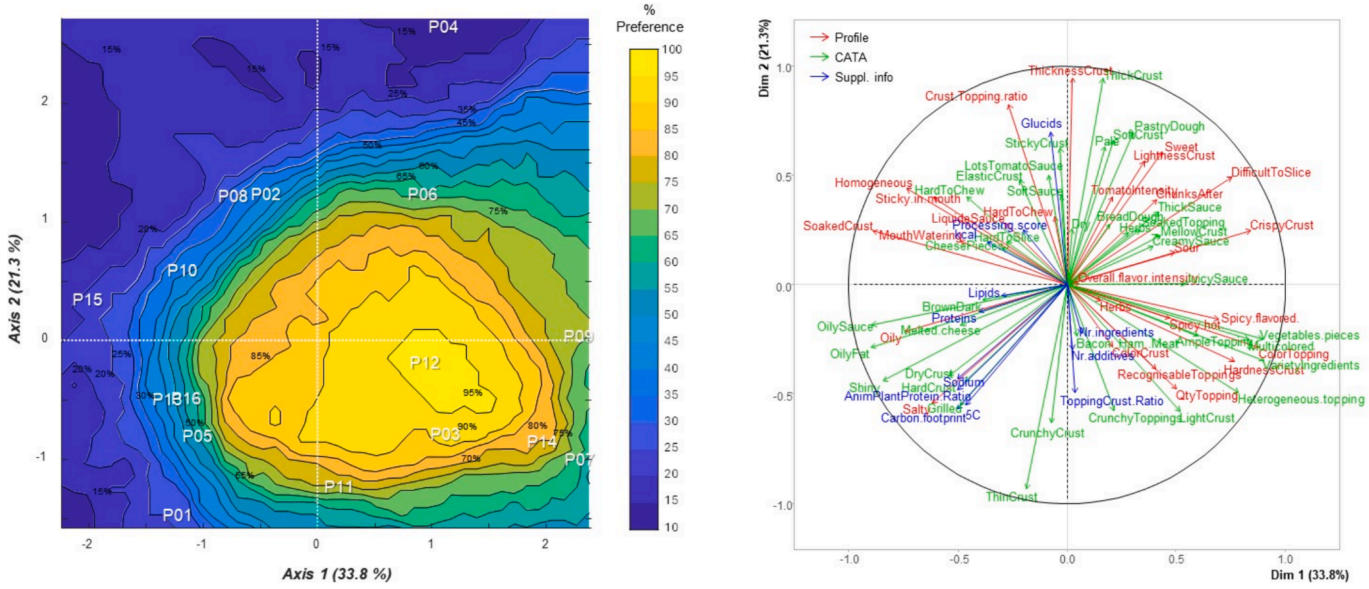

Fig. 10. MFA and external preference mapping for the evaluation after the first bite.

animal proteins is not directly related to liking, but the present study was not designed to investigate this effect specifically as we did not systematically vary the animal/plant protein ratio as an experimental factor. Nonetheless, should this result be confirmed, products or dishes with a mix of animal and plant-based ingredients, favoring a higher ratio of vegetables, may serve as an effective strategy for easing dietary transition without causing disruption to consumer behaviors, as previously documented in the literature (Spencer et al., 2018).

Parallel to this in-depth analysis of the sensory determinants preferences and of perceived healthiness and naturalness, it is worth mentioning that our results reveal a dissonance between consumer expectations and perception of the pizzas during consumption. For example, frozen pizzas are typically considered to be industrial and highly processed (85 % of the participants), whereas frozen pizzas from the French market are in the low-tier process score (Cortesi et al., 2022a). Besides, the frozen pizzas included in this study were amongst

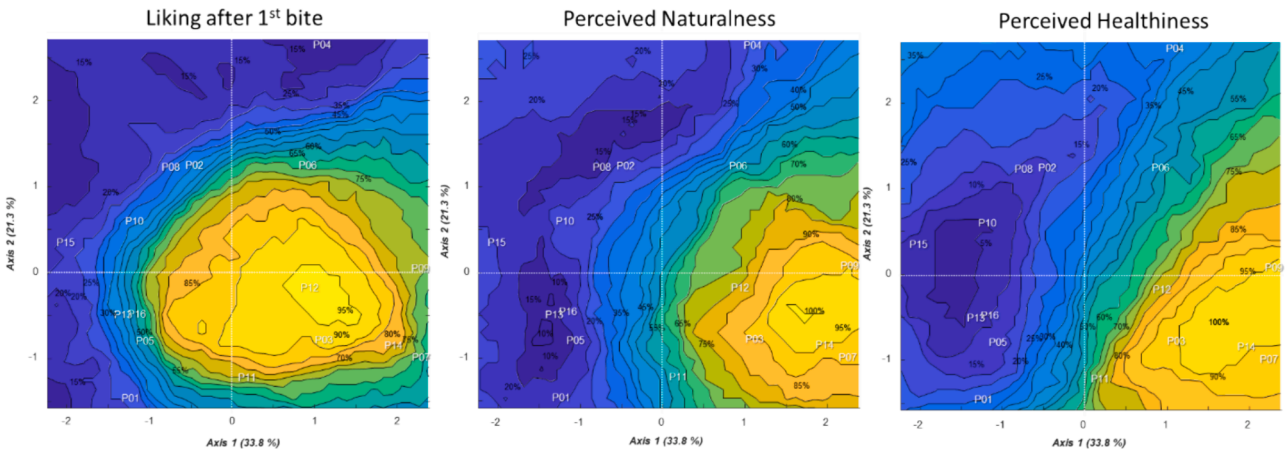

Fig. 11. External preference mapping and corresponding analyses for liking after the first bite, perceived naturalness and perceived healthiness, based on MFA map.

the most preferred pizzas when eaten in blind condition in the restaurant context.

From a methodological standpoint, specificities of pizza and pizza consumption led to several significant choices in the design of this study. First of all, describing multicomponent food products for such a diverse category as pizza is challenging. In this study, we chose to use conventional sensory profiling to evaluate by trained panelists the perceived intensity of descriptors that would apply across all selected pizzas. However, many characteristics were specific to few pizzas only. For this reason and to capture the diversity of the recipes, we chose to ask consumers to evaluate such specific attributes by utilizing a CATA questionnaire. Combined data from trained panelists and consumers provided a rich and complete description of the product set. In particular, the description by consumers was useful to reveal differences of aspect and identified toppings, while conventional descriptive analysis provided an accurate quantification of intensity and of subtle differences between products for key attributes such as *saltiness, stickiness,* or *hardness*. Attributes that were common to both evaluation methods such as *oily* and *thickness of the dough* were highly correlated. Overall, the relatively high RV coefficient (RV=0.73) between the two configurations indicates that both approaches led to consistent and comparable data. This supports prior findings of close agreement between conventional descriptive analysis and consumer-based methods like CATA, particularly with diverse food samples (Antúnez et al., 2017). In this case, analysis of pooled data with MFA was relevant and useful basis for external preference mapping.

Besides, we chose to conduct this study in a campus restaurant where participants have their usual dinner, an approach that have been successful implemented in other campuses (Spencer et al., 2018). Those conditions were thus as close as possible to participants' real life except for the fact that they signed up for the study, had to order pizzas and filled our questionnaire. All other contextual variables remained 'normal,' including the options for selecting sides, starters, and desserts, which were left unchanged. We thus assume this experiment bears high ecological validity (Galiñanes Plaza et al., 2022). As often with field studies, the downside of naturalistic conditions is that they involve greater sources of variations (e.g., ambient noise, social interactions, sitting location the dining room). Despite this variability, we observed significant differences in liking between the products and gained insightful results on consumer perception.

It should also be noted that in university restaurants in France, students pay a flat price that includes all basic courses (1 starter, 1 main course, 1 fruit, 1 dessert, free bread). Although participants were used to paying this price and would consider it to be normal, this is a major difference with most other dining out situations. We do not see this specific element of context as a limitation for the present study. However, price is known to play a significant role in food choices (French, 2003) and has also been shown to potentially affect liking (Just et al., 2017). Therefore, our design would be limited for the study of trade-offs between price and the various perceived qualities of the pizzas (taste, healthiness, naturalness).

In conclusion, the present study contributes to a better understanding of the drivers of liking, perceived naturalness, and perceived healthiness of a complex food product such as pizza. These three dimensions were found to be all positively correlated but large individual differences were observed, thereby highlighting the complex role of these factors in food preferences. Although surveys show that consumers may be increasingly less willing to compromise on taste for health (Verbeke, 2006), there is a lack of experimental data detailing the specific role of food sensory properties. Using pizzas as a case study, our results could lay the basis for the study of trade-offs between the different product qualities (taste, healthiness, sustainability) within a target food category. Our findings could also be used to inform the development of healthier and more sustainable options within a diverse and complex food category.

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CRediT authorship contribution statement

Anne Saint-Eve: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Isabelle Souchon:** Supervision, Funding acquisition, Conceptualization. **Louis-Georges Soler:** Supervision, Funding acquisition, Conceptualization. **Julien Delarue:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2024.105330.

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