Matching beer with food: pairing principles, underlying mechanisms and a focus on aromatic similarity

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Par

Melle Eschevins Anastasia

Associer la bière à un mets : principes d'association, mécanismes sous-jacents et focus sur la similarité aromatique

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Composition du Jury :

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Summary

Pairing between beer and dishes emerges as a new trend in France. Beer promoters or gastronomy professionals need to offer high-quality advices in terms of beer and food pairing to their customers. Within this context, the objective of the research was to identify pairing principles and to better understand the underlying perceptual mechanisms. Determinants of food and beverage pairing were first analysed from experts' discourses. Results showed that food and beverage pairings are governed by perceptual, conceptual and affective features, related to physicochemical, perceptual and cognitive processes. Experts often mentioned "Aromatic Similarity" as one of the main pairing principles. This "Aromatic similarity" principle consists in matching two products sharing similar aromas. Underlying perceptual mechanisms were then investigated. Results showed that aromatic similarity in food and beverage generally increases harmony and homogeneity and decreases complexity of the match. These effects can be reinforced by orientating the attentional focus on the shared aroma. From a theoretical point of view, this work concludes that beer and food pairing includes sensory dimensions with the search for harmony, as well as symbolic and contextual dimensions. From an applied point of view, this work provides useful information to gastronomy professionals with recent knowledge on perceptual mechanisms underlying food and beverage pairing principles.

Keywords: beer and food pairing, pairing principles, aromatic similarity, harmony, sensory complexity, liking.

Résumé

L'association de la bière avec les mets apparait comme une nouvelle tendance en France. Il est donc nécessaire pour les promoteurs de bière et les professionnels de la gastronomie de fournir à leurs clients des conseils de qualité en terme d'accord bière et mets. Au vu de ce contexte, l'objectif de la thèse était d'identifier les principes d'association et de mieux comprendre les mécanismes perceptuels qui les sous-tendent. Les déterminants des accords mets et boissons ont, dans un premier temps, été identifiés à partir du discours d'experts. Les résultats ont montrés que les associations mets et boissons sont régies par des caractéristiques perceptuelles, conceptuelles et affectives, liées à des mécanismes physico-chimiques, perceptuels et cognitifs. Les experts ont souvent mentionné la «similarité aromatique» comme l'un des principaux principes d'association. Ce principe consiste à associer deux produits partageant des arômes similaires. Les mécanismes perceptuels sous-jacents à ce principe ont été investigués. Les résultats ont montrés qu'une similarité aromatique entre un mets et une boisson augmente le niveau d'harmonie et d'homogénéité de leur association et diminue sa complexité. Ces effets peuvent être renforcés en orientant l'attention du dégustateur sur l'arôme partagé. D'un point de vue théorique, cette thèse conclut que l'association bières et mets inclut des dimensions sensorielles avec une recherche d'harmonie, mais aussi des dimensions symboliques et contextuelles. D'un point de vue plus appliqué, cette thèse fournit aux professionnels de la gastronomie, de nouvelles informations concernant les mécanismes perceptifs sous-tendant les principes d'associations.

Mots clés : association bière et mets, principes d'association, similarité aromatique, harmonie, complexité, appréciation.

Thesis Valorization

❖ Publication in peer-reviewed journal

- Eschevins, A., Giboreau, A., Allard, T. & Dacremont, C. (2018). The role of aromatic similarity in food and beverage pairing. *Food Quality and preference.* 65, 18-27

- Eschevins, A., Giboreau, A., Julien, P. & Dacremont, C. (under review) From expert knowledge and sensory science to a general model of food and beverage pairing with wine and beer. Paper Submitted in International Journal of Gastronomy and Food Science and revised in September 2018.

- Eschevins, A., Giboreau, A. & Dacremont, C. (in writing) Effect of products' labels refering to products' aroma on the effect of aromatic similarity in food and beverage pairing.

❖ Proceedings-book chapter

- Eschevins, A., Giboreau, A & Dacremont, C. (2017) Connaissances expertes des accords boissons/mets: Principes d'association des vins et bières avec les mets. Les accords mets-vins; un art français. CNRS-Edition. 257-267.

❖ Publication in the intern online journal of the Institut Paul Bocuse Research Center (MENU)

- Eschevins, A. (2016) Investigating key elements leading to food and beverage pairing: a methodological approach. *MENU: Journal of food and Hospitality research.* 5, 03-06.

- Eschevins, A. (2017) Investigation of food and beverage pairing. A review. *MENU: Journal of food and hospitality research*. 6, 11-18.

❖ Oral communication in national and international conferences

- Eschevins, A., Giboreau, A. & Dacremont, C. (2016) From beverage to companion food: Experts' principles for pairing wines and beers with food. Seventh European Conference on Sensory and Consumer Research, September, 11-14th.

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- Eschevins, A., Giboreau, A. & Dacremont, C. (2018) Effect of aromatic similarity on food-beverage pairing perception when consumers' attention is focused on aromas of interest. 2018 Meeting of the British Feeding and Drinking Group, April, 12-13th.

❖ Poster communication in national and international conference

- Eschevins, A., Giboreau, A. & Dacremont, C. (2017) Aromatic similarity and consumers' judgement of food-beer pairing. 12th Sensory Science Symposium, Pangborn, August, 20-24th.

- Eschevins, A.,Giboreau, A. & Dacremont, C. (2018) Food-beverage pairing: Does information modulate aromatic similarity effect? Eighth European Conference on Sensory and Consumer Research, Septembre, 2-5th. (Flash poster presentation)

❖ Oral communication in intern seminar

- Eschevins, A., Giboreau, A. & Dacremont, C. (2015) Beer and meal interactions: from perception to consumer judgment in actual eating and drinking situations. Annual scientific committee meeting Fund Baillet Latour Grant in Malting and Brewing Science, Leuven, January 13th.

- Eschevins, A. (2015) « Food and beverage pairing » Approches méthodologiques et premiers éléments de compréhension. Reasearch commitee of the Institut Paul Bocuse, Ecully, March, 30th.

- Eschevins, A. (2015) « A bière et à manger ». Journée des doctorants du centre des sciences du goût et de l'alimentation, Dijon, December, 15th.

- Eschevins, A., Giboreau, C & Dacremont, C. (2015) Beer and meal interactions: From perception to consumers' judgement in real eating and drinking situation. Annual scientific committee meeting - Fund Baillet Latour Grant in Malting and Brewing Science, Leuven, December, 11th.

- Eschevins, A. (2016) Ce que la science connait des accords mets & boissons. Air France formation, Institut Paul Bocuse, Ecully, January.

- Eschevins, A., Giboreau, C & Dacremont, C. (2016) Beers and meals pairing: From perception to consumer's judgement in real eating and drinking situation. Annual scientific committee meeting - Fund Baillet Latour Grant in Malting and Brewing Science, Leuven, November, 30th.

- Eschevins, A. (2017) Rôle de la similarité aromatique entre un mets et une boisson dans la perception de leur association. Atelier du Sensolier, Paris, June, 14th.

- Eschevins, A. (2017) Rôle de la Similarité Aromatique dans la perception des associations mets et boissons. Forum des jeunes chercheurs, Dijon, June, 16th.

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- Eschevins, A., Giboreau, C & Dacremont, C. (2017) Beers and meals pairing: From perception to consumer's judgement in real eating and drinking situation. Annual scientific committee meeting - Fund Baillet Latour Grant in Malting and Brewing Science, Leuven, October, 6th.

- Eschevins, A. (2017) Associations bières et mets: De la perception au jugement des consommateurs. Journée de visite de Vetagrosup au Centre de recherche de l'Institut Paul Bocuse. Lyon, November, 15th.

- Eschevins, A. (2018) Associations bières et mets: De la perception au jugement des consommateurs. Séminaire scientifique Centre de Recherche de l'Institut Paul Bocuse. Lyon, January, 18th.

❖ Poster communication in intern conference

- Eschevins, A., Dacremont, C. & Giboreau, A. (2015) Beer & food pairing: From perception to consumers' judgement in real eating and drinking situation. Scientific council of the Institut Paul Bocuse. Lyon.

- Eschevins, A., Giboreau, A. & Dacremont, C. (2016). Main principles to match wines and beers with food. Scientific council of the Institut Paul Bocuse. Lyon.

❖ Public communication

- Eschevins, A. (2016) Accords vins, bières & mets : Principes d'association. Forum des jeunes chercheurs, Besançon, June, 16th.

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Résumé en Français

1. Introduction Générale

La bière est l'une des plus anciennes boissons produites et consommées au monde (Colen & Swinnen, 2016). Des traces de boissons fermentées produites à base de riz, de miel et de fruits ont en effet été mises en évidence dans des poteries Chinoises datant de l'an 7000 av. JC. (McGovern et al. 2004). Depuis lors, les processus de brassage de la bière se sont progressivement améliorés parallèlement au développement des civilisations humaines et en particulier pendant la période des révolutions industrielles et scientifiques (voir Meussdoerffer (2009)). Puis, au cours du XXe siècle, cette boisson a acquis une renommée mondiale.

En France, selon l'institut Français d'Opinion Publique (Ifop), plus de deux consommateurs sur trois consomment régulièrement ou occasionnellement de la bière (Ifop, 2012) qui est considérée comme un produit à partager entre amis, ou en famille ou à apprécier à la terrasse d'un café. La bière est également considérée comme une boisson désaltérante, ayant un faible degré d'alcool et offrant une multitude de propriétés organoleptiques qui en font une boisson pouvant plaire au plus grand nombre. De plus, depuis quelques années, le marché des bières artisanales ne cesse de progresser et le nombre de microbrasseries recensées en 2017 en France a atteint les 1100 et ne cesse d'augmenter. Cet enthousiasme croissant pour la bière lui a permis d'être maintenant inscrite au patrimoine culturel gastronomique et paysager de la France.

Bien que seulement 11% des Français consomment de la bière pendant les repas, l'association des bières et des plats apparaît comme une nouvelle tendance en France (Pierre, 2014). Il semble en effet que la bière ait toutes les caractéristiques nécessaires pour créer une expérience plaisante lorsqu'elle est associée à un mets.

Dans ce contexte, **il est évident que les producteurs de bière ou les professionnels de la gastronomie doivent suivre cette tendance à la hausse en offrant à leurs clients des conseils de qualité en matière d'association bière et mets**.

La littérature culinaire (livres ou sites Web) est la première source d'informations pouvant aider les professionnels de la gastronomie à identifier les principes qui mènent à un bon accord bière et mets. De manière générale, les livres ou les sites Web fournissent des exemples spécifiques d'appariements (par exemple, «tacos Baja Fried-fish et une American Pale Lager», « des enchiladas de poulet au chili vert avec une bière Munich Dark Lager», etc…) ou des associations de catégories de produits. Par exemple, les bières aux fruits sont recommandées pour accompagner les desserts, les viandes blanches, les fruits de mer et les fromages, tandis que les bières IPA sont recommandées pour accompagner les plats épicés, les pizzas, les pâtes et les fromages. Cependant, en règle générale, aucune explication n'est donnée sur les raisons pour lesquelles l'association créé un bon accord.

Étendu au domaine des accords mets et boissons en général, certains experts tentent d'aller plus loin en proposant des directives pour créer un accord. En règle générale, ces directives reposent principalement sur les propriétés sensorielles des produits, de leur qualité à leur intensité. En effet, les mets et les boissons peuvent être appariés en recherchant une **similarité** (recherche de caractéristiques sensorielles similaires dans les deux produits (arômes, goût, texture, etc.)) ou du **contraste** (produit présentant diverses caractéristiques sensorielles), dans la mesure où **l'équilibre d'intensité** entre les deux produits est respecté (ni le mets, ni la boisson ne doit dominer l'accord en terme d'intensité globale). La boisson peut également jouer un rôle de nettoyant pour le palais, permettant d'apprécier la prochaine bouchée (Herz & Conley, 2015; Maresca, 1994; Pierre, 2014 , Harrington, 2008).

Même si les caractéristiques sensorielles des produits semblent contrôler principalement l'association, un autre principe souvent cité, qui n'est pas liée aux propriétés sensorielles, consiste à associer deux produits de la même région afin de créer ce qui est appelé un accord de «terroir» (Harrington, 2008; Pierre, 2014). Par exemple, «une choucroute avec

une pils alsacienne» ou «des huîtres avec un Muscadet». Ici, la dimension sensorielle de l'accord est éclipsée pour permettre aux facteurs extérieurs d'orienter le match.
Bien que ces règles ne proviennent pas spécifiquement du domaine des accords entre bière et mets, elles constituent un premier point de départ pour comprendre et identifier les objectifs des accords entre mets et boissons.

a. Parties prenantes et objectif du projet

Dans ce contexte, le **Centre de recherche de l'Institut Paul Bocuse,** le **Centre Européen des Sciences du Goût et de l'Alimentation (CSGA)** et le **Fond Baillet-Latour** ont collaboré dans le but de contribuer à la compréhension de ce qui conduit à un accord bière-mets et à l'identification des mécanismes qui sous-tendent la perception de ces accords. Le projet impliquant un laboratoire de recherche universitaire et un centre de recherche privé, une convention Cifre a été mise en œuvre (numéro de convention 2014-1465).

Les compétences et le savoir-faire respectifs des parties prenantes du projet, y compris moi-même en tant que doctorante et chef de projet, ont été nécessaires pour mener à bien ce travail. Comme mentionné ci-dessus, **l'objectif principal de ce projet était de contribuer à l'identification de ce qui constitue un accord bière et mets et de comprendre les mécanismes qui sous-tendent la perception de l'association.**

b. Questions de recherche

De nombreux déterminants de l'appréciation de l'accord, quelle que soit la boisson concernée, ont été mis en évidence dans la littérature scientifique. Ces déterminants, également appelés principes d'association, sont principalement liés aux propriétés sensorielles et collatives (Harmonie, Complexité) de l'association mais aussi aux préférences individuelles. Des conclusions semblables découlent de la littérature culinaire. En effet, la dimension sensorielle du match est celle qui est principalement abordée dans les livres ou les sites Web. **Cependant, les accords entre mets et boissons sont-ils uniquement régis par**

ces principes d'association identifiés ? Ces principes d'association sont-ils valables quelle que soit la boisson impliquée dans l'accord ? Quels sont les mécanismes physicochimiques, perceptuels et cognitifs à la base de ces principes d'association?

Pour répondre à ces questions, nous avons tout d'abord voulu vérifier que les principes d'associations identifiés dans la littérature étaient les seuls à l'œuvre dans la création d'un accord mets et boisson et s'ils pouvaient être généralisés quelle que soit la boisson impliquée dans l'accord. A cette fin, le chapitre 4 avait pour objectifs d'identifier les principes d'association à partir d'entretiens d'experts sommeliers et biérologues et de comparer les accords mets et bières et les accords mets et vins. Pour aller plus loin, nous avons confronté les principes identifiés aux connaissances des mécanismes physico-chimiques, perceptifs et cognitifs qui peuvent expliquer ces principes.

Le chapitre 5 s'est concentré sur l'un des principaux principes identifiés que nous avons choisi de mieux comprendre : la similarité aromatique. Selon les experts, une façon de créer un bon accord est d'associer deux produits qui partagent des arômes similaires. Cependant, à notre connaissance, aucune étude n'a été mise en œuvre pour vérifier cette déclaration. **Est-ce-que la similarité aromatique mène à un bon accord ? Quels sont les mécanismes sous-jacents ?** Pour répondre à ces questions, la perception et l'appréciation d'associations ayant différents niveaux de similarité aromatique ont été comparées.

Les caractéristiques aromatiques font partie des propriétés sensorielles qui déterminent la flaveur du produit tout comme les propriétés gustatives ou de texture. Les produits complexes tels que ceux que nous avons utilisés dans ce travail contiennent de nombreuses propriétés sensorielles. Chacune peut attirer l'attention des dégustateurs. Ainsi, selon les modalités sensorielles qui retiennent son attention, le dégustateur percevra une similarité aromatique entre le mets et la boisson plus ou moins forte. La provision de labels décrivant les aliments peut attirer l'attention du dégustateur sur la(les) caractéristique(s) mentionnée(s) (Spence et Piqueras-Fiszman, 2014). **L'apport de labels produits faisant référence aux arômes qui conduisent au niveau de similarité aromatique entre les mets et**

les boissons peut-elle aider à créer un bon accord en modulant la perception de l'association? Le chapitre 6 a permis de répondre à cette question.

Pour résumer, ce projet avait pour objectifs de contribuer à l'identification de ce qui sous-tend aux accords mets et bière en répondant à trois principales questions :

1) **Quels principes d'association gouvernent les accords mets et boissons and quels sont les mécanismes physicochimiques, perceptifs et cognitifs qui les sous-tendent ?** (Chapitre 4)
2) **Le niveau de similarité aromatique entre mets et boissons influence-t-il l'appréciation de leur association ? Quels sont les mécanismes perceptifs sous-jacents ?** (Chapitre 5)
3) **L'apport de labels produit faisant spécifiquement référence aux arômes qui induisent un certain niveau de similarité aromatique entre mets et boissons peut-il aider à la création d'un bon accord en modulant la perception de la paire ?** (Chapitre 6)

c. Principes d'association et mécanismes sous-jacents (Chapitre 4)

a. Introduction, Objectifs et Méthodes

Bien que l'examen de la littérature culinaire et scientifique nous a permis d'affirmer que l'association mets et boissons, quelle que soit la boisson concernée, est sous l'influence des propriétés sensorielles des produits et des préférences individuelles, de telles caractéristiques ne sont certainement pas les seules impliquées dans l'expérience d'un accord. Des facteurs externes tels que le contexte ou le cadre social dans lequel l'association est expérimentée ont également été suggérés comme étant impliqués dans l'expérience des accords mets et boissons (Nusswitz, 1991; Pettigrew et Charters, 2006; Pierre, 2014). Par conséquent, pour atteindre pleinement les objectifs de la thèse, il a d'abord été nécessaire de mettre en évidence les caractéristiques qui gouvernent les accords entre mets et boissons dans leur ensemble.

L'objectif principal du chapitre 4 a donc été d'identifier les principes d'association qui déterminent un accord entre mets et boissons. **Notre hypothèse était que les accords**

mets/boissons sont sous l'influence d'un grand nombre de facteurs qui sont principalement liés aux propriétés sensorielles des produits mais aussi à d'autres dimensions comme l'environnement social ou les caractéristiques conceptuelles des produits.

Pour résoudre cette problématique, les pratiques des experts Sommeliers et Biérologues en matière d'associations mets / boissons ont été étudiées grâce à la mise en place d'entretiens d'explicitation pendant lesquels les personnes interrogées effectuent une tâche et expliquent ce qu'elles font et pourquoi.

Vingt experts ont été interviewés. Ils ont reçu des descriptions de deux bières et de deux vins choisis de manière à ce qu'ils soient familiers pour les consommateurs français (pour le vin et la bière) et potentiellement consommés avec des aliments (en particulier pour le vin). À partir de ces descriptions et pour chaque boisson, les experts étaient invités à proposer des plats à y associer ou non et à expliquer leur suggestions. Les entretiens ont été enregistrés et transcrits puis une analyse thématique a été réalisée indépendamment par trois enquêteurs pour identifier les principes d'association.

En France, les accords mets et vins sont considérés comme le mariage «par excellence». Ils sont plus ancrés dans la culture française que l'association bière et mets et peuvent donc suivre différents principes d'association. De plus, les experts étant spécialistes du vin (sommeliers) ou de la bière (biérologues), il est possible qu'ils gèrent la tâche d'association de manière différente en fonction de la boisson concernée et selon que cela relève de leur domaine de compétence ou non. Comme indiqué dans la littérature, les associations bière/mets et vin/mets semblent suivre les mêmes règles lorsque les caractéristiques perceptuelles sont considérées, mais semblent différer en termes de dimension sociale et symbolique.

Ainsi, pour aller plus loin, ce chapitre visait également à vérifier si les principes d'association peuvent être généralisés aux deux boissons ou non et si ces principes dépendent du domaine d'expertise ou non.

L'hypothèse était que les principes d'association liés aux caractéristiques perceptuelles sont transférables d'une boisson à l'autre alors que les principes d'association liés aux aspects conceptuels et sociaux dépendent des boissons.

Pour répondre à cet objectif, une analyse factorielle des correspondances a été réalisée à partir d'une table de contingence.

b. Résultats et discussion

Les principes d'association identifiés à partir des discours des experts soulignent le fait que les associations mets-boissons sont régies par des caractéristiques perceptuelles, conceptuelles et affectives.

Les principes perceptifs identifiés sont liés aux propriétés sensorielles des produits (similarité, équilibre d'intensité, renforcement des propriétés sensorielles, etc.) et sont presque systématiquement évoqués pour justifier une association. Ces résultats confirment notre hypothèse stipulant que l'association mets-boissons est sous l'influence d'un grand nombre de facteurs principalement liés aux propriétés sensorielles des produits. Bien que la dimension sensorielle de l'association apparaisse comme étant la plus importante dans les accords, notre travail souligne également l'importance relative des autres dimensions. Les principes conceptuels sont liés aux caractéristiques autres que sensorielles des produits (identité géographique, niveau de qualité), au contexte de consommation (moment du repas, situation spécifique, saison) et aux normes (normes). Les principes affectifs sont liés aux préférences individuelles et aux émotions.

Ces résultats confirment partiellement notre hypothèse stipulant que d'autres aspects, tels que l'environnement social et les caractéristiques conceptuelles interviennent dans l'association mets / boissons.

Les experts n'ont cependant pas directement mentionné l'aspect social des accords entre mets et boissons, mais certains principes d'association tels que le principe «situation particulière» peuvent refléter cette considération. En effet, le principe de «situation spécifique» est lié à certains événements tels qu'une soirée barbecue ou un apéritif impliquant des interactions sociales spécifiques.

Ce chapitre visait également à déterminer si les principes d'appariement dépendent de la boisson ou du domaine d'expertise considérés ou s'ils peuvent être généralisés. Les résultats soulignent que les mêmes principes sont utilisés pour associer le vin ou la bière aux mets. Certaines différences de fréquence d'utilisation des principes d'association ont cependant été mises en évidence.

En effet, les principes de « normes » et d'« identité géographique » ont été plus souvent mentionnés pour les associations avec le vin que pour les associations avec la bière.

Ces différences pourraient s'expliquer par la différence d'ancrage des bières et des vins sélectionnés dans la culture et le terroir français. Par exemple, les deux bières étaient des bières belges industrielles non liées à une zone de production spécifique pour les experts français. En revanche, les deux vins étaient des vins AOC (Appellation d'Origine Contrôlée) à forte identité régionale. Ce règlement protège les produits régionaux et favorise les activités rurales et agricoles. Il est bien connu des Français en général et pour le vin en particulier.

En ce qui concerne le domaine d'expertise, les principes perceptifs ont été mentionnés par les sommeliers et les biérologues, quelle que soit la boisson. Cela suggère que les connaissances sur les principes perceptifs des accords mets et boissons sont transférables d'un domaine d'expertise à un autre. Ainsi, les sommeliers et les biérologues sont en mesure de créer un accord basé sur les caractéristiques sensorielles des produits, quelle que soit la boisson concernée.

Cependant, les experts en bière se réfèrent plus souvent que les sommeliers à leurs propres expériences et aux préférences individuelles des consommateurs. Les sommeliers utilisent des principes conceptuels (niveau de qualité) et incluent davantage de considérations contextuelles. Ces différences peuvent s'expliquer par la différence de formation des experts. En France, le sommelier est un métier à part entière. Leur domaine d'expertise principal est lié aux accords mets/vins même s'ils exercent différentes professions (sommelier dans un restaurant, détaillant de vin ou enseignant). Ils sont généralement diplômés d'une école de sommelier où ils ont été formés à marier le vin et les mets. En revanche, il n'y a pas de formation formelle pour les biérologues en France. Les personnes

qui se considèrent comme des experts de la bière peuvent être des spécialistes de la production de bière, de sa dégustation ou même de son histoire et de sa culture. Ils n'ont pas systématiquement suivi une formation en matière d'accords bières / mets et sont donc moins expérimentés que les sommeliers en matière d'appariement mets / boissons.

Dans le domaine viticole, Ballester, Patris, Symoneaux et Valentin (2008) ont suggéré que l'expertise est davantage une expertise cognitive que perceptuelle. Étant donné que les principes d'appariement conceptuels semblent être davantage liés à des connaissances spécifiques, il n'est pas surprenant que Sommelier, ayant suivi une formation spécifique sur l'appariement des mets et des boissons, inclue de telles considérations plus souvent que les biérologues.

L'un des objectifs de la thèse ayant été de contribuer à une meilleure compréhension des mécanismes sous-jacents aux accords entre bière et mets et, plus généralement, aux accords entre mets et boissons, nous avons établi des liens entre les principes d'appariement et certains mécanismes connus impliqués dans la perception d'un stimulus. Un grand nombre des principes d'association identifiés étaient liés à des mécanismes physicochimiques, perceptuels et cognitifs connus. Cependant, il n'a pas été possible de conclure avec certitude sur les mécanismes sous-jacents de chaque principe d'appariement.

d. Similarité aromatique et association mets et boissons (Chapitre 5)

a. Introduction, Objectifs et Méthodes

Le chapitre 4 a permis d'identifier les principes perceptifs comme étant les principaux déterminants de l'association mets et boissons. L'un de ces principes, le principe de «similarité aromatique» a été largement évoqué par les experts pour créer un bon accord. Il consiste à associer deux produits partageant des arômes similaires; par exemple une bière avec des notes de citron et une tarte au citron. Dans ce cas, la similarité aromatique est considérée au niveau perceptuel. **Comment le niveau de similarité aromatique perçu entre**

mets et boisson influence-t-il l'appréciation de leur association et quels sont les mécanismes de perception sous-jacents?

La similarité aromatique, considérée au niveau perceptuel, relève de l'idée que les flaveurs des deux produits se fondent en une perception unique (chapitre 4). Ainsi, la similarité aromatique entre mets et boisson conduira à une perception multidimensionnelle plus homogène de leur association. La complexité perçue est une des propriétés collatives d'un stimulus connue pour refléter un manque de fusion perceptive des propriétés sensorielles d'un stimulus ou le caractère distinct des composants du stimulus (Berlyne, 1960). Ainsi, la similarité aromatique, en menant les deux profils sensoriels des produits à fusionner en une expérience unique, devrait entraîner une diminution de la complexité de l'association. Le niveau de similarité entre deux composants d'une association influence également son harmonie perçue. Cette relation a été démontrée pour la modalité visuelle. En effet, des paires de couleurs ayant des teintes similaires étaient en moyenne perçues comme plus harmonieuses que des paires ayant des teintes différentes (Schloss & Palmer, 2011). Ainsi, transposés à la modalité aromatique, l'idée est que plus deux produits partagent des arômes similaires, plus ils créeront un accord harmonieux.

L'harmonie et la complexité perçues sont toutes deux des propriétés collatives connues pour influencer l'appréciation du stimulus selon, respectivement, une relation linéaire positive ou en U-inversé. Paulsen et al. (2015) ont souligné l'importance de l'effet combiné de l'harmonie et de la complexité sur l'appréciation des associations entre mets et boissons. Cela nous conduit à envisager d'expliquer l'impact de la similarité aromatique sur l'appréciation de l'accord comme l'effet combiné des niveaux d'harmonie et de complexité de la paire, plutôt qu'avec chaque propriété séparément, comme cela est habituellement le cas.

Notre hypothèse est qu'une similarité aromatique perçue plus élevée entre les produits, en augmentant l'harmonie perçue du match et en modulant sa complexité perçue, conduira à un accord plus apprécié que les produits ayant un niveau de similarité aromatique perçue plus faible.

Pour tester cette hypothèse, la relation entre le niveau de similarité aromatique perçu entre les mets et les boissons et la perception de leur association en termes d'harmonie, d'homogénéité, de complexité et d'appréciation a été étudiée. Un modèle théorique prenant en compte nos résultats expérimentaux pour expliquer l'effet de la similarité aromatique sur l'appréciation de l'accord à travers la modulation de l'harmonie et de la complexité a également été proposé.

Des associations ayant des niveaux contrastés de similarité aromatique ont été comparées dans deux études distinctes. Dans les deux expériences, les niveaux de similarité aromatique entre la boisson et le mets ont été contrôlés par ajout d'arômes alimentaire et fixés à deux niveaux, soit élevé, soit faible. La différence entre les deux expériences réside dans la diversité des propriétés sensorielles des produits. La première concernait des produits simples (boissons sans alcool et produits laitiers aromatisés) dans lesquels l'arôme ajouté apparaissait comme la propriété sensorielle principalement perçue des produits. La seconde concernait des produits plus complexes (bières aromatisées et purées de pommes de terre aromatisées) dans lesquels l'arôme ajouté constituait une note aromatique parmi plusieurs autres propriétés sensorielles.

Ce chapitre contient également une étude visant à tester le modèle théorique fourni qui tient compte de l'effet combiné de l'harmonie et de la complexité sur l'appréciation. En effet, même si nos données expérimentales cadraient avec ce modèle, le nombre de points expérimentaux était trop petit pour nous permettre de le valider complètement. Un examen plus approfondi avec davantage de combinaisons complexité/harmonie était donc nécessaire.

b. Résultats et discussion

Les résultats de ce chapitre ont mis en évidence le fait que la similarité aromatique perçue entre les mets et les boissons contribue, dans une certaine mesure, au jugement hédonique de leur association. Cependant, les résultats soulignent également que le niveau de similarité aromatique entre les mets et les boissons n'est pas la principale caractéristique permettant de prédire l'appréciation de l'association. Comme les différentes variantes des

mets goûtés n'étaient pas également appréciées lorsqu'elles étaient dégustées seules, la valeur hédonique de leur association avec la boisson dépendait principalement de l'appréciation des produits testés seuls. Selon le design expérimental, une boisson a été dégustée avec différents mets. Le mets le plus apprécié était celui qui conduisait au meilleur accord. Cette relation a également été soulignée par Bastian et al. (2010); Donadini et Fumi (2014); Donadini et al. (2012, 2013); Donadini et al. (2015); Harrington et al. (2008); et Harrington et Seo (2015). Cependant, lorsqu'on examine les résultats au niveau individuel, 25% des participants ont attribué à la paire présentant le niveau de similarité aromatique le plus faible un score supérieur à celui de la paire présentant le niveau de similarité aromatique le plus élevé. Nous avons suggéré que même si d'autres propriétés collatives telles que la familiarité et l'équilibre d'intensité étaient maintenues constantes sur les appariements, ce n'était probablement pas le cas pour chaque individu. Ainsi, l'appréciation de la paire peut également dépendre de son niveau relatif de familiarité et d'équilibre d'intensité.

Les résultats démontrent également que le rôle de la similarité aromatique sur l'appréciation de l'association est dû à la modulation des propriétés collatives telles que l'harmonie et la complexité. Plus précisément, un niveau élevé de similarité aromatique entre les mets et les boissons peut permettre de créer un percept multidimensionnel plus homogène, perçu comme plus harmonieux et moins complexe que deux produits présentant un niveau de similarité aromatique plus faible.

Sur la base des relations entre harmonie et appréciation d'une part et complexité et appréciation de l'autre, nous avons suggéré un modèle tenant compte de l'impact de la similarité aromatique sur l'appréciation. Bien que l'étude de validation n'ait pas permis de démontrer complètement le modèle, les données expérimentales restent compatibles avec ce modèle.

La modulation de la perception de l'appariement en fonction de la similarité aromatique a été observée avec des associations très contrastés en terme de niveau de similarité aromatique (boisson sans alcool à base de sirop de citron - produit laitier aromatisé), alors

qu'une seule modulation, soit une augmentation de l'harmonie et de l'homogénéité, soit la diminution de la complexité, a été observée avec des appariements modérément contrastés en terme de niveau de similarité aromatique (bière – purée de pommes de terre aromatisées). Ces différences observées entre les deux études peuvent être expliquées par la composition des produits en termes de propriétés sensorielles caractérisant la flaveur des produits. En effet, contrairement aux produits laitiers aromatisés et aux sirops où les arômes ajoutés contribuent de manière significative aux arômes des produits, la bière et la purée sont des produits complexes aux propriétés sensorielles diverses qui caractérisent leurs flaveurs. Cela laisse place à une modulation de l'attention dans la perception du stimulus (Keller, 2011; Marks, 2003). **Concernant la perception des associations mets et boisson, l'attention des dégustateurs peut se concentrer sur d'autres caractéristiques que l'arôme partagé, ce qui diminue la perception de la similarité aromatique.** Pour vérifier cette hypothèse, nous nous sommes demandé si l'effet de la similarité aromatique sur l'harmonie, la complexité et donc l'appréciation peut être renforcé si l'attention du dégustateur est concentrée sur les arômes d'intérets du produit qui conduisent à un degré différent de similarité aromatique.

Les label descriptifs des produits peuvent attirer l'attention du dégustateur sur les caractéristiques mentionnées (Spence et Piqueras-Fiszman, 2014). Conformément à cette idée, le chapitre suivant visait donc à déterminer si le fait de fournir des labels produits faisant explicitement référence à l'arôme modulerait l'effet de la similarité aromatique sur la perception de l'association purée/bière aromatisées.

e. Labels produits et similarité aromatique dans les accords mets et boissons (Chapitre 6)

a. Introduction, Objectifs et Méthodes

Le niveau de similarité aromatique entre deux produits module la perception de leur association. Une association mets/boisson à haute similarité aromatique est, dans une certaine mesure, plus appréciée, perçue comme plus harmonieuse et moins complexe qu'une association ayant une plus faible similarité aromatique. De telles modulations ont été

clairement montrées lorsque l'arôme partagé était pratiquement la seule propriété qui détermine la flaveur des produits. Cependant, avec des produits plus complexes dans lesquels l'arôme partagé était une note parmi d'autres propriétés sensorielles, ces modulations n'ont pas été systématiquement démontrées. Le fait que l'attention peut être portée sur les propriétés autres que les arômes peut expliquer de telles différences. En effet, dans la perception d'un accord entre mets et boisson, l'attention des consommateurs peut être centrée sur d'autres caractéristiques que l'arôme partagé par les deux produits, ce qui diminue la perception de la similarité aromatique entre le mets et la boisson. Dans ce cas, d'autres caractéristiques de l'association peuvent influencer sa valence hédonique.

Les labels produits décrivant les propriétés des produits peuvent attirer l'attention sur les caractéristiques mentionnées dans le stimulus (Spence et Piqueras-Fiszman, 2014). Conformément à cette idée, **l'objectif de ce travail a été d'étudier si l'apport de labels produit faisant référence aux arômes conduisant au niveau de similarité aromatique de l'association renforcerait l'effet de la similarité aromatique sur l'appréciation et la perception de l'accord.**

Notre hypothèse était que fournir un label produit qui mentionne explicitement l'arôme partagé renforcerait l'effet de la similarité aromatique sur la perception de l'harmonie et de la complexité de l'association ainsi que sur l'appréciation de l'accord.

Pour étudier cette hypothèse, les mêmes combinaisons bière-purée de pommes de terre que celles utilisées dans le chapitre précédent ont été préparées. Deux études ont été réalisées pour tester, d'une part, des accords entre une bière au citron et deux purées de pommes de terre différentes (avec un arôme citron ou fumé), et d'autre part, pour tester des accords entre une bière fumée et des purées de pommes de terre aromatisées au citron ou à l'arôme fumé. Dans les deux études, les associations ont été dégustées en condition aveugle puis en condition informée. En condition informée, les participants ont reçu un label produit indiquant les arômes d'intérêt (fumé ou citron). Le niveau de similarité aromatique entre les deux produits a donc été indirectement évoqué aux dégustateurs. Dans les deux conditions, chaque accord était dégusté de façon monadique et évalué pour son niveau d'appréciation, son harmonie et sa complexité. Les résultats résultant de l'évaluation des

paires réalisée en condition aveugle ont été comparés à ceux du chapitre 5. Ensuite, la perception des associations a été comparée entre la condition aveugle et la condition informée.

Étant donné que les laboratoires ne sont pas pleinement représentatifs des contextes actuels de consommation d'associations bières et mets, il serait nécessaire d'examiner cette question dans des contextes de consommation plus écologiques. Cependant, le design intra-sujet mis en œuvre dans les deux études n'est pas adapté à de tels contextes. Un design inter-sujet semble plus approprié et plus représentatif d'un contexte de consommation réel. Cependant, avant de mettre en œuvre les mêmes études dans un contexte de consommation écologique, il était nécessaire de vérifier que le design inter-sujet peut permettre d'observer des différences significatives. Pour cela, une troisième étude basée sur la même méthodologie que celle utilisée dans les deux premières études a été réalisée. La seule différence est qu'un design inter-sujet a été utilisé. Les résultats de cette étude ont été analysés avec les résultats des deux autres études.

b. Résultats et Discussion

Les résultats de ce dernier chapitre ont montré que l'apport de labels produit mentionnant explicitement les arômes d'intérêts augmentait considérablement l'écart de complexité entre les deux niveaux de similarité aromatique autant pour les paires avec la bière citron que les paires avec la bière fumée. Les labels produits augmentaient également de manière significative l'écart d'harmonie entre les deux niveaux de similarité aromatique pour les paires avec la bière fumée. Aucun effet n'a été démontré sur l'appréciation. Plusieurs raisons peuvent expliquer les différences observées entre les accords avec la bière citron et ceux avec la bière fumée.

Premièrement, le nombre de participants n'était peut-être pas assez élevé (N = 36) pour pouvoir observer une significativité statistique pour chaque paramètre. La même étude devrait être mise en œuvre avec un nombre plus élevé de participants pour rendre le test statistique plus puissant.

Deuxièmement, les arômes choisis n'étaient certainement pas autant familiers dans la bière pour les dégustateurs. L'arôme citron est couramment rencontré dans la bière par les consommateurs. Nombre de bières commerciales font la promotion de leur arôme citron (bières blanches, bières commerciales aromatisées). Même si l'on peut également rencontrer un arôme fumé dans les bières fumées, ces bières sont moins familières pour les consommateurs lambda. Il serait intéressant de sélectionner les consommateurs en fonction de leurs connaissances en matière de bière afin de s'assurer qu'ils sont également familiers avec les bières fumées. Une autre possibilité pourrait être de choisir un autre arôme souvent rencontré dans la bière et avec la purée de pommes de terre.

Néanmoins, les résultats de ce chapitre montrent que les labels produits faisant référence aux arômes impliqués dans le niveau de similarité aromatique entre le mets et la boisson renforcent l'effet de la similarité aromatique sur la perception de leur association.
De telles modulations peuvent s'expliquer par plusieurs processus. Fournir un label produit mentionnant explicitement les arômes d'intérêt peut amener les participants à porter leur attention sur ces arômes (Piqueras-Fiszman & Spence, 2015) et ainsi augmenter (lorsque les mêmes arômes sont mentionnés dans la bière et la purée) ou diminuer (lorsque deux arômes différents sont mentionnés dans la purée et la bière) le niveau de similarité aromatique perçu. Ces informations peuvent également créer des attentes qui peuvent influencer la perception de l'accord indépendamment de la similarité aromatique perçue de la paire bière-purée (Yeomans, Chambers, Blumenthal et Blake, 2008).

Ce chapitre souligne également que la mise en œuvre de design inter-sujet, mieux adaptés à un contexte écologique de consommation, ne permet pas de mettre en évidence l'effet de la similarité aromatique sur la perception des associations. Une attention particulière doit être portée au design expérimental à mettre en œuvre dans de tels contextes de consommation écologiques.

f. Conclusion générale

Pour rappel, l'enthousiasme pour la bière a atteint un niveau qui pousse les producteurs de bière et les professionnels de la gastronomie à proposer de nouvelles alternatives pour la consommation de bière. Même si seulement 11% des Français consomment de la bière pendant les repas, associer bière et mets apparaît comme une nouvelle tendance en France (Pierre, 2014) et la bière est de plus en plus suggérée pour accompagner les plats. Dans ce contexte, les promoteurs de bière ou les professionnels de la gastronomie doivent suivre cette tendance à la hausse en offrant aux clients des conseils de haute qualité en matière d'accord bières et mets. La première source d'information pouvant orienter ces professionnels est la littérature culinaire (livres ou sites Web) qui fournit un certain nombre de recommandations. Cependant, en règle générale, aucune explication n'est donnée sur les raisons pour lesquelles l'association crée un bon accord. Certain experts (sommeliers ou biérologues) essaient d'aller plus loin en proposant des lignes directrices pour créer un accord. Cependant, il est parfois difficile de distinguer les connaissances partagées par ces experts de leurs opinions personnelles.
Dans ce contexte, l'objectif principal de ce travail de doctorat était de contribuer à l'identification de ce qui fait le mariage entre une bière et un mets, et de contribuer à la compréhension des mécanismes qui sous-tendent la perception de l'appariement.

Ce travail a d'abord mis en évidence le fait qu'il existe plusieurs façons d'associer bière et mets et que cette association peut viser différents objectifs:
(1) profiter de l'association des deux produits d'une manière qui va bien au-delà de ce que l'on pourrait obtenir en ne goûtant que l'un ou l'autre;
(2) Mettre en évidence l'un des deux produits en améliorant ses fonctionnalités;
(3) Rafraîchir la bouche en permettant une expérience optimale de chaque produit au cours d'une dégustation répétée et alternée.

Selon l'objectif, différentes stratégies peuvent être mises en œuvre. Ce travail a mis en évidence que l'association bière et mets peut être régie par plusieurs principes perceptifs (modulation des propriétés sensorielles du produit), conceptuels (caractéristiques du produit

autre que sensorielle (appartenance à une région), contexte de consommation et normes) et affectifs (préférences individuelles et émotions). Certains de ces principes d'association peuvent être plus ou moins pertinents en fonction de l'objectif visé. Le principe de similarité aromatique induit un effet de fusion de la flaveur des deux produits. Il oriente l'appariement vers la création d'une association où les deux produits sont appréciés dans leur ensemble. En effet, la similarité aromatique, en créant un percept multidimensionnel homogène, harmonieux et moyennement complexe, contribue à la construction d'un bon accord.

Alors que les principes d'association ont été identifiés à travers les discours d'experts français, l'une des questions principales découlant de ce travail est de se demander s'ils peuvent être généralisés à d'autres cultures que la culture française. Existe-t-il d'autres principes d'appariement dans d'autres cultures gastronomiques? Les principes identifiés s'appliquent-ils de la même manière d'une culture à l'autre?
La culture pourrait influer sur le contenu des principes. Par exemple, quand on considère le principe des «pratiques culinaires», l'association de deux propriétés qui fonctionnerait dans une culture pourrait ne pas être pertinente dans une autre. Ainsi, les experts de différentes cultures, invoquant ce même principe, aboutiraient peut être à des combinaisons différentes selon les accords classiques dans leur propre culture culinaire. La culture peut également affecter le poids relatif des principes utilisés en combinaison. Le principe d' «identité géographique» sera probablement plus important dans un pays comme la France où les produits d'origine protégée ou contrôlée (AOP-AOC) sont nombreux et bien établis, par rapport à d'autres pays où la notion de «terroir» est moins développée. En fin de compte, des experts de différentes cultures peuvent envisager des principes autres que ceux des experts français. Ainsi, il serait intéressant d'examiner comment des experts d'autres pays justifient un match pour savoir s'ils mentionneraient des principes d'association similaires ou différents.

D'un point de vue plus appliqué, ces travaux suggèrent que les professionnels de la gastronomie ont besoin d'identifier le souhait de leurs clients en termes d'accord bières et mets, afin de déterminer quel est l'objectif à atteindre avec l'association de ces deux produits. Ils peuvent également leur suggérer ces différents objectifs et les laisser choisir

celui qu'ils souhaitent expérimenter. L'objectif oriente la sélection des principes d'association à suivre.

D'un point de vue méthodologique, ce travail de thèse souligne que, pour les études sur les associations mets et boissons, la façon dont les produits sont testés par les participants et les dimensions sensorielles évaluées par les participants (au-delà de leur appréciation) doivent être en accord avec l'objectif visé. Par conséquent, l'objectif de l'association doit être clairement énoncé dans les études futures sur les accords mets et boissons.

D'un point de vue théorique, ce travail montre que des propriétés collatives, telles que l'harmonie et la complexité, arbitrent l'effet de la similarité aromatique sur l'appréciation de l'association. Il souligne également que ces propriétés doivent être considérées en combinaison pour comprendre leurs relations avec l'appréciation. Ce travail s'est concentré sur les mécanismes qui sous-tendent la similarité aromatique, mais de nombreux autres principes d'appariement ont été identifiés et doivent être étudiés pour pouvoir comprendre l'appariement des mets et des boissons dans son ensemble. Ces travaux suggèrent que des principes d'association autres que la similarité aromatique peuvent moduler la similarité perçue entre les mets et les boissons, tels que les principes conceptuels, et que les mêmes mécanismes sous-jacents pourraient être en jeu.

En conclusion cette thèse témoigne qu'il y a encore beaucoup de chemin à faire pour comprendre les accords mets et bières. Cela ouvre la porte à de nombreuses nouvelles pistes de recherche.

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Chapter 1: General Introduction

2. Beer context

Beer defined as all fermented beverages made of starch, is one of the oldest produced and consumed beverages worldwide (Colen & Swinnen, 2016). The oldest evidence for grain-based fermented drinks comes from a chemical analysis of potteries from china dated of around 7000 BC in which evidence for fermented beverages of rice, honey and fruits production were discovered (McGovern et al., 2004). In Europe, the earliest evidence of beer production, dated for 5000 years ago (Colen & Swinnen, 2010). Since that time, beer brewing processes improved steadily in line with advances in human civilizations development (see Meussdoerffer (2009)). At the end of the 19th century, the industrial and scientific revolutions allowed brewing processes to progress and during the 20th century, the globalization allowed to raise this beverage to an orrery level.

Considering France, several thousands of breweries existed at the beginning of the 20th century, number that has continued to decline until the 80s. However during the current century, the number of small breweries developing craft beers increased again to end-up a number of 1100 in 2017. In the same line, the consumption of beer raised of 3% each year since 2015. This rising enthusiasm for beer allows it for being now listed in the cultural gastronomic and landscape heritage of France. According to the French institute of public opinion (Ifop, 2012), more than two out of three French consumers regularly or occasionally drink beer. For French beer consumers, this beverage has a strong positive image. Indeed, they state that beer is a convivial drink they like to share with friends or family members or to enjoy being sat outside a cafe. They also consider beer as a thirst-quenching drink, low in alcohol and offering a variety of flavours making it a drink that may suit everybody.

Even though only 11% of French people consume beer at meals, the pairing between beer and dishes emerges as a new trend in France (Pierre, 2014). More and more events dedicated to beer are organized and often offer recommendations or tasting workshops about beer and food pairing. In 2015 a communication campaign on beer was implemented in France and provided messages such as “it's a fact, it's not just sauerkraut that goes with beer” or “beer and gastronomy, all matches are possible” (Figure 1). This campaign aimed at

promoting beer as a product that can be offered to be consumed with dishes in the same way as wine.

Figure 1: Advertising posters

Hence, beer appears having all necessary characteristics to create a pleasant experience, when paired with a food. Added to the pleasurable characteristic of pairing beer with food, this beverage is a good alternative to wine at restaurant because of a lower level of alcohol and affordable price. This may allow consumers to drink a larger amount of fluids while respecting the legislation concerning the maximum allowed blood alcohol level, to drive and while keeping tasting pleasure.

Within this context, **it is obvious that beer promoters or gastronomy professionals need to follow this raising trend in offering to their customers, high-quality advices in terms of beer and food pairing.** One of these professional recommendations' keystones appears to be the understanding of the basic pairing principles and the underlying mechanisms. This will reinforce professional self-confidence in their advices and customers' perception of professionalism of service. All together, they make consumers' experience more enjoyable and thus will allow for improving the bottom-line profits as well as improving return business.

3. Culinary recommendations for food and beer pairing.

The first information resource that may help gastronomy professional to identify guidelines in terms of good food and beer pairing is the culinary literature such as books or websites. It provides numbers of recommendations. Generally, books or websites provide examples of matches, either in suggesting specific pairing (e.g. " Baja Fried-fish tacos and American Pale Lager", "green chile chicken enchiladas with Munich Dark Lager", "Broccoli rabe skillet pizza with white IPA", etc…) or associations of products' categories (Figure 2). For example, fruit beers are recommended as companion to desserts, white meat, seafood and cheeses whereas IPA beers are recommended as companion to spicy food, pizza, pasta and cheeses. However, usually, no explanation is given about why the association creates a good match.

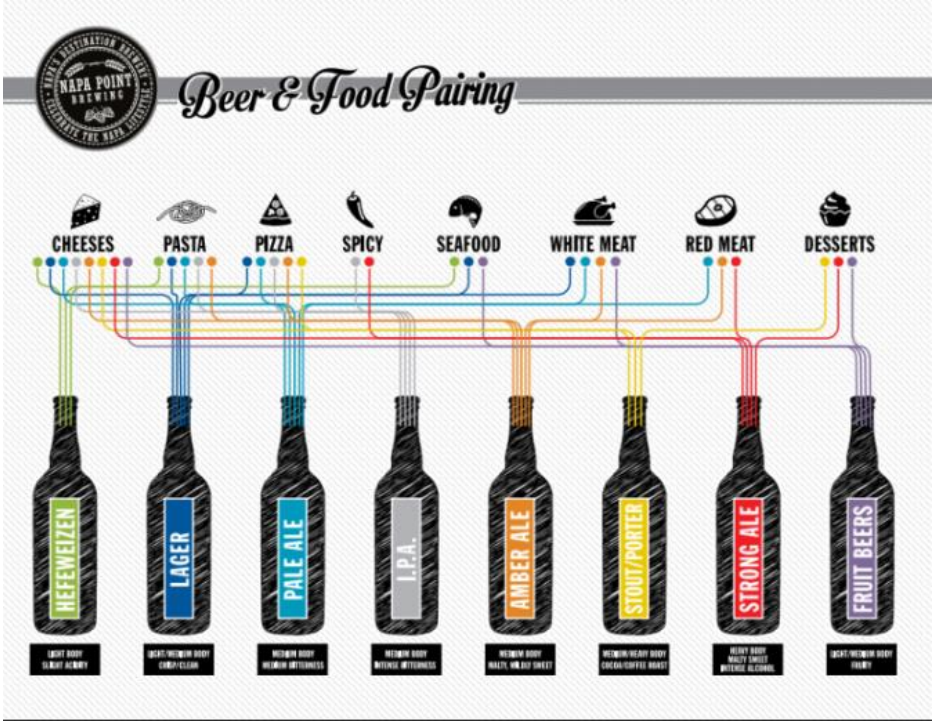

Figure 2: Example of recommendations about beer and food pairing according to products' categories.
(From www.brewbound.com)

Extended to the overall food and beverage pairing area, some experts try to go further in offering guidelines to create a match. Generally, these guidelines mainly rely on products sensory properties from their quality to their intensity. Food and beverage can be matched according to **similarity** (finding similar sensory characteristics in the two products (aromas,

taste, texture...) or **contrast** (matching product with various sensory characteristics) while the **balance in intensity** (neither the food, nor the beverage has to dominate the match) is met. The beverage may also have a role of **palate cleanser** (Herz & Conley, 2015; Maresca, 1994; Pierre, 2014).

Harrington, a culinary expert, wrote a book related to the sensory experience of food and beverage pairing. This book offers detailed guidelines to create food and wine pairing (Harrington, 2008). These rules mainly rely on experts' knowledge, but Harrington investigated also some of them thanks to sensory studies. These rules are the following:

- **Rule #1**: Food sweetness level should be less than or equal to wine sweetness level
- **Rule #2**: Food acidity level should be less than or equal to wine acidity level
- **Rule #3**: Highly salty foods work better with wines that have high effervescence
- **Rule #4**: The negative impact of bitter food is lessened when combined with wines of moderate to high levels of effervescence
- **Rule #5**: Wine tannin levels should be equal to animal-based food fattiness levels
- **Rule #6**: Wine acidity levels should be equal to vegetable-based food fattiness level
- **Rule #7**: Wine overall body should be equal to food overall body
- **Rule #8**: Food spiciness should be equal to wine spiciness
- **Rule #9**: Spicy food should be paired with off-dry, acidic white wines
- **Rule #10**: Food and wine flavor types can be matched using similarity or contrast
- **Rule #11**: Wine and food flavor intensity should be equal
- **Rule #12**: Flavor persistency of wine and food should be equal

The relationships between beverage effervescence and food saltiness and bitterness and between wine tannins and animal based food fattiness were investigated thanks to the implementation of sensory evaluations (Harrington & Hammond, 2006, 2009). Another study allows verifying if the rules #1, #7, #8 and #11 are supported in pairings between food and wine. Only the rule #11 was not supported. However these demonstrations result only from one or two studies. There is therefore a need to investigate these rules more deeply to know if they can be generalized to all pairings.

In their paper, Paulsen, Rognså, and Hersleth (2015) consulted twelve culinary books and made an overview of the most commonly cited pairing principles. Because the book of Harrington was one of the consulted references, the authors entitled the guidelines as Harrington did. The rules #1, #2, #5, #7, #10, #11, #12 were quoted in several references meaning that experts agree about these guidelines. They also identified that fatty food requires a wine that cuts through the fat (acidic, fruity or tannic) hence completing the rules #5 and #6 highlighted by Harrington.

Even if the products' sensory characteristics seem to mainly control the match, another often mentioned guideline, not related to sensory properties, consists in matching two products that come from the same region in order to create "terroir" pairing (Harrington, 2008; Pierre, 2014). For example, "a sauerkraut *with an Alsatian Pils"* or *"Oysters with a Muscadet wine"* are suggested. Here, the sensory dimension of the match is overshadowed to allow extrinsic factors to lead the match.
Although these rules do not come specifically from the area of beer and food pairing, they are first basis to understand and identify food and beverage pairings objectives.

4. Project Stakeholders and project objectives

Within this context, the present PhD project is a joint initiative by the **Institut Paul Bocuse Research Centre**, the **European Center for Taste and Feeding Behaviour** and the **Fund Baillet-Latour**. They collaborated in order **to contribute to the understanding of what leads to a beer-food matching and to the identification of the mechanisms underlying the perception of these parings.**

The **Fund Baillet-Latour** has been awarding scholarships for PhD since 1995 to promote research projects on beer, from its production to its consumption. They funded this project to help beer promoters or gastronomy professionals to better understand the basics of beer and food pairing.
The **Institut Paul Bocuse Research Centre** is a multidisciplinary center devoted to investigate the food behavior. For this purpose, researchers in food sciences, nutrition, cognitive

sciences, economy or social sciences and specialists from culinary arts and hospitality cooperate in multi-disciplinary projects.

The European Center for Taste and Feeding Behaviour (Centre des Sciences du Goût et de l'Alimentation (CSGA)) is a joint research unit (UMR) under the supervision of AgroSup Dijon (French National Higher Institut of agronomic, food, and environmental sciences), CNRS (French National Center of Scientific Research), INRA (French National Insitute of Agronomic Research) and Bourgogne-Franche Comté University. It aims at a better understanding of the physico-chemical, molecular, cellular, behavioral and psychological mechanisms that underlie the perception of food and beverages. This project was elaborated with the team CEP: "Culture, Expertise and Perception" of the CSGA that develops theoretical knowledge about perceptual and cognitive mechanisms related to the food and/or beverage experience.
As the project involved an academic research laboratory and a private research center, a Cifre convention has been implemented (convention number 2014-1465).

The respective skills and know-how of the project stakeholders, including me as a PhD student and project manager, have been necessary to complete this work. As mentioned above, the main objective of this project is to contribute to the **identification of what makes a beer-food match and to contribute to the understanding of mechanisms that underlie pairing perception**. Two research axes emerging from the literature review, contributed to clarify this problematic. The first one is dedicated to the **identification of determinants (or pairing principles) of a food and beverage pairing as reported by food and beverage experts.** The second one is dedicated to **the investigation of mechanisms that underlie one of the most mentioned pairing principles: the aromatic similarity** which consists in creating pairings with products sharing one or more similar aromas.

Chapter 2: Literature review

A beer and food pairing is the result of the combination of two complex food products that create together, a pleasant consumption experience. **What happens when two complex products are associated? What leads to a beer-food match?** To tackle these issues, we explore the scientific literature dealing with food-beer associations and extended to any food-drink pairing studies.

The present literature review provides an overview of current scientific knowledge about food and beverage associations. The currently available research papers dealing with food and beverage pairing mainly aimed at identifying the determinants of pair liking. These determinants appear to be from diverse origins and are related to the individual as well as the products' characteristics.

1. Products' liking as determinant of pair liking

Products' liking considered as the appreciation of food and drink tasted on their own, has being demonstrated as influencing the liking of the association. Several authors demonstrated that, the more the beverage or the food is liked, the more the pairing, in which they are involved, is liked (Bastian, Collins, & Johnson, 2010; Donadini, Fumi, & Lambri, 2012, 2013; Harrington & Seo, 2015; Tuorila, HyvÖNen, & Vainio, 1994). Such result was also brought into light by Harrington, Miszczac, and Ottenbacher (2008) who showed that individual preference for a type of beer when consumed without any food is a strong indicator of their best match when consumed with pizza. They asked participants to choose their preferred beer when tasted alone, and their preferred beer-pizza match. The majority of participants (67.6%) chose the beer they preferred the most to match with pizza. However, some authors advised to temper this conclusion because any preferred food and any preferred beverage do not systematically create the better match (Donadini & Fumi, 2014; Donadini et al., 2013).

The relationship between products' liking and the pair liking is not strictly linear but may reach a ceiling effect when the levels of products' liking are both high (Donadini & Fumi, 2014; Harrington & Seo, 2015). Donadini and Fumi (2014) demonstrated that the effect of beverages liking on the pair liking is not significant whenever beverage ratings fall in the

positive range of the hedonic scale. This was also suggested by Harrington and Seo (2015) results. They tested pairs of wines (Ruby Port and Sauvignon blanc) and goat cheese or dark chocolate. They asked participants to assess the liking of each product tasted alone and each association. They demonstrated that a significant relationship between liking of the food and the pair liking was observed for goat cheese and wine pairing but not for chocolate and wine pairing. Considering that participants liked chocolate significantly more than goat cheese, a ceiling effect of chocolate liking appears to reduce a potentially significant relationship between liking of the food item and the pair liking. When a food is not liked very much, the pairing liking follows the food liking: The better (less bad) the food, the better the association. But, when a food is very much liked, it may be paired with about any beverage and the resulting pairing is equally liked (providing that beverages are not too bad). Such effect was also demonstrated with wines they used in their study. Indeed, the Sauvignon Blanc was in average more liked than Ruby Port wine. As chocolate, higher liking of Sauvignon Blanc wine might induce a ceiling effect in the liking of the match. The relationship between products liking and pair liking is established. However, it can be modulated by the suitability of the bouquet of flavours that results from food and drink pairings (Donadini & Fumi, 2014; Donadini, Fumi, & Newby-Clark, 2015). In Harrington et al. (2008)'s study, the addition of moderate spiciness level to pizza changes, for some tasters, the match toward more flavourful fuller-bodied beers than those selected with non-spicy pizza. This suggests that individuals may select product to balance the flavour intensity and/or persistency of the other product.

2. Pairing intensity balance and liking

Pairing intensity balance is the extent to which, food or beverage dominates the match in terms of global intensity. A match is balanced when neither the food, nor the beverage dominates. As stated by sommeliers, a match needs to be balanced to be appreciated. Some authors considered this statement to evaluate food and beverage pairing. Donadini, Spigno, Fumi, and Pastori (2008) used a 9-point Likert-like scale anchored from (1) “definitely not appropriate” to (9) “extremely harmonic and balanced”. King and Cliff (2005), and Bastian, Payne, Perrenoud, Joscelyne, and Johnson (2009) used a 12-cm “just about right” scale with

"ideal match" at the midpoint of the scale, the left end corresponds to the dominance of the food (anchored as" food dominates excessively"), the right end to the dominance of the beverage (anchored as "beverage dominated excessively"). With the use of such scales, it is impossible for the participant to distinguish the hedonic valence of the match from its balance of intensity. Both scales convey the idea that a good match is balanced. This not allows for investigating the relationship between pair liking and pair balance of intensity.

Other authors investigated this relationship in providing participants with two distinct scales; one for the match liking (9-point rating scale) and one for the match's balance of intensity (Modified JAR scale anchored with "food dominates" at one end, "beverage dominates" at the other end and "neither the food nor the beverage dominates the match" in the middle). Controversial results have been reported. Some authors demonstrated that balanced pairings were better liked (Donadini & Fumi, 2014; Donadini et al., 2008; Paulsen et al., 2015), however unbalanced pairing may also be preferred over balanced ones (Donadini et al., 2012, 2013). This seems to depend on the hedonic valence of the dominant flavors in a given match. Donadini and Fumi (2014) declared that when bitter, roasted, tobacco-like and astringency notes are dominant flavors, consumers dislike the chocolate/tea or coffee pairing they taste. However if the dominant flavors are sweet, vanilla-like, caramel-like and milk-like notes, consumers liked the pairing.

Balance is mostly at global intensity level but some authors also explore the balance in texture perception. The body-to-body relationship is defined as the relative match between the food and the wine in regards to the feeling of weight, lightness-to-richness, smoothness-to-roughness (Harrington, McCarthy, & Gozzi, 2010) or fattiness-to-tannin (Harrington & Hammond, 2006) in the wine and food match. Harrington and Hammond (2006) focused their investigation on the balance between wine and food body. They found that for wine and food pairing, the level of match was significantly related to the balance between the wine and food body (neither dominating). When food fattiness and wine tannin are at similar intensity level when products are tasted separately, the two products would match.

To summarize, for texture, balance between food and wine body leads to a good match. However, for other modalities (aroma or taste), unbalanced pairs may be favoured over perfect balance in intensity, whenever the dominant property has a positive hedonic valence.

3. Pairing' sensory characteristics and liking

The liking of a match seems to be influenced by the dominant properties of the pairing sensory profile. Galmarini, Dufau, Loiseau, Visalli, and Schlich (2018) investigated the relationship between the temporal dominance of liking (TDL) and the temporal dominance of sensation in cheese and wine pairings. They demonstrated that the negative TDL is related to the dominance of wine sourness, bitterness and astringency. Bastian et al. (2010) demonstrated that a cheese and wine pairing is less liked when it tends to be astringent, with coarse tannins, barnyard type aroma, and low fruit intensity. For cheese and beer pairing, the liking of the match was lessened by acidity, perceived carbonation, fruitiness and the perceived alcohol level in beer, but was positively related to beer sweetness (Donadini et al., 2013). For chocolate and tea pairing sweetness as well as the caramel-like flavor, milk-like flavor and vanilla-like flavor, drove positively the liking of the match. Whereas astringency, stickiness, mouth coating, cocoa-like flavor, bitterness, tobacco-like flavor and firmness drove negatively the liking of the match between chocolate and tea. The sweetness, vanilla-like flavor, fattiness, smoked, caramel-like and milk-like flavor drove positively the liking of chocolate and coffee pairing. The flavor persistency, bitterness, astringency, sourness and dried fruit-like flavor drove negatively the liking of chocolate and coffee pairing (Donadini & Fumi, 2014).

According to these results, properties related to texture (astringency) or tastes (bitterness, sweetness, sourness) seems to influence the match liking generally always in the same way. This is no surprising because these properties, perceived in some intensity, are known to generally induce affective reactions either negative (astringency, bitterness, sourness) (Dinnella, Recchia, Tuorila, & Monteleone, 2011; Gonzalez, Adhikari, & Sancho-Madriz, 2011; Lesschaeve & Noble, 2005) or positive (sweetness) (Lindemann, 2001). However, it seems

that the hedonic valence of properties related to aroma depends on its appropriateness with the type of tasted pairing (fruitiness) (Bastian et al., 2010; Donadini & Fumi, 2014; Donadini et al., 2013).

Therefore, one way to match products would be to associate one product that will mitigate some “negative” properties and / or strengthen some “positive” properties, in the other product of the pair.

4. Modulation of products’ sensory properties.

Most of the authors that investigated the modulation of products’ sensory properties in a match compared sensory profile of one product tasted alone VS sensory profile of the same product tasted in combination with another one. To assess these modulations, authors used two different tasting methods: mixed or sequential. The mixed tasting method consists in tasting both products simultaneously in the mouth. The sequential tasting method consists in tasting one product after the other. However, even if it has been demonstrated that the modulation of tastes and flavors was greater when the pairing was assessed by mixed tasting method compared to sequential tasting method (Nygren, Gustafsson, & Johansson, 2003a), the two tasting methods can’t be strictly differentiated. Indeed, in sequential tasting method, after a first bit or sip, residuals of food and beverage stay in the mouth cavity and are mixed with the next bit or sip (O'Mahony, 1972). Thus, the nature of modulations demonstrated by both tasting methods can be considered as somehow similar.

As expected, the consumption of food could decrease or enhance the perception of some sensory properties of the drink and vice versa in a pair. Nygren, Gustafsson, Haglund, Johansson, and Noble (2001) and Madrigal-Galan and Heymann (2006), demonstrated that buttery flavor in wine was enhanced by the prior consumption of fatty food (cheese or hollandaise sauce). Nygren, Gustafsson, and Johansson (2003b) observed that wine prior consumption causes a decrease in buttery flavor, saltiness and sourness of blue cheeses. Nygren et al. (2001) also demonstrated that high fat Hollandaise sauce decreases citrus flavor of Chardonnay unoaked wine, and Madrigal-Galan and Heymann (2006) found that cheese consumption decrease oak, bell-pepper and mushroom aromas of red wines.

Donadini and Fumi (2014) found that teas consumed with 30% cocoa chocolate were perceived as sweeter and richer in milky, caramel and dried fruit aromas than when tasted alone. However, they also found that teas were perceived as more astringent, sour, bitter and salty when paired with 70% and 99% cocoa chocolate than when tasted alone. Parmigiano decreases perception of bitterness, malty flavor, carbonation and level of alcohol of beer (Donadini et al., 2013) and cheeses decrease astringency, bitterness, fruitiness, sweetness, level of carbonation, perceived level of alcohol, caramel-like, licorice-like and burnt flavors in pairing with beer (Donadini et al., 2015). Harrington and Hammond (2009) demonstrated that food bitterness was lessened when combined with drink having moderate to high levels of effervescence.

These results not allow for identifying any generalities; various properties may be modulated in pairing. A same property may be increased or decreased depending on the match. Moreover, in these studies, authors investigated how the consumption of one product can influence the perception of the other one, but their results do not allow for identifying which properties interact together. Information about how different modalities interact and what mechanisms underlie these interactions will help professionals to match products according to properties that need to be attenuated or enhanced.

5. Mechanisms underlying food and beverage pairing

Different strategies may be set up to create a match according to the properties to modulate. Based on results presented in section 4 and on general knowledge about the physicochemical, perceptual and cognitive underlying mechanisms, we suggest avenues to decrease or increase some characteristics in a match.

Concerning texture

Texture plays an important role in food and beverage liking. High astringency associated with a drying or a puckering sensation on the tongue and in the oral cavity, generally leads to a bad match. This sensation is often perceived during the consumption of beverages such as tea or wine and comes from astringent compounds (polyphenol) found is such beverages.

Peyrot des Gachons et al. (2012) and Galmarini, Loiseau, Visalli, and Schlich (2016) demonstrated that the perception of astringency increases after repeated sips of tea or wine respectively. Therefore, and because too much astringency lead to low appreciation there is a need to reduce or suppress the build-up effect of astringency in the course of consumption (repeated sips). Donadini et al. (2015) demonstrated that the prior consumption of cheese decreased the perceived astringency of beer. Such results were also demonstrated in pairings of dried meat with tea and cheeses with wines. Peyrot des Gachons et al. (2012), suggested that fattiness of dried meat allows to reduce and prevent the increase of tea astringency occurring after multiple sips. As mentioned above, Galmarini et al. (2016), showed that wine astringency temporal dominance increases over repeated sips. However, this effect almost disappears when bites of cheese were consumed in between. The astringency sensation comes from the astringent compounds that create, with salivary proteins, an insoluble complex that will precipitate in the oral cavity or alter the lubricating mucosal pellicle, inducing a loss in lubrication of oral surfaces (Garcia-Estevez et al., 2018; Ployon et al., 2018). When fatty food is consumed, the polyphenols of the beverage will bind food macromolecules in place of salivary and oral epithelium proteins inducing that lubricating salivary protein will not be precipitated (Relkin, Fabre, & Guichard, 2004). When such beverages are consumed with fatty food such as cheese or dried meat, fat from the food decreases friction in the mouth and restores lubrication (de Wijk and Prinz, 2005). The perception of astringency will be therefore mitigated.

Mouth coating effect is related to a greasy layer leaves by the product in the mouth. It is related to the amount of oily residues left on surfaces of mouth and was identified as leading to less liked match. This effect was demonstrated in pairing between chocolate and tea where it appears after the consumption of the food. In this case, there is a need to “rinse” the mouth in order to get rid of oily residues. Peyrot des Gachons et al. (2012) demonstrated that tea consumption between bites of fatty food provided a greater decrease of oral fattiness compared to water. This phenomenon may be explained by the highly emulsifying properties of saponins present in teas. Because of their amphiphilicity, the saponins create a link between hydrophobic (oil) and hydrophilic (water) compounds helping to disperce oil

into droplets in saliva (Mura et al., 2017). Those droplets are eliminated with the flow of saliva.

To summarize, texture sensation such as astringency and fattiness related to mouth coating effect, generally lead to a less liked match. To increase the appreciation of the products in a match, such sensations need to be attenuated either in restoring mouth lubrication or in rinsing the mouth from the greasy layer that forms after eating a food product.

Concerning taste

Tastes such as bitterness and sourness were also identified as negative drivers of match liking. As for astringency, there is a need to suppress or reduce such taste in pairing to enjoy the match.

Taste sensations result from the activation of gustatory receptors by sapid molecules. Thus, one way to reduce the perceived intensity of tastes is to prevent the sapid molecules to reach gustatory receptors. It can be achieve in changing the dispersion medium of sapid molecules (Coupland & Hayes, 2014) or in building a physical barrier between sapid molecules and gustatory receptors in creating a mouth-coating effect induced by the oily residues left in the mouth (Green, Lim, Osterhoff, Blacher, & Nachtigal, 2010).

Another way to reduce or suppress taste is to modulate the gustatory receptors' activation or response. Indeed, in the oral periphery, an inhibitor may interfere with taste receptor cell function or transduction mechanisms. The signal sent to the processing regions of the brain is modified at the source of the signal. For example, the umami peptides that can be found in cheese induce an inhibition of bitter taste receptor responses (Kim et al., 2015). They operate as non-competitive inhibitor of bitter components.

These ways to reduce bitterness by pairing are based on bottom-up processes inducing a change in the stimuli himself and in the information sent to the central nervous system. However, top-down processes are also involved in sensory modality perception. Indeed, central cognitive effects can occur when different taste stimuli are mixed together and the perceived intensity of one or more of the components is reduced by the perception of the

others. For example, mixture suppression occurs when sugar is added to coffee; both the sweetness of the sugar and bitterness of the coffee are reduced. Sucrose suppress bitterness through central effect (Kroeze & Bartoshuk, 1985). To demonstrate such central effect, the authors applied stimulus either simultaneously in mixture on the tongue or separately on different sides of the tongue. They found that bitterness was equally reduced whatever the procedure demonstrating that receptors are not responsible but effect occurs at central level.

Tastes not always lead to bad match. Indeed, sweetness generally leads to a good match. One possibility is therefore to enhance or create a sweetness sensation to build a good match. Perceived sweetness may be enhanced in adding another sweet stimuli (Keast & Breslin, 2003). According to this statement, on possibility to enhance sweetness in a match is to associate products that have both sweet components. However, this statement needs to be considered with care. Indeed, the enhancement of sweetness perception in sweet-sweet mixture is concentration dependent. An enhancement appears generally for low concentration whereas at higher concentration, enhancement is less common but suppression has been reported.

At the receptor levels, the enhancement of sweet intensity may results from the raise of temperature. This phenomenon is explained by the heat activation of TRPM5 which is a cation channel expressed in taste buds of the tongue where it has a key role in the perception of sweetness (Talavera et al., 2005). Thus, eating a food or a beverage that was heat up before consumption may therefore increase the sweetness perception.

Another way to increase sweetness is to play with aromas-taste interactions that are explained by central mechanisms. For example, the perceived sweetness may be enhanced by a congruent aroma (e.g. strawberry or lemon) (Schifferstein & Verlegh, 1996).

To summarize, strategies to reduce undesirable taste or enhance pleasant ones require a deep understanding of physical, chemical, transduction and central mechanisms involved in food perception.

Concerning aromas

As previously demonstrated, aroma may also lead to more or less liked match. The hedonic valence of aromas depends on the considered products' association. For example, in wine perception, oak aroma may be considered as positive or negative aroma, depending on the considered product (Madrigal-Galan & Heymann, 2006; Verdú Jover, Lloréns Montes, & Fuentes Fuentes, 2004). Indeed, the aromatic properties may be more or less appropriated to a given product.

However, depending on the hedonic valence of the aromatic property in the match, its perceived intensity will need to be decreased or enhanced. To be perceived, the volatile compounds need to be released in the gas phase in the mouth. Once in the gas phase, the volatile compounds will be able to reach the olfactory receptors present in the olfactory epithelium. Therefore, as for taste, one way to reduce undesirable aroma is to avoid aromatic compounds to reach the olfactory receptors in changing the dispersion medium of aromatic compounds (Ebeler, Pangborn, & Jennings, 1988). Thus, depending on whether the volatile compounds are retained or released, the perception of beverages' aromatic compounds will be modified. As for taste, top-down processes may also induce a decrease or even a suppression in aroma perception through, for example, masking or blending effects (Thomas-Danguin et al., 2014). Thus as for taste, strategies to reduce undesirable aroma require a deep understanding of physical, chemical, transduction and central mechanisms involved in food perception.

Considering aromas, such experts suggest to match two products sharing the same aroma. The similarity as basis of association is the basis of the food pairing theory. This theory states that products sharing aromatic components will work together. The food pairing theory was first imagined in 1992 by the chef Heston Blumenthal and the flavourist, François Benzi. It starts when the chef suggested to match caviar with white chocolate and asked François Benzi to help him to understand why these two products lead to a successful match. After a chemical analysis of both products, they stated that ingredients sharing aroma components are more likely to taste well together than ingredients that do not. Since that time the popularity of this theory has continued to rise including among reputed culinary experts who

advocated this theory to the public audience. A website, (www.foodpairing.com) dedicated to help professionals and consumers to create new food combination according to their similarity in terms of flavor components was implemented.

Despite its popularity, the knowledge about perceptual mechanisms of aroma perception and information provided by data-mining studies (Ahn & Ahnert, 2013; Ahn, Ahnert, Bagrow, & Barabási, 2011; Ahnert, 2013; A Jain, Rakhi, & Bagler, 2015; A. Jain, Rakhi, & Baglerb, 2015; Varshney, Varshney, Wang, & Myers, 2013) and experimental studies (Kort, Nijssen, van Ingen-Visscher, & Donders, 2011; Traynor, Burke, O'Sullivan, Hannon, & Barry-Ryan, 2013) refute this food pairing theory as highlighted by de Klepper (2011). These arguments led the chef Blumenthal himself to recognize the shortcoming of the flavor pairing approach. Unfortunately, this theory is currently still used as a justification of many of ingredients associations in culinary domain and is extolled as an association technique based on science.

However, science explains that it is impossible to predict aromatic quality from chemical composition. First, it is long-known that the perceived intensity of aroma is dependent on the volatile compound concentration. First, an aromatic compounds needs to reach its concentration threshold to be detected. If the detection threshold is reached, the perceived aroma intensity bear a logarithmic relationship with aromatic compounds concentration (Kamadia, Yoon, Schilling, & Marshall, 2006). This is supported by the psychophysical law of Stevens. Moreover, the perceived quality of the resulting aroma is also concentration dependent (Gross-Isseroff & Lancet, 1988). In this study, pairs from a pool of six odorants at different concentrations were presented to the participants. For each pair, they were requested to state whether the two entities of the pair were qualitatively “similar” or “different”. They found that while pairs with the same odorant at identical concentrations were judged ‘similar’ in more than 90% of the cases by all subjects, scores went down to less than 10% ‘similar’ judgements in some cases when the same odorant was presented at a 100-fold concentration difference. Moreover, food or beverage contains more than one aromatic component. The perception of aromatic component in mixture may follow different processes. In odor mixture, the perceived quality of the combination of aromatic components may be homogeneous when a single odor is perceived. This phenomenon may be the results of a complete blending or overshadowing effect. Blending effect corresponds

to the blending of the odorants in a new odor perceived as an entity which corresponds to a configural or synthetic perception process. Overshadowing effect corresponds to the masking effect of one odorant on the others because of its higher perceived intensity level. The quality of odorant mixture may also be heterogeneous when at least some odorants are perceived within the mixture. This refers to an analytical processing or olfactory information. In mixture, the perceived quality of the resulting percept is not the only dimension that is involved. Additive, synergistic and antagonistic effects may occur in intensity perception. A synergistic effect occurs when the perceived intensity of the combined components is greater than the sum of the intensity of each component considered alone. Antagonistic effect occurs when the combined intensity of two components is lesser than the sum of each component's intensity. Additive effect occur when the intensity of the combination of the two components is equal to the sum of each components' intensity (Thomas-Danguin et al., 2014).

Such arguments confirm that creating a match according to the products' sharing aromatic components does not necessarily ensure that the resulting association will work, especially if only the presence or absence of aromatic components are considered. The investigation of the perceptual processes involved in such matches should not be overlooked.

6. Complexity and harmony as determinants of pair liking

The first part of literature review highlighted that match is governed by several variables such as products' liking, the hedonic valence of the dominant properties in the match and the ability of products to reduce or enhanced respectively "negative" and "positive" properties.

Paulsen et al. (2015) introduced a new approach in investigating the match by introducing the role of collative properties such as harmony and complexity in the match appreciation. In this study, the match is considered as a whole, as a joint perception of the two products. The authors defined the perceived complexity of the match as the amount/number of sensations and aromas the taster perceived when consuming both food and beverage together.

Harmony is how the different perceived sensations go together in the match. Considered separately, the level of harmony was demonstrated as influencing the level of pair liking in a positive relationship. The authors demonstrated that the more harmonious a match, the more liked. This relationship was also reported by Choi et al. (2015) who demonstrated that the harmony of the barbecue sauce with chicken was a positive driver of liking of the association. For complexity, no clear relationship with the level of pair liking was demonstrated. However, at individual level, a highly complex pairing needs also to be highly harmonious to be appreciated. Indeed, the correlations between mean complexity and mean liking were significant only for pairings that were perceived as highly harmonious. They therefore demonstrated that the concept of "unity in variety", developed in visual modalities area is also standing for food and beverage perception.

The concept of "unity in variety" states that people prefer stimulus with a high level of complexity while the stimulus maintains a maximum of perceived unity or harmony. Variety refers to the number of perceptual properties (Berlyne, 1972). Unity refers to the perception of a whole, and coherence between properties (Berlyne & Boudewijns, 1971).

As mentioned above, complexity and harmony are both collative properties. These collative properties are stimuli's characteristics that lead to a state of arousal. The level of each of these perceived properties is dependent of the set of tasted products, and thus need some references. This implies that they are dependent of the previous experience of the responder. Lévy, MacRae, and Köster (2006) indeed reported that the relative perceived complexity of stimuli diminish with exposure.

These collative properties define the stimulus' arousal potential. Depending on its arousal potential, a stimulus will induce an arousal state, defines as a state of psychobiological alertness related to both specific and measurable physiological changes (e.g. brainstem activity), as well to behavioral processes such as attention. Generally, the higher the arousal potential, the higher the response is (Steenkamp, Baumgartner, & van der Wulp, 1996). The arousal level, induced by a stimulus experience, is itself related to liking according to an inverted U-shaped relationship (Figure 3). There is an optimum level of arousal that leads to

the highest appreciation level. Because the level of arousal is considered as directly linked to perceived complexity, the same U-shaped relationship is considered between stimulus complexity and liking, if the perceived complexity is lower or higher than the optimum of complexity, the object is less liked.

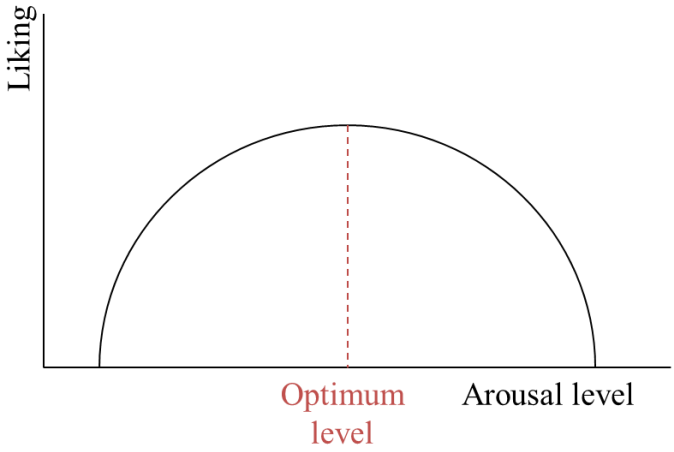

Figure 3 : Inverted U-shaped relationship between arousal level and liking adapted from Lévy et al. (2006)

This relationship is rarely highlighted for food products (Giacalone, Duerlund, Bøegh-Petersen, Bredie, & Frøst, 2014; Paulsen et al., 2015). The authors suggested that they failed in spanning the spectrum sufficiently enough to activate the minimum rejection threshold for this variable with the set of tested products. Moreover, other collative properties, such as familiarity and novelty (Berlyne, 1963, 1967), may also influence liking of a food or beverage through an arousal effect. Familiarity was identified as one of the most important drivers of food products' liking because it reduces the product uncertainty and reduces the discrepancy between expectations and product's characteristics (Tuorila, Meiselman, Bell, Cardello, & Johnson, 1994). Generally, the more familiar, the better liked (Porcherot & Issanchou, 1998). However, the relationship may reach a saturation phase if the set of tested products allow reaching higher level of familiarity. Indeed, depending on the set of tested products, the relationship between familiarity and liking may appear as being linear or as a saturation curve, suggesting that an inverted U-shaped relationship may be observed if the "rejection threshold" is reached (Giacalone et al., 2014). Contrary to familiarity, a stimulus' novelty level appears as being related to its surprising elements, not necessarily one that has not been encountered before, therefore, it is related to the difference between expectation

and perception (Giacalone et al., 2014). The relationship between novelty and liking was investigated by Giacalone et al. (2014) for different sets of beers. They found that novelty is related to liking through an inverted U-shaped relationship, more or less pronounced depending on the tested set of beers. However, the liking decreased less after the optimum level of novelty that it increased before it. The authors suggested that only very high arousal level decrease hedonic appraisal.

To summarize, the individual preferences for each products appears as being an important determinants of match liking. Generally, a products which is not so much liked will not create the better match. However, each preferred food and each preferred beverage not systematically lead to the better match. Match liking depends on the suitability of the bouquet of flavours that result from food and drink pairings. The literature review highlighted, in one hand, the importance of the complementarity function of the two products considered separately in the match. The sensory properties of each product may induce the decrease or increase of some properties of the other product involded in the match. In the other hand, the literature review highlighted the ability of the two products to create a joint percept when paired (harmony and complexity). Different strategies may therefore be implemented to create a match and the knowledge of mechanisms that underly these modulations are a strong basis to select the most proper pairing strategy.

Chapter 3: Research questions

Pairing beer and food emerges as a new trend in food service. Professionals such as beer promoters or gastronomic professional need therefore to offer high-quality advices to their customers in terms of beer-food match. These advices need to be based on strong knowledge related to determinants of beer-food pairing and to their underlying perceptual mechanisms.

The objective of this work is to contribute to the identification of what makes a beer and food match and to the better understanding of the underlying perceptual mechanisms.

Number of determinants of match liking, whatever the involved beverage, were highlighted in the literature. These determinants, also called pairing principles, are mainly related to perceptual characteristics including the pair's sensory and collative properties, but individual characteristics related to individual preferences were also identified. Regarding the culinary literature, the same conclusions emerged. Indeed, the sensory dimension of the match is the one which is mainly addressed in books or websites. **However, are the food and beverage pairings solely governed by these identified pairing principles? Do these pairing principles are suitable to different beverages involved in the match? What are the physicochemical, perceptual and cognitive mechanisms that underlie these pairing principles?**

The present work aimed at tackle these issues. We will first **verify if the pairing principles identified in the literature are the only ones involved in the creation of food and beverage matches and if they can be generalized to different beverages beyond the expertise domain.**

For this purpose, the identification of pairing principles derived from experts' interview and the comparison between pairings with beer and pairings with wine constitute the **Chapter 4**. To go further, we confronted identified principles to knowledge about chemico-physical, perceptual and cognitive mechanisms that can explain such principles.

Chapter 5 focuses on one of the main identified principles we selected to better understand: aromatic similarity. It consists in matching two products that share similar aromas. Experts state that finding aromatic similarities in two products is one way to create a good match.

However, to our knowledge, no study was implemented to verify this statement. **Does aromatic similarity leads to good match? What are the underlying mechanisms?** To answer these questions, the perception and liking of pairings with different level of aromatic similarity were compared.

Aromatic characteristics are part of the sensory properties determining product's flavors with several others such as taste or texture properties. Complex products such as some of those we used in this work contain many sensory properties. Each one may tune tasters' attention. Thus according to the sensory modalities that tunes his attention, the taster will perceive aromatic similarity between food and beverage more or less high. Descriptive food labels may tune attention toward the mentioned characteristics in the stimulus (Spence & Piqueras-Fiszman, 2014). **Does the provision of products' labels referring to the aromas that lead to the level of aromatic similarity between food and beverage may help to create a good match by modulating the pair perception? The chapter 6** allowed to answer these questions.

To summarize, this project aims at contributing to the identification of what underlie a beer and food pairing in answering three main questions:

1) Which pairing principles govern food and beverage matches and what are their underlying physicochemical, perceptual and cognitive mechanisms? (Chapter 4)

2) Does the level of perceived aromatic similarity influence the pair liking? What are the underlying perceptual mechanisms? (Chapter 5)

3) Does the provision of products' labels referring to the aromas that lead to the level of aromatic similarity between food and beverage may help to create a good match by modulating the pair perception ? (Chapter 6)

Chapter 4: Pairing principles and underlying mechanisms

1. Introduction

This thesis aims at contributing to the identification of what makes a beer and food match and to the better understanding of the perceptual mechanisms underlying beer and food pairing experience. Although the literature review (Chapter 2) allows us to claim that food and beverage pairing, whatever the involved beverage, is under the influence of perceptual and individual features related to products' sensory properties, and individual preferences, such characteristics are certainly not the only one involved in the food and beverage pairing experience. External factors such as context or social surrounding, considered as elements conditioning the overall gastronomic satisfaction, were also suggested as being involved in food and beverage pairing experience (Nusswitz, 1991; Pettigrew & Charters, 2006; Pierre, 2014). Therefore, to fully satisfy the thesis objectives, it is first necessary to brought out characteristics that govern the food and beverage pairing in its whole.

The main objective of this chapter is therefore **to identify pairing principles that determine a match between food and beverage.** Our hypothesis is that the **food-beverage pairing is under the influence of a large number of factors that are mainly related to product's sensory properties but also to other dimensions such as social surrounding and conceptual features**

To achieve this issue, investigating the experts' practices in terms of food and beverage pairing seems relevant. As reviewed by Hoffman, Shadbolt, Burton, and Klein (1995), number of methodologies may be implemented to elicit experts' knowledge. The authors classified them into three categories: (1) Analysis of the tasks that experts usually performed, (2) interviews and (3) contrived techniques.

The first category aims at investigating what experts do when they conduct their usual problem solving or decision-making tasks. Generally knowledge elicitation starts with a "*Document analysis"* which allows for identifying promptly available basic knowledge and definitions, from books, protocols, teaching supports, website, etc…(Bowen, 2009). The extracted Information generally not meets all the terrain realities but may allow orientating and developing protocols to go further in the task investigation. Task analysis may also be

performed directly in observing experts at work in order to describe jobs and subtasks and/or to yield job objectives or specifications. However, such methodologies not allow identifying the cognitive processes that lead to the tasks. To highlight such processes, protocol analysis or "think aloud problem-solving" methodology where interviewee explain what they do, may be implemented. They can yield information about the reasoning sequences and goal structures in experts' problem solving.

Research interviews aim at investigating what experts report doing in order to explore expert's knowledge and reasoning.

In *Unstructured interview,* respondent develops the topic by answering an open question. The investigator will only use reminders to help the respondent to deepen his discourse, but will not introduce new information or orientation. In *Semi structured interview* introductory instruction are provided, then the various themes are introduced in function of the respondent' discourse progress. The investigator prompts the respondent whenever one theme is not spontaneously addressed. *Structured interview* is similar to the questionnaire method, but with open questions rather that multiple choices or scales. Focus *group* differs from the interviews because they are carried out with small groups of respondents. Thus respondents shared their opinions and discuss about their views.

Explanation interview or *Self-confrontation interview* may also be implemented to explore experts' knowledge and practices. These interviews aim at developing "the experience or pre-reflexive conscience (that can be discussed or explain) or immediate comprehension of the actor upon each moment of his/her activity" (Theureau, 2002). The respondent is confronted with records related to his/her activity and invited to detail, demonstrate and comment on the most significant points of this activity, in the presence of the interviewer (Theureau, 2010). It could be also carried out from what experts remember about an action.

Contrived techniques consist in modifying familiar task in asking experts to perform an unfamiliar task (e.g. rating and sorting tasks) in order to force them into conforming their reasoning strategies to unfamiliar formats. Such methodologies are another way to reveal experts' knowledge and reasoning.

In our case, the most appropriated methodology to identify pairing principles seems to be explanation interviews where test cases are presented. Interviewees perform a task and

explain what they do and why. Such methodology was implemented with Sommeliers and Beer experts, specialists in food and beverage pairing.

Twenty experts were interviewed. They were provided with descriptions of two beers and two wines selected as to be familiar for French consumers (for wine and beer) and as potentially consumed with food (especially for wine). From these descriptions, experts were asked to suggest dishes what would match and explain why. They were also asked to suggest dishes that would not match and why. Experts are placed in realistic situations. The objective is to be as close as possible of their usual practices. Interviews were recorded and transcribed. A thematic analysis was performed independently by three investigators to identify pairing principles.

In France, wine and food pairing is the match “par excellence”. It is more anchored in French culture than pairing beer with food and may follow different pairing principles. Moreover, experts in beverage may be specialist of wine (Sommeliers) or beer (Beer experts) and handle pairing task in a different way according to the beverage involved depending whether it falls under their expertise domain or not. As raised from the literature, beer-food and wine-food pairings seems to follow the same rules when perceptual characteristics are considered but seem to differ about social and symbolic dimension.

Thus, to go further, this chapter also aimed at verifying if pairing principles are domain-dependent or if they can be generalized to the two beverages beyond the expertise domain.

The hypothesis is that pairing principles related to perceptual characteristics are transferable from one beverage to another whereas pairing principles related to conceptual and social aspects are beverage-dependent.

To satisfy this objective, a correspondence analysis was performed from a frequency matrix built with the number of sommeliers and beer experts mentioning each principle, for each drink.

This work is presented in Article 1, submitted to the International Journal of Gastronomy and Food Science (in revision).

2. From expert knowledge and sensory science to a general model of food and beverage pairing with wine and beer (Article 1)

Title: From expert knowledge and sensory science to a general model of food and beverage pairing with wine and beer.

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Abstract: Pairing food and beverages is a traditional practice in French gastronomy. Culinary literature provides recommendations in terms of food and beverage pairing but identifying general strategies to create a match is still difficult.

This work aims at identifying what makes a match between food and beverage according to experts and at investigating whether explanations are domain-specific or generalizable. Explanation interviews (or self-confrontation interviews) were conducted with Sommeliers (n=10) and Beer experts (n=10). They were asked to suggest food-beverage pairings and to explain why the pairs would or not would match. From these interviews, fifteen pairing principles were identified. They correspond to strategies and prerequisites to consider to create a match. They are related to perceptual, conceptual and affective categories and aim at creating pairing according to various objectives: creating a unique match experience, highlighting one of the two products, and enjoying the experience of each product in the pair. These principles are related to both perceptual and physiochemical underlying mechanisms. Generally the same pairing principles may be considered to match food with either wine or beer. However matches based on norms and conceptual association were more often mentioned for wine than beer. Some differences were also highlighted between experts of different domain: beer experts used more experiential discourse than sommeliers who more often referred to conceptual principles.

Keywords: Wine, beer, food-beverage pairing, pairing principles, experts.

1. Introduction

Pairing food and beverages is a traditional practice of French gastronomy. Most (87%) French consumers consider wine to be the most important element to match with food (Ifop, 2014) and food-wine pairing is part of the French Gastronomic Meal, registered since 2010 in the Intangible Cultural Heritage of Unesco. Although beer is less culturally anchored in France, with the exception of some regions, it was added to the "French protected cultural, gastronomic and landscaped" heritage in 2014. Although only 11% of French people consume beer at meals (Ifop, 2012), pairing beer and dishes is emerging as a new trend in addition to the deeply embedded wine and food pairing (Pierre, 2014).

Generally, culinary books or blogs suggest dishes to go with a selection of beverages, or vice versa, but without any explanation on why they match. However, Maresca (1994, p.7) mentioned that "Success in wine and food matching depends on nothing more abstruse than finding out why certain foods and wines affect each other for good or for ill and learning how to generalize from that simple information to predict the way other wines and food will interact". In line with this comment, some experts try to go further by listing the main pairing principles corresponding to strategies and prerequisites to consider to create a match (Harrington, 2008; Paulsen et al., 2015; Pierre, 2014). These principles rely primarily on products' perceptual properties including all sensations perceived during tasting: tastes (acid, bitter, sweet, salty, umami), aromas (lemon, smoked, red fruits, etc.), texture (fattiness, astringency, carbonation), appearance (colour, shape, turbidity, etc.), temperature (hot, cold, cool etc.), and trigeminal sensations (pungency of mustard, fresh menthol or hot pepper). Principles are also based on non-perceptual properties, such as the principle based on "geographical identity" consisting of matching two products related to the same area.

However, experts' terminology related to pairing principles is not always standardized and different experts may use different words to refer to the same principle. It is often difficult to distinguish shared knowledge from personal opinions. Moreover, external factors such as context or social surrounding, considered as elements conditioning the overall gastronomic satisfaction, were also suggested as being involved in food and beverage pairing experience (Nusswitz, 1991; Pettigrew & Charters, 2006; Pierre, 2014).

The main objective of this work was to identify, in a more exhaustive way, what makes a match between food and beverage according to experts.

To overcome these issues, several experts were interviewed. They were placed in a realistic situation, asked to suggest food-beverage pairings, and asked to explain why the pairs would or would not match.

Another objective was to determine whether pairing principles are product-specific or can be generalised. As a matter of fact, Pettigrew and Charters (2006) reported that consumers' and experts' expectations differ when pairing food with either beer or wine. The symbolic, social, and hedonic aspects weight differently. Moreover, because sommeliers and beer experts differ in their expertise, the objective of this work was also to verify whether experts mention similar principles according to their expertise domain or if their discourse differs.

Thus, Sommeliers and beer experts were interviewed and asked to suggest dishes that would match with two wines (one white and one red) and two beers (one blond and one white).

Pairing principles were first identified from the experts' statements based on a thematic analysis of the transcripts. Then, the use of these principles was compared according to expertise domains (sommeliers vs. beer experts) and product types (wine vs. beer).

2. Materials and Methods

2.1. Participants:

Ten Sommeliers (3 women and 7 men) and ten Beer experts (1 woman and 9 men) were interviewed. Wine experts, of French nationality, were recruited through the ASLERA (Association des Sommeliers Lyonnais et de la Région Rhône Alpes) and the Trophée Lyon Beaujolais Nouveau contest. Beer experts, 9 French and 1 French Belgian, were recruited through the Association Française des Biérologues (Association of French beer experts). All the experts practice in France with the exception of one who works in Belgium. The experts had a professional experience of 1 to 48 years (mean = 18 years). They have different occupations: consultants (3 sommeliers / 4 beer experts), teacher at culinary school (1 sommelier), wine or beer retailers (2 sommeliers / 4 beer experts), restaurant sommeliers (3 sommeliers), contests organizer (1 sommelier), brewing group employee (1 beer expert) and a beer expert still in the training period.

2.2. Procedure:

Face-to-face explanation interviews were conducted with the experts. Two French wines and two international Belgian beers were selected to be presented as descriptions to the experts in a randomized order. The two wines were selected by a French sommelier to represent French wines often offered with food (one red wine and one white wine). The two Belgian beers are among the most popular commercial beers in France. The beverages were chosen to be different enough to elicit different pairings.

For wines, the appellation, the vintage, the producer, the cuvée, and a general description from the producer's web site were available. For beers, the products' name and description were available and came directly from the producer (See Appendix A).

Interview guides were used to ensure topics of major interest were covered. For each beverage, experts were asked, first, to suggest dishes to match it and to explain the reasons for their choices and second, to suggest dishes that do not go well with the beverage and to explain these choices also. Appendix B provides a list of suggested dishes, for each beverage.

Before starting the interview, all experts gave their informed consent. Each interview lasted about one hour and was recorded with a voice recorder. The participants' anonymity was assured according to the laboratory's instructions.

3. Analyses

The discourse analysis was performed by three investigators. In the first step, they identified principles used by experts from interviews. This led to an analysis matrix used for the final analysis. Each investigator, independently, identified for each expert and each wine/beer the mentioned principles. Then, they compared their analyses. Whenever disagreement was observed, they sought consensus by discussion. When consensus was not possible, the verbatim was not considered for further analysis.

In the second step, the number of sommeliers and beer experts who had mentioned each principle was determined for wines and beers separately. Data were arranged in a frequency matrix with principles in columns and every expert type/beverage type combinations in rows. The matrix was analyzed by a Correspondence Analysis (CA) which converts data into graphical display to describe the relationships among variables (pairing principles) (Benzécri & Bellier, 1976).

4. Results and discussion

4.1. Identified pairing principles

Experts mentioned eighteen pairing principles related to three categories: a perceptual category related to characteristics such as aroma, taste, texture, etc., a conceptual category related to geographical identity and context of consumption, and an affective category related to consumers' preferences and emotions.

Category	Pairing principle	Proportion of experts mentioning the principle (%)				
		Total experts	Sommeliers	Beer experts	Wine	Beer
Perceptual	Balance of intensity	100	100	100	90	90
	Balance of quality	75	70	80	70	50
	Harmony	65	60	70	45	55
	Similarity	100	100	100	90	95
	Culinary practices	75	80	70	65	50
	Avoid off-flavor	30	40	20	30	5
	Rinsing effect	70	70	70	55	45
	Decrease of sensory property	85	90	80	70	50
	Enhancement of sensory property	80	80	80	70	35
Conceptual	Norms	65	60	70	60	40
	Geographical identity	75	90	60	65	35
	Quality level	65	90	40	40	55
	Moment of the meal	80	80	80	60	45
	Specific situation	65	90	40	50	50
	Season	40	40	40	20	30
Affective	Individual preferences	60	50	70	30	40
	Surprise	40	30	50	25	30
Other	Experience	25	20	30	10	15

Table 1: Identified pairing principles and proportion of experts who used them, in total, by expert specialty (Sommelier vs Beer experts) and by beverage type (Wine vs Beer).

4.1.1. Perceptual pairing principles

Balance of intensity

The prerequisite to match food and beverage seems to be a global balance of intensity between the two products such that neither the food nor the beverage dominates overly within the pair:

"*We stay in a range where both wine and dish are balanced in terms of power, degree of power, that is very important at that level*" "*on reste dans un registre où on a à la fois un vin, à la fois un plat qui s'équilibrent en terme de puissance, de degrés de puissance qui est très important à ce niveau-là*" *(Sommelier).*

Balance of intensity seems so obvious that experts specified this principle to explain reasons for bad matches, whereas they rarely mentioned it when suggesting good matches. Indeed, they stated that whenever the properties of the dominant product completely mask the properties of the other one, it is not a match.

"we would not choose a cabbage stew, because there is pork with a lot of salt, and with strong tastes, so the white beer will be crushed" "on ne mettrait pas une potée au choux, parce qu'on est sur du porc avec beaucoup de sel, et avec des goûts marqués, donc là, la bière blanche elle va se faire écraser" (Sommelier).

Few studies have demonstrated such a principle except Paulsen et al. (2015) who showed that for beer and soup pairing, balance of intensity was a good predictor of liking the match. Others studies showed similar results (Bastian et al., 2010; Bastian et al., 2009; Donadini et al., 2008; King and Cliff, 2005). However, the authors used bi-polar rating scales anchored with "the food dominates" at one extremity, "the drink dominates" at the other, and "ideal match" in the middle. As the scale itself conveys the idea that balance of intensity leads to a good match, finding a link between those two dimensions seems to be tautological. By contrast, Donadini and colleagues (2014; 2012, 2013), reported that unbalanced pairs are favoured over balanced ones. The discrepancies between Donadini's findings and experts' statements may come from the fact that experts refer to a massive imbalance with one product that "overwhelms" the other one or one product that "disappears". In Donadini's studies, imbalance seems rather moderate; one product is more intense than the other one but both are still perceived. Therefore, a strong imbalance could be detrimental to pairing

whereas a moderate imbalance may leave room for other association principles. Donadini et al. (2012) and Donadini and Fumi (2014) hypothesised that unbalanced pairing could be favoured over perfectly balanced ones as long as the dominant property has a positive hedonic valence. Experts bring out another consideration in justifying a slight imbalance of intensity in pairing: the aim of the association. If the pairing is aimed at valuating one of the two products in the pair, this product should be slightly more intense. The second product is then perceived in the background, highlighting or enhancing the "main" product.

"Sometimes a food and wine pairing can be ah ... Stéphane Montez (a wine producer) presents his products, we may imagine that we make dishes a little bit below, a little more discreet, which finally let the wine express fully, because we will try to flatter the wine. [...] the wine will dominate the dish a little" "Parfois un accord mets et vin ça peut être ah... Stéphane Montez présente ses produits on peut imaginer qu'on fasse des plats un petit peu en-dessous, un peu plus discrets, qui laissent finalement le vin s'exprimer, parce qu'on va chercher à flatter le vin. [...] le vin va dominer un peu le plat" (Sommelier).

This shows that food-drink pairing may address two goals. It can either promote a unique consumer's experience where food and drink are perceived as a whole with both products' characteristics perceived together, or it could be aimed at promoting one product, the characteristics of which should dominate, whereas the companion product is in the background.

Balance of quality

Together with balance of intensity, a good match needs a balance of quality. Balance of quality implies that contrasted flavors are perceived with equivalent intensity levels, as illustrated by this quote: *"I would choose Blue cheese for its smooth, fresh, sweet, acid characteristics, so with the sweet bitterness of the white beer, there will be sweetness, sourness, bitterness, forming some balances in the mouth" "pour le coté onctueux, frais, sucré, acide donc avec la douce amertume de la blanche là on aura le sucré, acide, amer et en bouche il y a des équilibres qui se formeraient" (Sommelier).*

Here, sweetness, sourness, and bitterness intensities are balanced; thus, the resulting flavor is equilibrated. Such balance of quality, also called "contrast" in expert literature, seems

close to the oenologists' notion of well-balanced wine. It refers to a balance in intensity of taste and astringency perceptions, in line with Meillon et al. (2010)'s definition of wine balance: "none of the perceived sensations dominate in the mouth".

However, experts moderate this statement, explaining that if the intensities of the opposed flavors are too strong, the contrast is too pronounced and does not lead to a good match: *"A total opposition between sweetness and sourness, very strong on both sides, too much to match" "opposition complète de l'univers du sucre et l'univers de l'acidité très marqué des deux côtés, trop pour qu'ils puissent s'entendre" (Sommelier).*

In both balance of intensity and balance of quality principles, the pair is considered as a whole and the match as a global perceptual experience. Characteristics of the two products should be perceived as a harmonious whole.
"For me, in a pair, the ideal is that the two products express themselves, are harmonious [...] the idea is that we can taste both of them" "Pour moi, dans un accord, l'idéal est que les deux produit s'expriment, soit harmonieux […] l'idée c'est qu'on puisse sentir les deux" (Beer expert).

Harmony

Experts stated that a good match should have a high level of harmony. Harmony, defined as "how well sensations go together", highly correlates with the liking of the match (Eschevins et al., 2018; Paulsen et al., 2015). Therefore, harmony seems to be the goal when pairing food and beverages.

Experience

In some occasions, experts suggested matches based on autobiographic memories. They only mentioned that they already tasted the association and experienced harmony. In this case, they do not analyze the match in terms of pairing principles. However, this way of suggesting pairing is not very frequent. Generally, experts refer to one or several principles to explain their choice.

Similarity

Similarity consists of associating two products that share one or more properties namely aroma and taste but other modalities such as texture and color were also considered. For aromatic similarity, the idea is that similarity between the two products increases with the number of their shared aromatic note.

“a small fruit salad with a small scoop of vanilla ice-cream because we would have also the vanilla aroma that is there (in the beer)” “une petite salade de fruit avec une petite boule de glace vanille parce qu'on retrouverait la vanille qui est là (dans la bière)” (Sommelier).

Or " *A St Joseph wine with a "black forest" patisserie [(a cake with cherry, Chantilly cream, and chocolate)] where we would have also the red fruit aromas" "avec une Forêt Noire où on va retrouver les arômes de fruits rouges"* (Beer expert).

Aromatic similarity has been found to increase harmony as well as to modulate complexity of the pairing and thus increase pair liking (Eschevins et al., 2018).

Experts reported similarity as an easy and safe way to match products, while minimizing risks of mismatch. They also mentioned that associating food and beverages based on similarity increases the intensity of the shared properties in the match. Therefore, the pleasurable disposition of this type of pairing may depend on both the hedonic valence and the resulting intensity of the shared characteristics.

“with a vanilla dessert, all of a sudden, it will drive the Blond Leffe in a totally different direction, suddenly the vanilla of the blond Leffe stands out with an <u>enhancement on both sides</u>” “si on la met sur un dessert à la vanille tout à coup ça va mettre la Leffe blonde en avant sous un angle totalement différent, tout à coup la <u>vanille de la Leffe blonde ressort</u> de façon qu'il y ait <u>une accentuation qui se répète des deux côtés”</u> (Beer expert).

Culinary practices

More challenging than similarity, associating characteristics that have different qualities was mentioned by 75% of the experts. They stated that this association mimics common culinary practices. The principle is that one product, usually the drink, adds some target property to the food. This type of pairing works because it echoes a classical accord in the culinary

tradition, in which food is often consumed in association with another one, for instance a seasoning, which brings about a target property:

"you have that fruit, so it's like you'd served a red and black fruit coulis with your chocolate mousse" "vous allez avoir que le fruit donc c'est comme si vous avez servi un coulis de fruit rouge et noir avec votre mousse au chocolat" (Sommelier).

Because two flavors are encountered together on a regular basis, the association becomes familiar and its appreciation increases. This could be explained by a mere-exposure effect (Zajonc, 1968).

Avoid off-flavor

Associating similar or dissimilar aromas aims to create harmonious associations. However, experts explain that it may also lead to an opposite effect by creating an "off-flavor" or "off-taste" that was not originally perceived in the food or in the drink. The idea is therefore to avoid the emergence of off-flavor to create good match.

"Of course, we will avoid goat cheese […] for the chemical issue, tannins flocculate in the presence of lactic acid. Then, they become soapy, sapid and generate a lot of bitterness" "on évitera bien entendu tous les chèvres […] pour la problématique chimique, les tannins floculent avec la présence de l'acide lactique. Donc ils vont devenir savonneux, sapide et générer énormément d'amertume" (Sommelier).

Off-flavor or off-taste seems to result from physicochemical interactions leading to new compounds as mentioned above. For example, Spence, Wang, and Youssef (2017) mentioned that the association of red wines with seafood is known to develop an unpleasant fishy aftertaste resulting from physicochemical interactions between the wine's ferrous ions and lipid hydroperoxides derived from unsaturated fatty acids in seafood (Tamura et al., 2009).

The pairing principles presented so far create a match because the food-drink association leads to a unified experience. But, experts also match products in order to preserve or even enhance the experience of each product. They distinguish three principles: 1) **rinsing** aims to preserve the original qualities of each product, 2) **masking** aims to suppress off-flavor in one product, and 3) **synergy** aims to enhance one positive characteristic in one product. All three

289 principles relate to temporal modulation of perceptions in repeated and alternate
290 consumption, originating from carry-over effects.
291
292 **Rinsing effect**
293 In a pair that employs the rinsing effect, the beverage allows the taster to take full
294 advantage of the next bit of food by "rinsing his palate" and preventing an increase in
295 intensity. A number of experts stated that some beverage characteristics allow for taking the
296 grease out of the mouth. This rinsing effect may be due to acidity, astringency, or
297 carbonation:
298 *"Blond Leffe will give me a light fizzing on the tongue, […], and thus, I will get rid of the*
299 *greasiness of my foie gras. So, I would not have saturation enjoying the slice of foie gras"*
300 *"Leffe blonde va me donner un léger pétillement sur la langue, […], et que du coup, je vais me*
301 *débarrasser du gras de mon foie gras. Donc, je vais dire que je n'aurais pas de saturation*
302 *pour apprécier la tranche de foie gras." (Beer expert)*
303 This phenomenon has also been raised in interviews in which the interviewee claimed to
304 drink a great deal of wine "because it's a good beverage to wash down food" (Pettigrew and
305 Charters, 2006, p 174).
306 Peyrot des Gachons et al. (2012) demonstrated that tea consumption between bites of fatty
307 food decreased oral fattiness more than water. This phenomenon is due to the highly
308 emulsifying properties of tea-leaf saponins (Mura et al., 2017). Conversely fatty food
309 consumption decreases astringency perception. For instance, Donadini et al. (2015) showed
310 that cheeses such as Gorgonzola or Mozzarella decrease beer astringency. Peyrot des
311 Gachons et al. (2012) also found a similar effect with dried meat and tea. This effect is
312 especially noticeable in repeated consumption. For instance, Galmarini et al. (2016) showed
313 that wine astringency increases over repeated sips, leading to a decrease in liking. However,
314 this effect almost disappears when bites of cheese are consumed between consecutive sips.
315 Consequently the liking of the wine was stable over the series of sips. In this case, matching
316 wine and cheese keeps both products enjoyable over the whole tasting experience.
317 The mechanisms that underlie astringency perception are complex (Laguna, Bartolomé, et
318 al., 2017; Laguna, Sarkar, et al., 2017). Among others, astringency is related to the creation
319 of an insoluble complex between astringent compounds (tannins in wine for instance) and

salivary proteins, inducing a loss in lubrication of oral surfaces (Garcia-Estevez et al., 2018; Ployon et al., 2018). But when wine is consumed with cheese, fat from the cheese decreases friction in the mouth and restores lubrication (de Wijk and Prinz, 2005).

Decrease of sensory property

Beyond a mere rinsing effect, the companion product may have a corrective effect by masking a negative or disliked characteristic in the primary product:

"(*the Blond Leffe beer*) *will bring a refreshing side, it will somewhat mitigate the violence of anchovies or certain olives" "(la bière Leffe Blonde) apportera un côté rafraichissant, ça atténuera un peu la violence des anchois ou de certaines variétés d'olives" (Sommelier).*

Such interactions were demonstrated for pairings between wine and cheese (Madrigal-Galan and Heymann; 2006). The prior consumption of cheese induced a decrease in the perceived intensity of oak and mushroom aromas in wine. Such aromas were identified as factors that negatively influence pair liking.. In the same vein, prior consumption of Parmigiano cheese decreases bitterness, astringency, malty flavor, carbonation, and level of alcohol of beer (Donadini et al., 2013); high fat Hollandaise sauce decreases the citrus flavor of Chardonnay unoaked wine (Nygren et al., 2001); and wine decreases the buttery flavor, saltiness, and sourness of blue cheeses (Nygren et al., 2003).

This modulation occurs with off-flavor (Bastian et al., 2010) or with a property at a higher than optimal intensity. In both cases, pairing improves liking of a product which was initially moderately liked. Such an effect may involve several mechanisms. It could involve peripheral interactions such as bitterness suppression by umami due to suppression of the salicin-induced activation of the hTAS2R16 bitter taste receptor (Kim et al., 2015), or the competitive interactions at the olfactory-receptor level for aroma-aroma interactions. It could involve perceptual interactions occurring at the central level, such as lateral inhibition in the olfactory bulb, leading to a loss of information about an odorant in a mixture (Thomas-Danguin et al., 2014). Such an intensity decrease could also originate from a change in the stimuli themselves. For instance, increasing viscosity decreases aroma diffusion and thus increases the time to reach maximum aroma intensity (Tournier et al., 2009). Thus,

consuming a drink (liquid) and food (solid or semi-solid) in sequence increases the viscosity of the bolus and decreases the intensity of some of the drink aromas.

Once again, as stressed by one expert, if the masking effect can act for the best by decreasing negative characteristics, it can also be detrimental by decreasing the intensity of positive characteristics; the product is less liked and the match is not so pleasant.

Enhancement of sensory properties

Finally, experts mentioned the enhancement of sensory properties. This refers to the increase of the intensity of one or more positive characteristics of one product by the other one:

"The slightly spicy aspects that we will find in this beer with cloves, delicately spiced, even a little caramelized will be able to bring out the aromas of the cheese" "les aspects un peu épicés qu'on va retrouver dans cette bière là avec clous de girofle, délicatement épicé, voire même un peu caramélisé va pouvoir faire ressortir les gouts du fromage" (Beer expert).

In their studies, Nygren et al. (2001) and Madrigal-Galan and Heymann (2006) demonstrated that buttery flavor in wine was enhanced by the prior consumption of fatty food (cheese or hollandaise sauce). Donadini and Fumi (2014) found that after the prior consumption of chocolate with 30% cocoa content, teas were perceived as sweeter and richer in milky, caramel, and dried fruit aromas. However, they also found that teas, paired with 70% and 99% cocoa, were perceived as more astringent, sour, bitter, and salty than when tasted alone, stressing that according to the hedonic valence of the enhanced property, the carry-over effect can lead to a good or bad match.

Carry-over effects may be due to a change in the stimuli. For instance, residues from the first product remain in the mouth and distort the perception of the subsequent product. They can involve central mechanisms such as a synergy effect in aroma mixture perception (two odorants in a mixture are both perceived with an intensity higher than their perceived intensities alone) (Thomas-Danguin et al., 2014). Nevertheless, the taste-aroma interaction is a well-known phenomenon inducing aroma enhancement (Noble, 1996). An expert indirectly mentioned this type of interaction without necessarily knowing the underlying perceptual mechanism:

"in the mouth it could develop the lemon pie aromas as there is sourness" "en bouche ça pourrait développer les arômes de la tarte au citron comme on est sur de l'acidité" (Beer expert).

4.1.2. Conceptual pairing principles

Although perceptual principles are the most often mentioned and usually in first position, experts consider other kinds of principles that rely on extrinsic properties of the foods and drinks as well as the context of consumption.

Geographical identity

Experts also suggested to associate two products that have the same geographical identity related to a region or country (ex: Muscadet Sèvre et Maine with oysters or Belgian beer with Flemish carbonade).

"We echo the designation of origin that echoes a region, and that by default, when we have regions with some gastronomic typicality, we speak of a local pairing and it may be interesting to consider all products that can be found in this region" "on fait écho à l'appellation qui fait écho à une région et que par défaut, lorsqu'on a des régions avec certaines typicités de gastronomie, on parle d'accord de terroir et ça peut être intéressant de s'orienter sur l'ensemble des produits qu'on peut trouver dans cette région" (Sommelier).

In the culinary literature, this pairing is also called "Terroir" pairings (Pierre, 2014). However, the word "terroir" is not only related to geographical origin but also refers to some traditional practices. Thus, the wording "geographical identity" seems more relevant. In this case, conceptual categorization rather than perceptual features orients the match.

Norms

Some experts evoked norms when suggesting matches**.** This refers to usual/classical associations encountered in the French culinary culture, such as white wine with fish, or beer with sauerkraut:

"It's purely dogmatic, that's because we've got used drinking [...] we've maintained this dogma to the point that it's a constant, that in the bibliography you will find a lot, but that's just transmitted and reproduced for no other reason than its existence at a given moment"

"c'est purement dogmatique, c'est à dire que c'est parce qu'on a pris l'habitude de boire ou de dire [...] on a entretenu ce dogme au point que c'est une constante qui là dans la bibliographie vous allez pouvoir retrouver énormément mais qui est juste transmise et reproduite sans aucune autre raison que son existence à un moment donné" (Beer expert).

Such pairings are often encountered, thus they are familiar and consequently widely appreciated (Borgogno et al., 2015).

The principles of norms and geographical identity might overlap as, historically, food transportation was limited and people tended to consume local products. However, what may have once been related to "geographical identity" may have evolved. The norms are rather related to the type of products than to the products' geographical identity. For instance, pairing sauerkraut and beer may come from the fact that both used to be commonly consumed in Alsace. At this time, it was a match related to products geographical identity. But, nowadays it becomes pairing norms as it may work with Belgian beer as well.

Quality level

The same principle applies to products' quality level. An exclusive wine matches with a fine dish made with high quality products. It is irrelevant to associate it with a basic dish even though their perceptual properties would go well together.

"even though this wine is beautiful, it remains a Muscadet, hm and so we will not necessarily give it dishes of exceptional nobility, so we must also stay in a pairing according to nobility"
"donc aussi belle cette cuvée là, ça reste un Muscadet, hum et donc on va pas forcément lui accorder des plats d'une noblesse exceptionnelle, donc il faut aussi rester dans cet accord de noblesse" (Sommelier).

In their study, Pettigrew and Charters (2006) also reported such a principle. One of their interviewees indeed stated that "good" wine would be wasted at a barbecue, but at a formal dinner, it was appropriate while cask wine would fail.

Moment of the meal

According to experts the moment of the meal i.e., starter, main dish, or dessert, modulates pairings and not only because the kinds of food consumed at these moments, are different.

Experts refer to vertical pairing as when the pairs consumed before and/or after are taken into account.

"So it makes it possible to finish a meal on a kind of lightness, a kind of thirst-quenching" "Donc ça permet de finir un repas sur une forme de légèreté enfin une forme de désaltèrant" (Sommelier).

Specific situation

In addition to the moment of the meal, experts took into account the context of consumption and some of them mentioned a specific situation in which the pair would work well. They mentioned for instance, an aperitif with a friend on a terrace or a dinner in a gastronomic restaurant. Giacalone et al. (2015) demonstrated that consumers perceived several beers as significantly different in appropriateness across different usage contexts. For example Steinlager classic beer, gold medal Ale beer and Lion red beer were considered as more appropriated to sport event such as rugby match, camping or fishing than Hopwired IPA beer or Pot Kettle Black beer more appropriated to serve to guests or drink in a public house (*e.g*. Bars). The same principle holds for food and beverage pairs and the pair needs to be congruent with the consumption situation. Sester et al. (2013) showed that congruence between the ambiance and the drink would orient consumers' choices. There is a large body of literature dedicated to contextual effect on food choice and liking. The underlying processes at work are also relevant to understanding food-beverage pairing.

Season

As part of the context, 40% of the experts took into account the season:

"But in mid-summer, I would make a citrus salad, slightly spicy, with sweet spices such as a little bit of cinnamon and I would serve this wine, and it would be surprising because when one thinks of a dessert wine, one thinks of a sweet wine, and there in summer I do not want to offer a sweet wine" "Mais en plein été je ferais une salade d'agrumes, légèrement épicées, avec des épices douces comme par exemple un petit peu de cannelle et je servirais ce vin, et ça serait d'ailleurs étonnant parce que quand on pense à un vin de dessert, on pense à un vin sucré, et là en été j'ai pas du tout envie d'offrir un vin sucré" (Beer expert).

Indeed, preferences may change according to the season. Seo et al. (2009) found that cinnamon aroma was more pleasant during the Christmas season than summertime. Wada et al. (2012) demonstrated that infants tend to prefer an image of a strawberry tasted with a congruent odor of strawberry when the task was performed during the strawberry season than when the task was performed out of the strawberry season. In another study, Ristic et al. (2019) asked participants to indicate their preference for different wine aromas in different seasons. They found that chocolate aroma is more appropriate for winter whereas lemon, strawberry, rose and passionfruit aromas are more appropriate for summer. These changes can be explained by the ecological valence theory which suggests that stimulus preferences arise from people's average affective responses to stimulus-associated objects (Palmer and Schloss, 2010). This theory explains seasonal changes in color liking such as preference for dark-warm colors (dark-red, brown, olive, and dark-chartreuse) during fall more than other seasons (Schloss et al., 2017), following the color of leaves in nature. This theory can be transposed to other sensory modalities and seems relevant in the area of food-drink pairing.

4.1.3. Affective pairing principles

Individual preferences

A large share of the experts included individuals' preferences as a parameter to consider in the search for a good match:

"It may work with a buffet, if people prefer to take beer over wine" "ça peut aller sur un buffet campagnard par exemple, si les gens préfèrent prendre de la bière plutôt que d'aller prendre des vins" (Sommelier).

The liking of the products, tasted alone, affects the liking of the pairing in which they are associated (Bastian et al., 2010; Donadini and Fumi, 2014; Donadini et al., 2012, 2013; Donadini et al., 2015; Harrington et al., 2008; Paulsen et al., 2015). However, pairing the preferred food with the preferred beverage is not enough to create the perfect match (Donadini et al., 2013; Tuorila et al., 1994). The enhancement of certain properties in food-drink pairs could explain inter-individual differences in match assessments. Appreciation will depend on the valence of the dominant notes in the pair for each consumer. If a pairing

induces the development of a lemon aroma, the liking of the match will depend on the consumers' liking of lemon.

Surprise

Tradition and custom are often at stake in pairing principles. However, thinking outside the box may be relevant on some occasions. Experts sometimes suggested a pairing that deliberately breaks the rules, especially conceptual rules. Because the association is unexpected, it would surprise tasters.

"We prepare a very classic meal and we have a big surprise, we have blond Leffe beer and a cake for dessert" "on fait un repas tout à fait classique et pis on fait une grosse surprise, on fait gouter Leffe blonde et un gâteau au dessert" (Beer expert).

4.2. Comparison of the usage of pairing principles according to expert and beverage types.

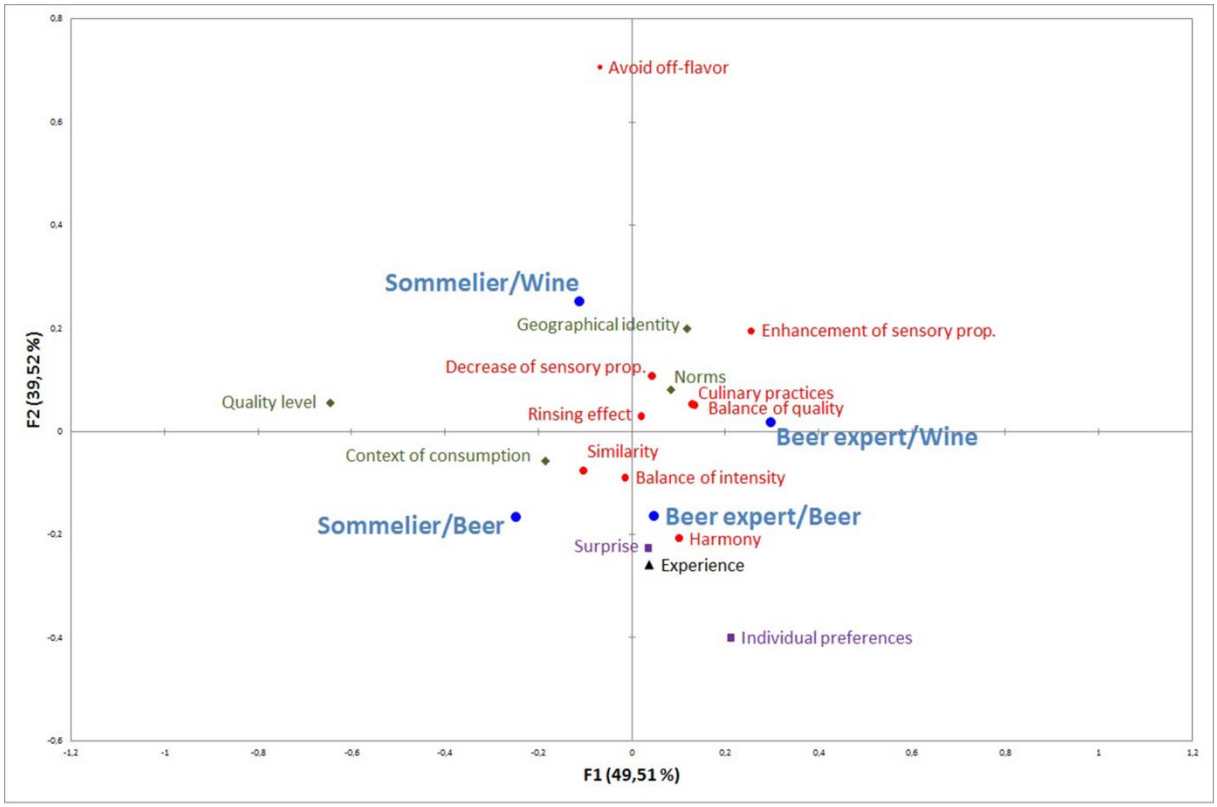

Figure 1: Overview of the usage of pairing principles according to expert type and beverage type (+, blue). Markers shapes and colors represent the categories to which pairing principles are related: perceptual (●, red), conceptual (♦, green) and affective (■, purple). "Experience", (▲, black) is not related to any of the categories.

Use of pairing principles according to expert and beverage types was examined with a correspondence analysis (Fig 1). The two first dimensions explain 89.03% of total variance. The F1 axis distinguishes Beer experts, represented on the positive part of the axis, from Sommeliers, represented on the negative part of the axis. The F2 axis divides pairings with wine on the positive part of the axis, and pairings with beer, on the negative part. Moreover, to help with reading, the principles of “Season”, “Specific situation” and “moment of the meal” were merged in “context of consumption”.

Overall, perceptual principles such as “similarity”, “balance of intensity”, or “rinsing effect”, are equally mentioned by Sommeliers and Beer experts whatever the beverage. Beer experts seem to use pairing principles in a similar way when creating pairings with beer and wine. In addition to perceptual principles, they used experiential arguments to justify a match. They refer more often than Sommeliers to their own tasting experiences and to the individual preference of consumers. Sommeliers more often use conceptual principles and include contextual considerations to match food and beverages. The relative weight of experiential and conceptual dimensions has already been pointed out as an indicator of level and kind of expertise in wine (Langlois et al., 2011).

Overall, matching food with either wine or beer seems to mobilise the same principles. A few differences were observed. “norms” and “geographical identity” were more often mentioned with wine than with beer. This is not surprising as in France, pairing food with beer is a relatively new trend whereas pairing food and wine is part of the French culture and history. The region of production of wine is an important characteristic of the beverage but it is less advertised for beer.

By contrast, the notion of “surprise” was mentioned more often with beer than wine. In France, pairing wine with food is very normative. Unlike drinking beer, drinking wine is a habit and an element of the French cultural background (Do, Patris, & Valentin, 2009). Hence offering beer as companion to food may be a first source of surprise for French consumers.

From a more methodological point of view, these differences could also be explained by the differential anchoring of selected beers and wines in the French culture and terroir. For example, the two beers were industrial Belgian beers not linked to a specific production area for French experts. By contrast, the two wines were AOC (Appellation d’Origine Controlée)

554 wines with a strong regional identity. AOC is one of the French geographical indications. This
555 system works in parallel to the European PDO (protected designation of origin) / PGI
556 (protected geographical indication) system. This regulation protects the reputation of
557 regional products and promotes rural and agricultural activity. It is well known by French
558 people in general and in the area of wine particularly. A study with French craft beers, for
559 which the production area is emphasized, would be necessary to see whether the
560 "geographical identity" pairing principle would be used as frequently for beer than for wine
561 or if it is really product-dependent.
562
563 Sommeliers also used the notion of "new characteristics" that emerge when associating food
564 and beverages but only for wine. They actually mentioned a potential risk of creating "off-
565 flavor" when pairing food and wine.
566
567 5. General discussion
568 This work confirms that pairing food and beverages may be a complex task. There are
569 several methods to match food and beverages. The method to implement primarily depends
570 on the objective of the pairing: to create a unique perceptual experience by combining the
571 two products, to highlight one of the two products and make it more attractive, or to enjoy
572 each of the two products in the pair as much as possible. According to the objective, one
573 principle or another would be as a means to reach the objective. Moreover, principles are
574 used in combination including several perceptual, conceptual, and affective principles. The
575 weights of the three kinds of principles may vary according to the expertise of the person
576 pairing the food and beverage as well as the person for whom the pair is intended.
577 Individual factors were also mentioned by experts. They acknowledged inter-individual
578 differences in food-pairing perception, underlining the importance of liking (liking of each
579 product, tasted alone). This is undoubtedly a major issue. But other inter-individual
580 differences based on attitudes and motivations such as health issues, cultural specificities, or
581 social influences, are probably as relevant, since they are known to affect eating behavior
582 (Higgs and Thomas, 2016; Renner et al., 2012).
583

584 Interviews were conducted with 10 wine and 10 beer experts. Considering such a number,
585 analyses based on number of occurrence needs to be confirmed with a larger group.
586 Moreover, all experts were French. Thus, results have to be considered cautiously when
587 generalized to other cultures. Culture may affect the content of the principles. For instance,
588 when considering the principle of “Culinary practices”, two flavors that would work in one
589 culture may not be relevant in another. So experts of different cultures, calling upon this
590 same principle, would end up with different pairings according to classical accords in their
591 own culinary culture. Culture may also affect the relative weight of principles used in
592 combination. The principle of “geographical identity” is likely to be more important in a
593 country such as France where products of origin (PDO) are numerous and well established,
594 compared to other countries where the notion of “terroir” is less developed. Ultimately,
595 experts from different cultures may consider principles other than those considered by
596 French experts.
597
598 ## 6. Conclusion
599 The results demonstrate that French Sommeliers and Beer experts use pairing principles
600 related to perceptual, conceptual and affective categories. Overall, matching food with
601 either wine or beer seems to rely on the same principles. However, matches based on norms
602 and conceptual association, were more often mentioned for wine than beer. Beer experts
603 used more experiential discourse than sommeliers who referred more often to conceptual
604 association.
605 Further work is needed to experimentally test the principles listed by experts. Some have
606 already been studied using sensory science approaches. But others need to be explored
607 deeper. Finally, as principles are called upon in combination rather than in isolation, further
608 work needs to be undertaken to understand how experts choose one combination rather
609 than another.
610
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761

762 **Appendix A:** Product information provided to the experts

Muscadet Sèvre et Maine	**Vintage**	2014
	Produceur	Joseph Landron, domaine de la Louveterie
	Cuvée	Cuvée amphibolite nature
	Description (from the producer's website)	Dry white wine Produced at the top of the Nantes vineyards, on the slopes of the Sèvre Alcohol content: 12% Intense aroma of ripe citrus Lemon flavor Grapefruit flavor Rich and complex palate, underpinned by mineral acidity. Superb balance with a crystalline mineral density. Persistence of salinity remains pure with high precision of the fruit.
St Joseph	**Vintage**	2013
	Produceur	Stéphane Montez, domaine du Monteillet
	Cuvée	Cuvée du papy
	Description (From the producer's website)	Red wine produced on the right bank of the Rhone, in the department of the Loire Alcohol content: 12.5% Red fruit aromas (blackcurrant) Violet aroma Spice (nutmeg, pepper) Licorice aroma Vanilla aroma The palate is elegant and long with a solid tannic structure with soft tannins.
Hoegaarden	**Description (from the producer)**	Belgian white beer internationally sold Alcohol content: 4.9% Lemon aroma Sweet Acid Smooth Clove aroma Coriander aroma Creamy Bitter Banana aroma
Blond Leffe	**Description (from the producer)**	Belgian blond beer internationally sold Alcohol content: 6.6% Fruity Delicately spiced Clove aroma Vanilla aroma Smoky aroma Phenolic aroma Caramel aroma Butterscotch aroma Grilled aroma Sulphide in aftertaste Sweet Bitter Dense Alcohol aroma

763 **Appendix B:** Examples of dishes suggested by experts (at least three of them) to match each
764 beverage (no matches were also included).

765 Table B1. Example of dishes suggested to be matched with **Hoegaarden** beer.

Match/no match	Dishes category + number of experts (total and by specialty (B= beer experts/ S= Sommeliers))	Dishes
Match	Cheese (10 experts (B=6/ S=4))	Bannons, chaourse, raclette, panacotta, comté, beaufort goat cheese
	Desserts (7 experts (B=7))	Lemon pie, fruit pie, tiramisu with beer, meringue
	Fish (5 experts (B=5))	
	Seafood (5 experts (B=5))	Shrimp, Oysters, mussels with French fries
	Mixed salad (3 experts (B=3))	Cesar salad, avocado salad, rocket salad
No match	Red meat (8 experts (B=2/S=6))	Beef meat
	Desserts (7 experts (B=4/S=3))	Chocolate desserts, coffee desserts
	Game meat (6 experts (B=3/S=3))	Duck, deer meat
	Cheese (4 experts (B=2/S=2))	Roquefort, intense cheese, Epoisse, Maroilles
	Dishes with sauce (3 experts (B=1/S=2))	Powerful sauce

766

767 Table B2. Example of dishes suggested to be matched with **Blond Leffe** beer.

Match/no match	Dishes category + number of experts (total and by specialty (B= Beer experts/ S= Sommeliers))	Dishes
Match	Cheese (11 experts (B=5/S=6))	Mainly cow cheeses (Comté, St Marcelin, Maroilles, Livarot, etc…)
	White meat and poultry (8 experts (B=3/S=5))	
	Dessert (5 experts (B=4/S=1)	Dessert with vanilla, yellow or white fruits pie, chocolate, cakes …
	Fish (4 experts (B=1/S=3))	Fried fish, smoked or grilled fish, with vanilla or honey;
	Mixed salad (3 experts (B=2/S=1))	
	Red meat (3 experts (B=1/S=2)	Horse meat, beef meat
No match	Dessert (6 experts (B=3/S=3)	Speculoos biscuit (crunchy biscuits flavoured cinnamon), chocolate
	Red meat (5 experts (B=1/S=4))	Beef meat, red meat with sauce
	Fish (5 experts (B=3/S=2))	Red mullet, fine-textured fish
	Cheese (3 experts (B=1/S=2))	Brie de Melun, Maroilles
	White meat (3 experts (B=1/S=2))	Calf sweetbread, pork meat

768

769 Table B3. Example of dishes suggested to be matched with **Muscadet Sèvre et Maine** wine.

Match/no match	Dishes category + number of experts (total and by specialty (B= Beer experts / S= Sommeliers))	Dishes
Match	Fish (17 experts (B=8/S=9))	
	Seafood (16 experts (B=6/S=10))	Oysters, seafood
	Cheese (12 experts (B=5/S=7))	Mainly Goat cheese
	Mixed salad (3 experts (S=3))	Salad with citrus fruit
No match	Red meat (5 experts (S=5))	Beef meat
	Dessert (3 experts (S=3))	Chocolate, cake, cream

770

771

772 Table B4. Examples of dishes suggested to be matched with **St Joseph** wine.

Match/no match	**Dishes category + number of experts (total and by specialty (B= Beer experts/ S= Sommeliers))**	**Dishes**
Match	Red meat (10 experts (B=2/S=8)	Beef, lamb meat
	Game meat (8 experts (B=3/S=5))	Duck, deer, guinea fowl, hare, boar meat
	Dessert (7 experts (B=5/S=2))	Chocolate cake, Forêt Noire cake, Pear with wine
	White meat (6 experts (B=3/S=3))	
	Fish (5 experts (B=3/S=2))	Salmon, eel, fish prepared with wine
	Cheese (5 experts (B=3/S=2))	St Nectaire, Nanterre cheese, Picodon
	Barbecue (4 experts (B=2/S=2))	
	Charcuterie (3 experts (B=2/S=1))	
No match	Fish (12 experts (B=5/S=7))	White fish
	Cheese (5 experts (B=1/S=4))	Goat cheese
	Seafood (4 experts (B=2/=2))	Oysters, shellfish
	Red meat (4 experts (B=2/S=2))	Powerful meat, kangaroo meat
	Game meat (3 experts (S=3))	Boar meat, doe and pheasant meat

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774

3. Conclusion

This first chapter aimed at identifying pairing principles that governs match between food and beverage. The pairing principles identified from experts' discourses, argue that **food and beverage pairing is governed by perceptual, conceptual and affective features**.

The identified perceptual principles are related to product sensory properties *(e.g. Similarity, balance of intensity, enhancement of sensory property, etc…)* and were almost systematically evoked to justify a match. These results confirm our hypothesis stipulating that the food-beverage pairing is under the influence of a large number of factors that are mainly related to product sensory properties. Although sensory characteristics appear as being the most important issue in pairing, our work also highlights the relative importance of other dimensions. Conceptual principles are related to extrinsic characteristics *(geographical identity, quality level)*, context of consumption *(moment of the meal, specific situation, season)* and norms *(norms)*. Affective pairing principles are related to individual preferences and emotions.

These results partially confirm our hypothesis stipulating that other dimensions such as social surrounding and conceptual features are involved in food-beverage pairing.

The social aspect of food and beverage pairing were not directly mentioned by experts, but some pairing principles such as "specific situation" may reflect this consideration. Indeed, "specific situation" principle is related to some events such as barbecue party or aperitif that imply specific social interactions.

This chapter also aimed at determining whether pairing principles are product or domain-dependent or if they can be generalized. Results highlight that **the same principles are used to match either wine or beer with food**. All the pairing principles identified in this work, were mentioned for both products and by both sommeliers and beer experts. Some differences in the occurrence of pairing principles usage were brought out. These differences could be explained by the differential anchoring of selected beers and wines in the French culture and terroir. For example, the two beers were industrial Belgian beers not linked to a specific production area for French experts. By contrast, the two wines were AOC (*Appellation d'Origine Controlée*) wines with a strong regional identity. AOC is one of the

French geographical indications. This system works in parallel to the European PDO (protected designation of origin) / PGI (protected geographical indication) system. This regulation protects the reputation of regional products and promotes rural and agricultural activity. It is well known by French people in general and in the area of wine particularly. A study with French craft beers, for which the production area is emphasized, would be necessary to see whether the "geographical identity" pairing principle would be used as frequently for beer than for wine or if it is really product-dependent.

Concerning the expertise domain, pairing principles related to perceptual category were equally mentioned by Sommeliers and Beer experts, whatever the beverage. This suggests that knowledge about perceptual principles of food and beverage pairing are transferable from one expertise domain to another. Thus, both sommeliers and beer experts are able to create a match based on sensory features whatever the involved beverage is.

However, Beer experts refer more often than Sommeliers to their own tasting experiences and to consumers' individual preferences. Sommeliers use conceptual principles (quality level) and include more contextual considerations. These differences may be explained by the difference in experts' training. In France, sommelier is a full-fledged occupation. Their main expertise domain is related to wine and food pairing even though they practice different occupations (e.g. restaurant sommelier, wine retailer or teacher). They are generally graduated of sommelier school where they were formally trained to match wine and food. By contrast, there is no formal training for beer experts in France. People who considered themselves as beer expert may be specialists of beer production, tasting or even beer history and culture. They not systematically received training in beer and food pairings, and therefore they are less experienced than sommeliers in terms of food and beverage pairing.

Chollet, Valentin, and Abdi (2005) compared beer discrimination ability of assessors trained to detect and identify added flavor in beer in order to evaluate the intensity of global beer characteristics, and novices for two sets of beers, one with familiar beers and one with new beers. They demonstrated that trained assessors were better than novices at discriminating previously learned beer samples but any difference in discrimination ability was found for new beers. In wine domain, Ballester, Patris, Symoneaux, and Valentin (2008) suggested that

expertise is more a cognitive expertise than a perceptual one. Because conceptual pairing principles seems to be more related to specific knowledge it not surprising that Sommelier, having had a specific training in food and beverage pairing include such considerations more often than beer experts did.

As one of the objectives of the thesis is to contribute to a better understanding of mechanisms that underlie beer and food pairing and more generally food and beverage pairing, we made connections between pairing principles and some known mechanisms involved in stimulus perception. **Many of the identified pairing principles were related to known physicochemical, perceptual and cognitive mechanisms**. However, it was not possible to definitely conclude about the underlying mechanisms for each pairing principle. In the second part of our work, we chose to focus on one principle: the principle of aromatic similarity. This principle is one of the most often mentioned by experts but was not experimentally study in sensory science yet. The objective of the following chapter (chapter 5) is to tackle mechanisms underlying the principle of aromatic similarity.

Chapter 5: Aromatic similarity in food and beverage pairing

1. Introduction

The chapter 4 allowed identifying perceptual principles as the main determinants of food and beverage pairing. One of these pairing principles, the “Aromatic similarity” was largely mentioned by experts to create a good match. It consists in matching two products that share similar aromas; for instance a beer with lemon notes and a lemon pie. As outlined in the literature review, the creation of a match through the association of products that share aromatic characteristics is the basis of the controversial “food pairing theory». For this theory, the aromatic similarity is considered at a molecular level. By contrast, in the current work, aromatic similarity is no longer considered at a molecular level but at a perceptual one. **How the level of perceived aromatic similarity between food and beverage influences the match liking and what are the underlying perceptual mechanisms?**

Aromatic similarity, considered at a perceptual level, falls under the idea that the flavours of the two products somehow blend into a unique perception (chapter 4). Thus, in creating a blending effect of flavours perception, aromatic similarity between food and beverage will lead to a more homogeneous multidimensional perception of the match. Perceived complexity is a stimulus' collative property known to reflect a lack of blending or a distinction of the mixture's components (Berlyne, 1960), thus aromatic similarity, in blending the two products' flavours into a unique experience, should lead to a decrease of perceived pair complexity. The level of similarity between two components of an association also influences its perceived harmony. This relationship was demonstrated in visual modalities. Indeed, pairs of colours with similar hues were on average perceived as more harmonious than pairs with different hues (Schloss & Palmer, 2011). Thus, transposed to the aromatic modality, the more two products share similar aromas, the more they will create a harmonious match.

As highlighted in the literature review, perceived harmony and complexity are both collative properties related to liking according respectively, to a positive linear or an inverted U-shaped relationship. Paulsen et al. (2015) underlined the importance of the combined effect of harmony and complexity on food and beverage pairing liking. This leads us to consider

explaining the impact of aromatic similarity on liking as a combined effect of harmony and complexity levels, rather than with each property separately as is usually done.

Our hypothesis is that a higher perceived aromatic similarity between products, in increasing the match's perceived harmony and modulating its perceived complexity will lead to a more appreciated match than products with a lower level of perceived aromatic similarity.

To test this hypothesis, the relationship between the level of perceived aromatic similarity between food and beverage and the perception of their association in terms of harmony, homogeneity, complexity and liking was investigated. A theoretical model that account for our experimental results to explain the aromatic similarity's effect on liking through the modulation of harmony and complexity was also provided.

For this purpose, pairings with contrasting levels of aromatic similarity were compared in two distinct studies. In both experiments the levels of aromatic similarity between the drink and the food were controlled in adding culinary aromas and set at two levels either high or low. The difference between the two experiments lies in the diversity of products' sensory properties. This first one involved simple products (soft drink and flavored dairy products) in which the added aroma appeared as being the main perceived products' sensory property. The second one involved more complex products (aromatized beers and savory potatoes purées) in which the added aroma was an aromatic note among several other sensory properties.

This work is presented in an article published in the journal Food Quality and Preference.

This chapter also contains a study aiming at testing the provided theoretical model that account for the combined effect of harmony and complexity on liking. Indeed, even if our experimental data fit with this model, the number of experimental points was too small to allow us to validate it. Further investigation with more combinations of complexity and harmony levels was required.

2. The role of aromatic similarity in food and beverage pairing (Article 2)

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The role of aromatic similarity in food and beverage pairing

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ABSTRACT

Aromatic similarity is often mentioned by culinary experts and Sommeliers as a basic principle for matching food and beverages. The aim of this study was to investigate how this pairing principle modulates consumers' judgment of pairings.

Two kinds of beverage-food pairing were considered: syrup based lemon soft drink paired with aromatized dairy product (experiment 1) and beer flavoured with either lemon or smoky aroma paired with savoury verrines (experiment 2). In each experiment the flavoured drinks were associated with food flavoured with either the same aroma or another one, leading to two contrasting levels of aromatic similarity. We hypothesized that aromatic similarity would increase the liking of the pairing by increasing perceived harmony and homogeneity and decreasing complexity. Pairings were assessed by a group of about 50 participants in a within experimental design.

Experiment 1 confirmed our hypotheses. The pair that shared an aroma was preferred over the pair with different aromas. Aromatic similarity also increased the pairing's perceived harmony and homogeneity and decreased the pairing's complexity. Experiment 2 also supported our hypothesis but to a lesser extent. For lemon beer pairings, aromatic similarity induced an increase in harmony and homogeneity but did not affect complexity. In contrast, for smoky beer pairings, aromatic similarity did not affect harmony or homogeneity but induced a decrease in complexity. Moreover no effect or only a marginal effect was observed on liking. We suggest a model that could account for these results in which aromatic similarity would impact liking of the pair by modulating collative properties, specifically harmony and complexity, of the food-beverage pairing.

1. Introduction

Matching of food and beverages is rooted in cultural practices. All food and beverage pairings are not equivalently appropriate. For instance, Cornwell and McAlister (2013) reported that for US children, soft drinks are more appropriate with French fries than with steamed vegetables whereas the reverse is observed for water. Food and drinks are linked in consumers' representations (Cardello et al. 2016; Martinez, Hammond, Harrington, & Wiersma-Mosley, 2016; Pettigrew & Charters, 2006; Sester, Dacremont, Deroy, & Valentin, 2013). For instance, French people state that wine is key for a nice meal shared with friends and family (Ifop. 2014) and food and wine pairing is an integral part of the "Gastronomic meal of the French" inscribed in 2010 on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity. Food and beverage pairing refers to a complex task that is much more than merely associating two liked products. For instance, Donadini and Fumi (2014), Donadini, Fumi, and Lambri (2012, 2013), Donadini, Fumi, and Newby-Clark (2015) and Harrington and Seo (2015) showed that when several dishes are tested with several drinks, the best match is not systematically the one that associates the preferred dish and the preferred beverage. Actually, food and drink pairing involves many other aspects that require the expertise of culinary professionals or sommeliers, who can suggest excellent associations, even though experts and consumers might not fully agree on match level (Donadini, Spigno, Fumi, & Pastori, 2008). Some recommendations for pairing are provided by experts in specialized books, websites, or magazines. Often they merely suggest some beverages that could be associated with a specific dish. But in some cases, experts also explain the underlying principles that guide pairing. According to Paulsen, Rognså, and Hersleth (2015) and Harrington (2008), the most often cited principles refer to balanced intensities of tastes, body, flavour, and aftertaste; aromatic similarity between products; and contrasts such as association of fatty food with acidic or tannic wine.

In the literature, works dedicated to pairing did explore some of the

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above mentioned principles. For instance, Koone, Harrington, Gozzi, and McCarthy (2014), working with wines and several food categories, and Harrington and Hammond (2005), working with wine and cheese pairings, confirmed the importance of sweetness for a good match. In line with experts' views, they showed that wine sweetness level should be equal to or greater than food sweetness level. Flavour balance is another aspect receiving some attention in the literature. Experts recommend balancing the flavour intensity of food and drink such that neither the food nor the beverage dominates. Most reported results are in line with this recommendation (Bastian, Payne, Perrenoud, Joscelyne, & Johnson, 2009; Donadini & Fumi, 2014; Donadini et al., 2008; King & Cliff, 2005; Paulsen et al., 2015). In some cases however, unbalanced intensity can be favoured, depending on the respective valence of the products' dominating property (Donadini et al., 2012; Donadini et al., 2013).

The balance between wine astringency or acidity and animal based food fattiness levels was also confirmed by several authors. For instance, Koone et al. (2014) found a positive correlation between the perceived intensity of wine's tannin and the level of match with a fatty food (spicy Italian salami). Harrington and Hammond (2006) assessed the effect of combined food fattiness and wine tannin intensity on the match perception and found that when the intensity levels of the wine tannin and food fattiness are equivalent, the level of match is higher than when one dominates the pair.

Although often mentioned by experts, aromatic similarity received less attention in the pairing literature. This principle states that food and beverages that share some aromatic notes would match well. For example, a mineral white wine would be a good match with oysters because of the iodized notes of both products; similarly, a red wine expressing animal or leather notes would be a good match for game meat characterized by the same kind of aromas. To the best of our knowledge, no work dealing with the impact of aromatic similarity on pairing judgment was reported in the literature. The present work is aimed at exploring this experts' principle, i.e., testing whether products with some aromatic similarity are a better match than products with no similarity and identifying underlying mechanisms such as modulation of collative properties of the pairing's perceptual experience.

In the pairing literature, studies dedicated to food-drink pairing proceed from two main approaches. The first is based on the idea that two products match whenever one product of the pair preserves, or even enhances, the properties of the other. This is the typical situation for wine and cheese paring. The astringency of the wine "washes out" the fattiness of the cheese and conversely, cheese fat moderates wine astringency. For instance, Galmarini, Loiseau, Visalli, and Schlich (2016) found that the liking of highly astringent red wine increases in consecutive sips while eating bites of cheese in between. In this approach, participants are usually explicitly required to judge one product of the pair while consuming the other one concomitantly. The match is thus explained by some positive carry-over effects (Bastian, Collins, & Johnson, 2010; Donadini & Fumi, 2014; Donadini, Fumi, & Newby-Clark, 2015; Donadini et al. 2013; Galmarini et al., 2016; Madrigal-Galan & Heymann, 2006; Nygren, Gustafsson, Haglund, Johansson, & Noble, 2001; Nygren, Gustafsson, & Johansson, 2002; Nygren, Nilsen, & Öström, 2017; Peyrot des Gachons et al. 2012).

The second approach is based on the idea that the flavour of the two products should somehow blend into a unique perception. The flavour balance falls under this second approach. In such studies, participants are required to make judgments about the joint perception of the two products. The principle of aromatic similarity seems to fit within this approach too. Aromatic similarity could favour such blending through a high level of perceived harmony. This is suggested by observations made in the visual modality: pairs of colours with similar hues were on average perceived as more harmonious than pairs with different hues (Schloss & Palmer, 2011). Our first hypothesis is that aromatic similarity increases the perceived harmony of the pairing.

Going even further, aromatic similarity could link the two components of the pairing, pushing toward a higher level of integration of the two flavours. The pairing experience would be perceived as a homogeneous multidimensional percept. Our second hypothesis is that aromatic similarity increase the flavour homogeneity of the pairing.

Finally, the blending of the different components of the pair could also affect its perceived complexity. According to Berlyne (1960), the perceived complexity reflected a perceived lack of blending or a distinction of the mixture's components. Berlyne and Boudewijns (1971) demonstrated that the perceived complexity of visual stimuli made of two geometrical figures increased along with the number of differences between the two elements. Thus, our third hypothesis is that aromatic similarity decreases the complexity of the pairing.

Perceived complexity is one of the collative properties, described by Berlyne (Lévy, MacRae, & Köster, 2006) as influencing the arousal potential of objects, itself related to liking according to an inverted U-shaped relationship. There is an optimum level of perceived complexity that leads to the highest appreciation level. If the perceived complexity is lower or higher than this optimum, the object is less liked. In the case of food and beverage pairings, associating two products could lead to a highly complex percept, potentially more complex than the optimal level. Thus, aromatic similarity by decreasing complexity could increase liking. According to the concept of "unity in variety" introduced by Paulsen et al. (2015) in the field of pairing, highly complex stimuli need to also be highly harmonious for the match to be appreciated. Thus, aromatic similarity would also increase matching level by increasing harmony within the highly complex percept of a food-drink pair. Thus, our fourth hypothesis, which conforms to experts' know-whow, is that aromatic similarity increases liking of the pairing.

Paulsen et al. (2015), referring to the general principle of "unity in variety" for aesthetic pleasure, underlined the importance of the combined effect of collative properties (harmony and complexity) on liking. This leads us to consider explaining the impact of aromatic similarity as a combined effect of harmony and complexity levels, rather than with each property separately as is usually done.

To summarize, aromatic similarity's effect would be mediated by both harmony and complexity, which jointly modulate liking of the pairing. We propose a tentative model that accounts for this joint effect. In a first attempt, the combined effect of harmony and complexity will be considered additive.

The present study therefore aims to test whether aromatic similarity (1) leads to more harmonious, more homogeneous, and less complex matches and (2) increases liking of the paring. It also intends to provide a theoretical model that accounts for aromatic similarity's effect on liking through the modulation of collative properties harmony and complexity. To test these hypotheses, aromatic similarity was manipulated by aromatizing both the drink and the food in the pair. Two levels of aromatic similarity were contrasted; high aromatic similarity when the same aroma was added to the drink and the food vs. low aromatic similarity when different aromas were added. The experiment was run with two kinds of pairing. The first associated a lemon soft drink with an aromatized dairy product. The added aroma was dominant in each product, leading to a strong contrast in terms of aromatic similarity. The second one associated beer with an *amuse-bouche*. The added aroma was an aromatic note clearly perceived but that did not dominate, leading to a moderate contrast in terms of aromatic similarity.

2. Materials and methods

2.1. Pairings with high similarity contrast: Lemon syrup based soft drink and flavoured dairy product

2.1.1. Participants

Fifty-three participants (36 women and 17 men aged from 18 to 65 years old) were recruited on the Dijon campus and vicinities. They volunteered to participate in the experiment and were rewarded by a

Table 1
Flavoured dairy product recipes.

Dairy product samples	Syrups (% g) or aroma	Sugar (% g)	Still Water (% g)
Lemon	10%	0.5%	
Citrus and Lemon	7% (citrus) & 3% (Lemon)	0.5%	
Vanilla	1.1% (vanilla extract, Vahiné)	4.5%	2.5%
Strawberry and Lemon	4.5% (Strawberry) & 6.5% (Lemon)	0.3%	

snack and some sweet treats. Participants gave their consent in writing.

2.1.2. Products

The lemon soft drink was prepared by adding 900 mL of still water (Evian) to 10 mL of lemon syrup (Tesseire). Two aromatized dairy products were prepared from "fromage Blanc" (Calin, Yoplais), a kind of unsalted cottage cheese with the texture of Greek cheese, quite popular in France as dessert. One was flavoured with the same lemon syrup used for the drink (strong aromatic similarity); the other was flavoured with vanilla extract (strong aromatic dissimilarity). Two other flavoured dairy products, with citrus and strawberry-lemony flavours, were also included in the experiment. They were distractors intended to conceal the experimental design from participants. Table 1 gives the composition of the four dairy products.

For each dairy product, the level of perceived similarity with the lemon syrup was checked with a group of 19 participants recruited in the same conditions as the main group. The aromatic similarity was assessed on a linear scale anchored from "not similar at all" (0) to "very similar" (10). Results confirmed that the lemon flavoured dairy product was highly similar to the lemon syrup based soft drink (mean score 7.6 ± 2.4) whereas the vanilla flavoured dairy product was dissimilar (mean score 0.8 ± 1.8). The difference is highly significant (one-tailed paired Student test $t = 10.5$; $p < .0001$).

2.1.3. Procedure

For pairing evaluation, participants received about 150 mL of lemon syrup based soft drink presented in a 200 mL white plastic cup at room temperature. Dairy product samples were about 20 g, presented in opaque brown plastic cups coded with three digit numbers. The four flavoured dairy products were presented in random order. The lemon soft drink – flavoured dairy product pairs were assessed monadically. Participants were asked to take a sip of the drink then a spoonful of flavoured dairy product, and another sip of the drink and a spoonful of dairy product, before assessing the association in terms of liking, harmony, homogeneity, and complexity. Two other dimensions known for impacting liking were also assessed: intensity balance within the pair and familiarity (Whitfield, 1983). Scales are presented in Fig. 1. Scales for harmony, homogeneity, and complexity were inspired by those developed by Meillon et al. (2010). Ratings were converted into scores from 0 to 10, except for those of balance intensity, which were converted into scores from −3 to +3, with 0 representing an exact balance.

2.2. Pairings with moderate similarity contrast: Beers and savoury verrines

2.2.1. Participants

Forty-seven participants (29 women and 18 men, from 20 to 55 years old) were recruited in Dijon and vicinities. They volunteered to participate in the experiment; they gave their written, informed consent, and received snacks and goodies as rewards. Alcohol tests were carried out before and after the session. All participants started the session with a 0.0 blood alcohol level.

2.2.2. Products

A pale lager beer, Stella Artois (0.25 L glass bottle, 5.0% alcohol, ABV), was selected for its plain beer taste. Two flavoured beers were prepared by adding either lemon aroma (0.002%; aromecitron115, Selectarôme) or smoky aroma (0.06%, aromefume115, Selectarôme). These two aromas were selected to represent classical aromas (Schmelzle, 2009) encountered in white beers (lemon aroma) and in Belgian specialty beers as a note or in smoked beers (porter, stouts, amber lager, etc.) as a dominant aroma (smoky aroma). Flavoured beers were prepared half an hour before each session and kept at 4 °C ± 2 °C in a covered glass container before serving.

Savoury verrines were selected to be consumed with the beers as amuse-bouches. They are usually presented in small glasses and are trendy in France for cocktails or buffet dinners. Recipes were based on the Chef's advice. They were elaborated from mashed potato aromatized with the same aromas as those used for the beers, lemon and smoky. Thus, aromatic similarity between the beer and verrine was either high (lemon beer with lemon verrine, smoky beer with smoky verrine) or low (lemon beer with smoky verrine, smoky beer with lemon verrine). Two other aromatized verrines (cardamom and roasted chicken aroma) were included in the experiment. They were distractors intended to conceal the experimental design.

Verrines were prepared with 42 g of instant mashed potato (Mousline l'originale, Maggi) added to 600 mL of hot semi-skimmed milk (Lait de montagne, Carrefour) with two leaves (3.78 g) of edible gelatine (Vahiné) soaked in cold water for a few minutes, and 2 g of salt. Then, the mixture was aromatized by adding either 0.02 mL of lemon aroma (aromecitron115, Sélectarôme), 1.6 mL of smoky aroma (aromefume115, Sélectarôme), 0.8 g of cardamom powder (Ducros), or 0.6 mL of roasted chicken aroma (aromevolaillerotie58, Sélectarôme). The mixture was poured into verrines (crystal clear plastic cups), stored in the refrigerator overnight, and kept at room temperature one hour before tasting.

The perceived aromatic similarity between beers and verrines was checked with a group of 50 participants recruited in the same conditions as the main group. The aromatic similarity between each beer and each verrine was assessed on a linear scale anchored from "not similar at all" (0) to "very similar" (10). Results confirmed that lemon beer is significantly (one-tailed paired Student test $p = .0004$) more similar to the lemon verrine (mean score 5.7 ± 3.1) than to the smoky one (mean score 3.9 ± 2.7). Similarly, smoky beer is significantly (one-tailed paired Student test $p < .0001$) more similar to the smoky verrine (mean score 5.7 ± 3.3) than to the lemon one (mean score 3.2 ± 2.6).

2.2.3. Procedure

Participants attended two sessions, one week apart. The first session was dedicated to preference assessment and the second session was to assess the collative properties of the pairings, as well as liking of the beers and verrines standing alone. This ensured that the quantity of ingested alcohol kept the blood alcohol level under the legal threshold of 0.5 g/L.

In the first session, participants received one beer and four verrines. Beer samples were prepared about 5 min before serving. About 10cL of beer was slowly poured into tilted plastic glasses, creating about 5–8 mm of foam. Samples were coded with a letter. The verrine samples were about 2cL, presented in a 5cL clear plastic glass coded with three-digit random numbers. Participants were instructed to imagine they were organising a party where they would serve a glass of beer with an amuse-bouche. The beer was already chosen but they had to choose a verrine among the four proposed ones to go with the beer. The scenario was intended to root the task in a moment of consumption and thus increase participants' involvement. Participants were instructed to take a sip of beer, to taste the four verrines presented in random order, and to select the verrine that best matched the beer. They were allowed to resample both the beer and verrines as often as they wished. After making a first choice, they had to again choose the verrine that best

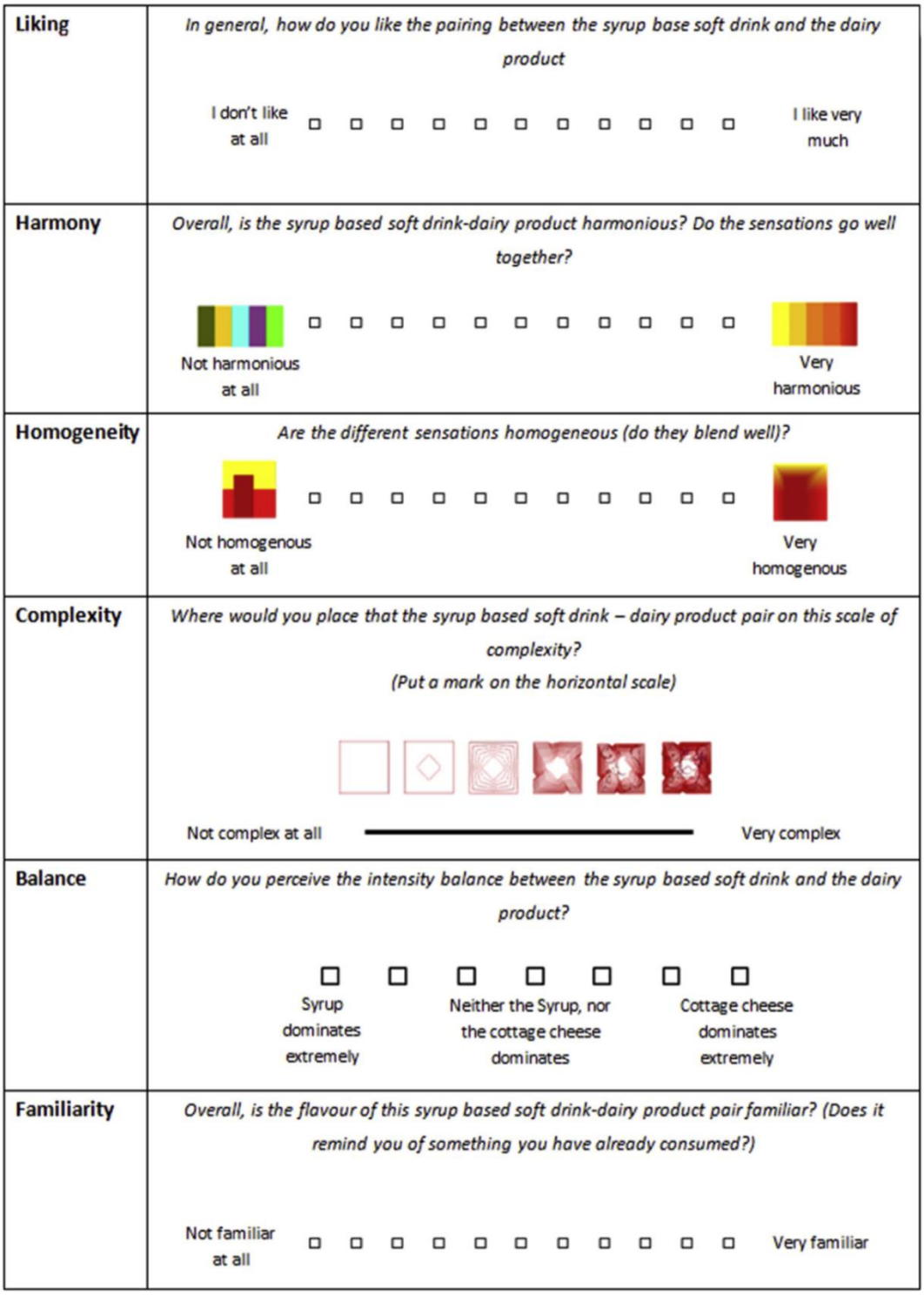

Fig. 1. Rating scales adapted from the complexity questionnaire of Medel et al. (2009).

matched the beer among the three remaining verrines, and at last choose again between the two remaining verrines. This provided a ranking of pairing choices from the best match to the worst. Afterward, participants performed the same task with the second beer. The presentation order of the two beers was counterbalanced over participants.

In the second session, participants received all possible beer-verrine pairs (2 beers × 4 verrines) in a random order. For each pair, they were instructed to take a sip of beer, a spoonful of verrine, a second sip of beer, and a second spoonful of verrine, and to assess the pairing in terms of intensity balance, familiarity, harmony, homogeneity, and complexity, on the same scales as in the previous experiment except that Intensity balance was assessed on an 11-point scale. Assessments were converted into scores ranging from 0 to 10 (−5 to +5 for intensity balance).

2.3. Statistical analysis

The data were analysed with XL-STAT (Addinsoft, USA) software.

Intensity balance and familiarity scores for aromatically similar pairs vs. non similar pairs were analysed with two-tailed paired t-tests. Liking, harmony, homogeneity, and complexity scores were analysed with one-tailed paired t-tests according to our hypotheses about aromatic similarity's impact on these dimensions.

Verrine choices were summarized separately for each beer in a contingency matrix and analysed by a Correspondence analyses confirmed by Chi-squared tests.

Two ways ANOVA were performed on the scores on each scale to assess the drivers of the beer and verrine pair choices.

2.4. Modelling

Providing that harmony and liking are linked by a positive linear relationship (Eq. (1)), on the one hand, and that complexity and liking are linked by an inverted-U shaped relationship (Eq. (2)), on the other hand, it is possible to represent the predicted liking level for any combination of complexity and harmony levels. Eq. (3) represents the additive effect assumption of these two parameters.

$$\text{Liking} = a + b*\text{Harmony} \quad (1)$$

$$\text{Liking} = a' + b'*\text{Complexity} + c*\text{Complexity}^2 \quad (2)$$

$$\text{Liking} = a'' + b''*\text{Harmony} + c'*\text{Complexity} + d*\text{Complexity}^2 \quad (3)$$

A way to represent the joint impact of complexity and harmony on liking is using a representation inspired by surface response methodology. Pairs are represented on a two-dimensional space. They are positioned according to their complexity level (x-axis) and harmony level (y-axis). The predicted liking values according to Eq. (3) are represented on the z-axis, defining a "liking surface". This surface is shaped like a semi-sphere with the highest liking level achieved for the highest level of harmony and the optimum level of complexity. For convenience for reading, the third dimension (liking) is represented on the 2D harmony – complexity map by iso-liking curves. Iso-liking curves represent all harmony – complexity level combinations leading to the same predicted level of liking.

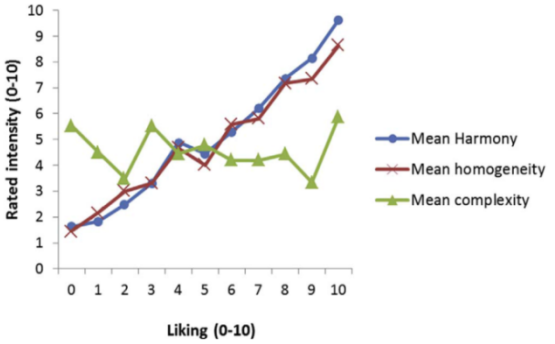

Fig. 2. Relationships between harmony, homogeneity, complexity, and liking. All pairs with the same liking score are pooled together regardless of their composition, to compute mean harmony, homogeneity, and complexity scores.

3. Results

3.1. Aromatic similarity and consumers' judgement of pairings with flavoured cottage cheese and syrups

Table 2 shows the mean score for each pairing on the six intensity scales. Intensity balance and familiarity were equivalent for the two pairings.

The lemon soft drink – lemon dairy product pair was perceived as significantly more harmonious ($P = .014$), more homogeneous ($P = .007$), and less complex ($P = .017$) than the lemon soft drink – vanilla dairy product pair. The lemon soft drink – lemon dairy product pair was also significantly preferred ($P = .044$).

At the individual level, the positive relationships between liking and perceived harmony ($r = 0.8$; $P < .0001$) and homogeneity ($r = 0.74$; $P < .0001$) are also demonstrated. Fig. 2 represents for each liking score value, the mean score for harmony, homogeneity, and complexity of any pair that received this liking score. It also shows that harmony and homogeneity are linked. Indeed, they are strongly correlated ($r = 0.89$, $P < .0001$) at the individual level. However, the negative relationship between perceived complexity and liking, observed in mean scores, is not demonstrated at the individual level.

3.2. Aromatic similarity and consumers' judgement of more complex products (beers and verrines)

First we checked that the two verrines were equally liked when tasted alone ($P = .184$).

Scores on each scale were analysed separately for lemon beer and smoky beer. Mean scores are presented in Table 3.

For lemon beer, the balance, familiarity, and complexity are not significantly different. The lemon beer – lemon verrine pair was perceived as significantly more harmonious ($P = .004$) and more homogeneous ($P = .005$) than the lemon beer – smoky verrine pair. For the smoky beer, the two pairs are significantly different for complexity only; the smoky beer – smoky verrine pair is significantly less complex ($P = .003$) than the smoky beer – lemon verrine pair.

Table 2
Mean scores and paired comparisons for liking, balance, harmony, familiarity, homogeneity, and complexity of the two lemon soft drink - dairy product pairs (N = 53), with standard deviation in brackets.

Pairs	Liking	Intensity balance	Harmony	Familiarity	Homogeneity	Complexity
Lemon-Lemon	5.8 (2.8)	0.2 (1.1)	5.9 (2.5)	5.4 (3.2)	5.8 (2.5)	4.3 (2.5)
Vanilla-Lemon	4.6 (3.3)	0.7 (1.7)	4.5 (3.3)	4.3 (3.4)	4.2 (3.2)	5.1 (2.2)
P-value	**.044**	**.109**	**.014**	**.064**	**.007**	**.017**

Table 3
Mean scores and paired comparisons for Balance, harmony, familiarity, homogeneity and complexity of the beer – verrine pairs (N = 47), with standard deviation in brackets.

Beer	Verrine	Balance	Harmony	Familiarity	Homogeneity	Complexity
Lemon	Lemon	$_{A}$ −0.4 (2.6)	6.9 (2.3)	5.4 (3.0)	6.4 (2.6)	4.3 (1.9)
	Smoky	0.2 (3.0)	5.3 (2.9)	4.7 (2.7)	4.9 (2.8)	4.8 (2.2)
	***P*-value**	**.341**	**.004**	**.292**	**.005**	**.121**
Smoky	Lemon	0.9 (2.2)	5.7 (3.0)	4.1 (2.9)	5.6 (2.9)	5.1 (2.4)
	Smoky	−0.1 (2.7)	5.4 (2.5)	3.8 (2.5)	5.2 (2.6)	3.7 (2.1)
	***P*-value**	**.067**	**.729**	**.520**	**.754**	**.003**

Table 4
Number of participants for each verrine according to the rank for each beer.

Beer	Verrine	Choice 1	Choice 2	Choice 3	Choice 4	Total
Lemon	Lemon	16	10	9	12	47
	Smoky	7	21	14	5	47
	Roasted chicken	14	11	11	11	47
	Cardamom	10	5	13	19	47
	Total	47	47	47	47	
Smoky	Lemon	12	10	13	12	47
	Smoky	11	11	18	7	47
	Roasted chicken	16	15	10	6	47
	Cardamom	8	11	6	22	47
	Total	47	47	47	47	

3.3. Ranking for flavoured beer and verrine match

Results are presented for each beer separately. Table 4 presents the contingency matrices (verrine x rank) for Lemon and Smoky beers respectively. Fig. 3 presents the CA map performed on these two matrixes.

For the Lemon beer (Fig. 3a) the lemon verrine tend to be preferentially chosen at the first position. This trend is confirmed by a Chi-squared test. The lemon verrine tend to be chosen on the first position more often than the other verrines ($\chi^2 = 2.76$; $P = .098$). On the contrary, smoky verrine was not preferentially chosen on the first place with smoky beer ($\chi^2 = 0.08$; $P = .77$) (Fig. 3b).

3.4. Verrine rank and perceived dimensions of pairing

For each beer and each dimension, scores are analysed by a two-way (rank and participant) ANOVA. Whenever a mean rank effect is significant, a Duncan post hoc test is performed (Tables 5).

For lemon beer, the rank was driven by the liking of the verrine ($P < .0001$). The verrine ranked first was significantly more liked than the verrines ranked third and fourth and tended to be more liked than that ranked second. For smoky beer, verrine rank seems also driven by verrine liking. As for the lemon beer, the more liked the verrine, the more often it was ranked first. Rejection (choice 4) was also related to an unbalanced intensity (the verrine dominates), and lower harmony, homogeneity, and familiarity levels.

3.5. Model

Fig. 4 represents all theoretically possible combinations of harmony and complexity levels and theoretical iso-liking curves according to Eq. (3). When harmony level is kept constant (horizontal line), liking first increases with complexity up to a maximal value and then decreases which illustrates the relationship between complexity and liking. When complexity level is kept constant (vertical line), liking monotonically increases with harmony which illustrates the relationship between harmony and liking.

Pairs tested in experiments 1 (lemon soft drink) and 2 (beers) are positioned on graphs, in Figs. 5 and 6 respectively, according to experimentally determined harmony, complexity, and liking scores obtained for each pair. For pairs with beer, liking scores are not known and relative values are inferred from ranking scores. Only a relative positioning of the pairs with similar or dissimilar aromas can be approximated.

Considering the number of degrees of freedom of the model and the number of experimental points (two in experiment 1 and four in experiment 2), it is no surprise that the model can account for the experimental data. With two points, the lemon drink pairs could be positioned about anywhere in the experimental space. It is similar for the

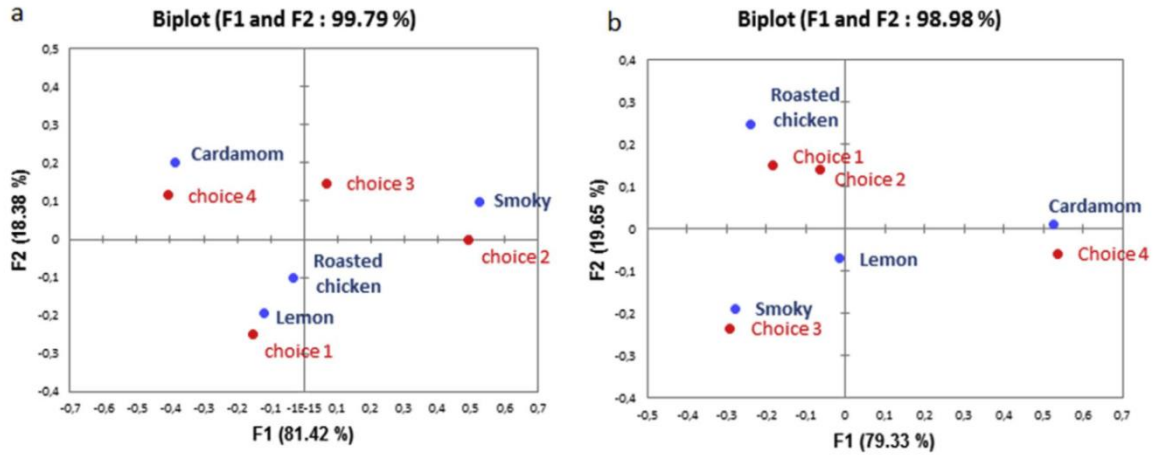

Fig. 3. Consumers' ranking of verrines to pair with beer (a. for lemon beer and b. for smoky beer).

Table 5
Balance, harmony, familiarity, homogeneity, and complexity mean scores for the pairs and liking scores of the verrines according to the ranking of verrines as good matches with the lemon and smoky beers (N = 47). Means followed by the same letter are not significantly different at the 5% level (Duncan post hoc test).

Beer		Balance	Harmony	Familiarity	Homogeneity	Complexity	Liking of verrine
Lemon	Choice 1	0.3	6.3	5.1	5.9	4.6	6.6 a
	Choice 2	0.0	6.3	5.0	5.9	4.7	5.8 ab
	Choice 3	0.6	5.8	4.5	5.3	5.1	5.2b
	Choice 4	1.4	4.9	4.0	4.6	4.8	3.3c
	P-value	.054	.074	.184	.072	.806	< .0001
Smoky	Choice 1	0.9b	6.3 a	4.5 a	5.9 a	5.0	6.6 a
	Choice 2	0.1b	5.6 a	4.0 a	5.3 a	4.2	5.7 ab
	Choice 3	0.7b	5.5 a	4.5 a	5.5 a	4.9	5.3b
	Choice 4	2.1 a	3.5b	2.9b	3.5b	5.3	3.3c
	P-value	.001	< .0001	.010	.0003	.101	< .0001

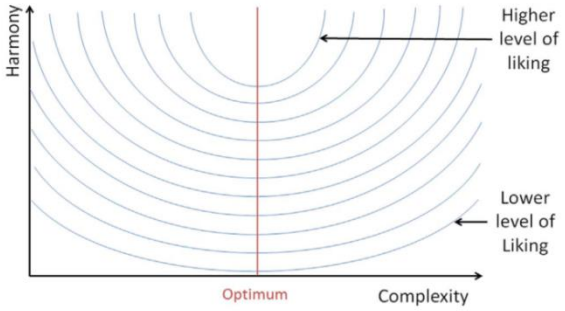

Fig. 4. Model of the relationship between Harmony, Complexity, and Liking.

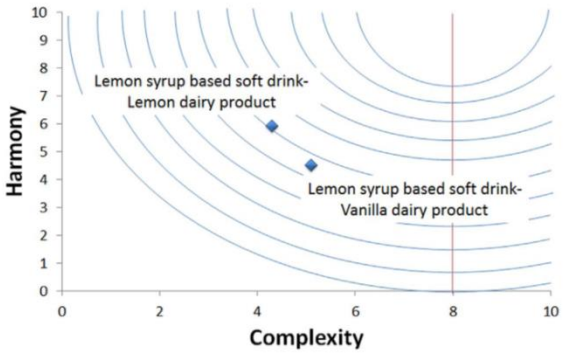

Fig. 5. Lemon soft drink - Dairy product pairs: experimental values for complexity, harmony, and liking superimposed on theoretical iso-liking curves from the model (Eq. (3)).

four points for the beer pairs. However, the model can fit the experimental data only if the theoretical optimal complexity is set in the same range as the measured complexity for those pairs.

4. Discussion

4.1. Aromatic similarity and perception of harmony, homogeneity, and complexity

The objective of the present work was to explore the experts' principle of aromatic similarity which states that two products with aromatic similarity would be a good match. We addressed this issue by comparing pairings with contrasting levels of aromatic similarity, i.e. sharing or not sharing some aromatic notes.

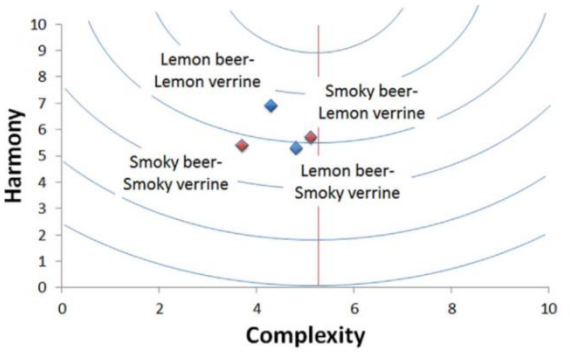

Fig. 6. Beer – Verrine pairs: experimental values for complexity, harmony, and liking superimposed on theoretical iso-liking curves from the model (Eq. (3)).

First, we hypothesized that aromatic similarity would modulate pairing properties, and specifically increase harmony and homogeneity and decrease complexity. Overall, results from the two experiments support this hypothesis. These modulations were observed with pairings that contrasted highly in similarity level (lemon syrup based soft drink – aromatized dairy product) whereas only one modulation, either increasing harmony and homogeneity or decreasing complexity was observed with pairings moderately contrasting in similarity level (beer – verrine). Aromatic similarity increased harmony and homogeneity for lemon beer pairings and decreased complexity for smoky beer pairings. These results emphasize that complexity, on one hand, and harmony and homogeneity, on the other hand, refer to two somehow independent properties. Schlich, Medel Maraboli, Urbano, and Parr (2015) also found this independence between harmony and complexity in a study in which consumers assessed a large set of Sauvignon blanc wines. Thus, aromatic similarity seems to impact harmony, homogeneity, and complexity, but to different extents according to pairing composition.

In both experiments, harmony and homogeneity are strongly correlated at the individual level ($r = 0.89$; $P < .0001$ for lemon soft drink - dairy product pairs and $r = 0.82$; $P < .0001$ for flavoured beer - verrine pairs). A similarly strong correlation was also found in a study on wine where both characteristics were assessed (Meillon et al. 2010). One possibility is that participants did not understand the difference between those two characteristics and assessed the same perception. In our experiment, we used the scales developed and optimized by Meillon et al. (2010). They devoted special care to illustrating the meaning of each dimension by providing examples in the visual modality of harmonious / non harmonious and homogeneous/non homogeneous stimuli. But that might not be effective when transposed to flavour assessment. Another explanation is that those two characteristics covary

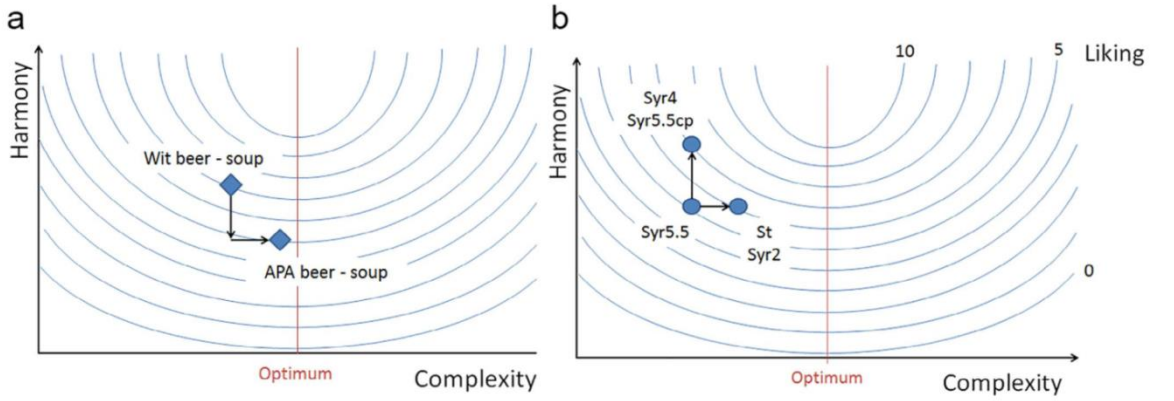

Fig. 7. Theoretical relationships between liking, harmony, and complexity: A. for the beer and soup pairings of Paulsen's study, and B. for the wine samples of Meillon's study.

within our stimulus set. This could be expected if the pairing is perceived as a whole, i.e. that the characteristics of the two products blend into a unique percept.

4.2. Aromatic similarity and liking (choice)

The experts' principle of aromatic similarity predicts that pairings with greater aromatic similarity between the two products would be preferred over pairings with less aromatic similarity. Results from the two experiments support this experts' principle. For highly contrasted pairings (lemon soft drink – dairy product) the pair with high aromatic similarity was actually preferred over the pair with low aromatic similarity. However, although the difference is significant, the advantage of similar over dissimilar aroma pairing is not very large; the difference is 1.2 points on a 11-point scale. Furthermore, when looking at individual results, 25% of the participants scored the dissimilar pair 3 points higher than the similar pair. Obviously, these participants did not base their appreciation on aromatic similarity and potentially used other criteria. Familiarity or intensity balance are known to be such criteria. We tried to keep them constant over pairings, but we probably did not succeed for every individual. One possible explanation is a discrepancy in product liking when tasted separately. Literature on pairing reports that when a set of variants have to be matched with one drink (or one food product), generally the best match includes the preferred variant (Bastian et al., 2010; Donadini & Fumi, 2014; Donadini et al. 2012; Donadini et al. 2013; Donadini et al. 2015; Harrington, Miszczac, & Ottenbacher, 2008; Harrington & Seo, 2015). As a matter of fact, for beer-verrine pairs, we observed weak or even no preferential choice of the verrine with aromatic similarity as a good match for the beer. Yet, in both instances, the verrine ranked first (whatever its flavour or its aromatic similarity level with the beer) tended to get higher liking scores when tasted alone than the verrine ranked second, that in turn tended to get higher scores than the verrines chosen third and fourth. Even though the differences are not always significant, the ranking is consistent for both beers.

Overall, the data indicate that the aromatic similarity principle is important and can drive the choice of food and drink as a good match, whenever the potential variants are equivalently liked.

4.3. How aromatic similarity impacts liking through harmony and complexity

We hypothesized that aromatic similarity modulates perceived properties of a pairing that in turn impact liking. What are the relationships between liking and the two collative properties harmony and complexity?

Concerning harmony, results showed positive relationships between harmony and liking at both group and individual levels. At the individual level, for lemon soft drink – dairy product pairs, the correlation is strong and highly significant ($r = 0.8$; $P < .0001$). The same trend was obtained for lemon beer – verrine pairs, as the lemon verrine tended to be ranked first and was also perceived as more harmonious with lemon beer than was the smoky verrine. For smoky beer, the smoky verrine was not judged more harmonious than the lemon verrine but was not a better match either. These results are in line with Paulsen et al. (2015) who found a strong positive relationship, at the individual level, between harmony and liking for craft beer – soup pairs. This was also supported by Choi et al. (2015) who reported that consumers tasting barbecue sauce mentioned that the harmony of the barbecue sauce with chicken was a driver of liking.

4.4. Combined effect of complexity and harmony on liking

Giacalone's work emphasized that complexity has to be considered along with other collative properties to explain liking. In their study, the authors predicted liking scores from a combination of novelty, familiarity, and complexity (Giacalone, Duerlund, Bøegh-Petersen, Bredie, & Frøst, 2014). Paulsen et al. (2015), referring to the general principle of « unity in variety » for aesthetic pleasure, also underlined the importance of the combined effect of collative properties (harmony and complexity) on liking. This lead us to develop a model that predicts liking from a combination of harmony and complexity levels.

This model can account for our experimental data. However, considering the very limited number of experimental points (2 for lemon soft drink – dairy product and 4 for beer – verrine pairs) we cannot validate it. A first step toward validation is to test the model on results from the literature. Two articles have reported results with harmony, complexity, and liking scores for a set of products. The first one (Paulsen et al. 2015) reported scores for beer – soup pairs with either a Wit beer or an APA beer. APA beer – soup pairs were perceived as more complex, less harmonious, and less liked than Wit beer – soup pairs.

The second one (Meillon et al. 2010) concerns five wines. The sample perceived as the least complex and harmonious was also the least liked (Syr5.5). The four other wines had equivalent liking scores. However, compared to the first sample, two (St, Syr2) were equivalent in complexity but more harmonious and the two others (Syr4, Syr5.5cp) were more complex than Syr5.5 but equivalent in harmony.

Both results could be accounted for by our model (see Fig. 7). The beer – soup results are consistent with the model regardless of the harmony level (the two points can be translated vertically) and the complexity level (the two points can be translated horizontally). The wine results are consistent regardless of the harmony level (the two

points can be translated vertically). However, they are consistent only with complexity levels lower than the optimal level.

Beyond experimental data, the model is also consistent with the general principle of "unity in complexity". When a stimulus is highly complex, above the optimum level, predicted liking is high if and only if harmony is very high too.

If validated, this model could provide a framework that accounts for experimental data that seems at first contradictory. It could also help to better understand how aromatic similarity impacts pairing judgments through modulation of collative properties. However, it has to be tested experimentally in a deeper way.

5. Limitations

Results from the present work have to be considered preliminary in addressing the aromatic similarity principle of pairing. We found general trends explaining how aromatic similarity impacts pairing judgments and liking. However, some participants may have used other criteria such as liking of the elements of the pair considered alone.

Moreover, because of the need to keep experimental conditions as controlled as possible, first to limit sources of variation, and second, to insure that tastings in session 1 and session 2 were done in similar conditions, the experiment was not performed in a natural setting. Scenarios were found to be good alternatives allowing for both situational immersion and controlled conditions.

A third limitation is that for beer – verrine pairs, participants were not directly asked for their liking but had to make successive choices among the set of verrines. This procedure was intended to be a more involving task than rating but may limit the direct comparison of results from the two experiments. However, hedonic rating and ranking, at least direct ranking, have been found to provide quite similar results (Villanueva, Petenate, & Da Silva, 2000; Wichchukit & O'Mahony, 2015). Another aspect to consider is the instructions provided to participants. The short scenario put them in the context of planning a party for friends. Thus, they were not explicitly asked to base their judgment on their own liking and some of them may have considered putative opinions of others to make their choice. However, this is probably not a common behavior as liking of the individual verrine tasted alone was also related to their choices.

6. Conclusion

The results demonstrate that aromatic similarity in food and beverage pairings modulates the levels of perceived harmony, homogeneity, and complexity of pairing.

According to the experimental design, the liking of the individual food seems to be an influential determinant of pairing choices. However, aromatic similarity, by enhancing the perceived harmony and modulating perceived complexity, also contributes to the hedonic judgment of the pairing. Our results also emphasize that these collative properties should be considered conjointly when studying mechanisms involved in the aromatic similarity principle.

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3. Paper's Conclusion

The main objective of this paper was to investigate whether aromatic similarity leads to a good match and to identify the underlying perceptual mechanisms. More specifically, the hypothesis of this Chapter was that a higher level of aromatic similarity between food and beverage will lead the two products to create a better match than two products with a lower level of aromatic similarity, in inducing a blending effect of the two products' flavors. The idea was that the higher this blending effect, the more harmonious, more homogeneous and the less complex and the more appreciated match.

The results demonstrate that beyond the respective appreciation of the two products, that mainly drive the match liking, as also demonstrated in the literature (Bastian et al., 2010; Donadini & Fumi, 2014; Donadini et al., 2012, 2013; Donadini et al., 2015; Harrington et al., 2008; Harrington & Seo, 2015), a higher level of aromatic similarity between food and beverage contributes, in some extent, to the hedonic judgement of the pairing, in creating a more homogeneous multidimentional percept perceived as more harmonious and less complex than the association of two products with a lower level of aromatic similarity.

The paper also aimed at providing a theoretical model that accounts for the effect of aromatic similarity on match liking through the joint modulation of harmony and complexity. Paulsen et al. (2015) indeed emphasized the need to consider harmony and complexity together to explain match liking. Providing that harmony and liking are linked by a positive linear relationship (Choi et al., 2015; Paulsen et al., 2015) and that complexity and liking are linked by an inverted-U shaped relationship (Berlyne, 1967; Lévy et al., 2006), the additive effect of these two parameters on liking was assumed.

According to the experimental results and to the results stemming from some other studies, the additive effect appears as being appropriate to explain the joint effect of harmony and complexity on liking. However the number of experimental points was too limited to validate this model. A study was therefore implemented to experimentally test this theoretical model.

4. Model testing

4.1. Introduction

The previous paper emphasized that complexity and harmony need to be considered together to explain liking. A theoretical model accounting for experimental data and data stemming from the literature was suggested. This model stipulates that the effect of harmony and complexity on liking may be considered as additive. Harmony is known to be related to liking according to a positive linear relationship (Choi et al., 2015; Paulsen et al., 2015). Complexity is theoretically related to liking through an inverted U-shaped relationship (Berlyne, 1967; Lévy et al., 2006). Thus, the idea of the model is that when harmony level is kept constant, liking first increases with complexity up to a maximal value and then decreases which illustrates the relationship between complexity and liking. When complexity level is kept constant, liking monotonically increases with harmony which illustrates the relationship between harmony and liking. According to this joint relationship, the liking should be predicted from the level of complexity and harmony according to the following equation (Eq.1)

$$[\text{Eq.1}] \qquad \text{Liking} = a + b*\text{Harmony} + c*\text{Complexity} + d*\text{Complexity}^2$$

The joint impact of complexity and harmony on liking were represented according to a representation inspired by surface response methodology. Experimental points were represented on a two-dimensional space according to their complexity level (x-axis) and harmony level (y-axis). The predicted liking values according to Eq. 1 were represented on the z-axis, defining a “liking surface”. This surface is shaped like a semi-sphere with the highest liking level achieved for the highest level of harmony and the optimum level of complexity. For convenience for reading, the third dimension (liking) was represented on the 2D harmony – complexity map by iso-liking curves. Iso-liking curves represent all harmony – complexity level combinations leading to the same predicted level of liking (Figure 4).

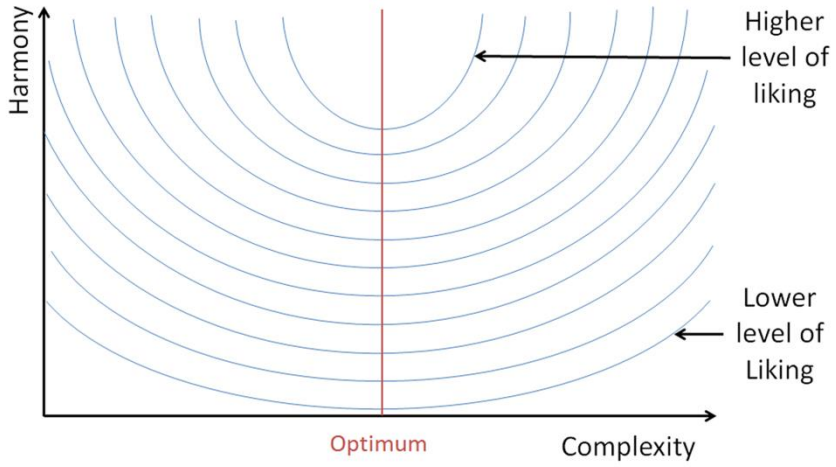

Figure 4 : Theoretical model of the relationship between Harmony, Complexity, and Liking (Eschevins, Giboreau, Allard, & Dacremont, 2018)

Even if this model accounts for the experimental data provided by the previous paper and some other studies where harmony, complexity and liking were reported, the number of experimental points was every time too small to validate the model. Thus, the objective of this work was to experimentally test this model with a higher number of experimental points.

To this end, dairy products were created to cover a large range of combinations of harmony and complexity levels. Participants tasted all dairy products and rated them in terms of liking, harmony and complexity. The model was then tested through a multiple linear regression according to eq.1 and the predicted liking resulting from the model equation was represented as iso-liking curves. This representation was compared to the theoretical representation presented in Figure 4.

4.2. Materials and Method

Participants

Thirty participants (19 women and 11 men, from 21 to 64 years old) were recruited in Dijon and vicinities. They volunteered to participate in the experiment; they gave their written, informed consent, and received gifts as reward.

Products

Eight dessert type products were prepared from "fromage blanc" (calin, Yoplais), a kind of unsalted cottage cheese with the texture of Greek cheese. These products were prepared by adjunction of different ingredients: Peach syrup (Teisseire), Lemon syrup (Teisseire), Strawberry syrup (Carrefour), Violette syrup (Moulin de Valdonne), Orgeat syrup (carrefour), Parlin (Vahine), White sugar (top budget), Gold sugar (Vahine), candied cherry (Vahine), candied orange (Vahine), blue or red Tapioca (Tipiak) prepared with different food colorants (blue, red and yellow, Vahine). Table 1 gives the recipes of the eight desserts.

Three types of tapioca differing from their color (red, blue or orange) were prepared. 25g of dry tapioca were cooked in 2L of tap water in which respectively 40 drops of red colorant (red tapioca), 40 drops of blue colorant (blue tapioca) or 20 drops of red colorant plus 32 drops of yellow colorant (orange tapioca) were added. Candied fruits were cut in small pieces prior to be added in the dairy product. Dairy products were prepared just before each session.

Dairy products	**Quantity (% w/w) of ingredients added to the "fromage blanc"**
PS	5% of peach syrup,5% of strawberry suryp and 2.8% of sugar
O	5% of orgeat syrup and 2.8% of sugar
LOV	5% of orgeat syrup,5% of lemon syrup and 5% of violette syrup
LS	5% of strawberry syrup, 5% of lemon syrup and 5% of white sugar
PS-TaRed-Cherry	5% of strawberry syrup, 5% of peach syrup, 8% of Tapioca red, 8% of candied cherry and 2.8% of white sugar
PS-TaOrange-Orange-gold sugar	5% of strawberry syrup, 5% of peach syrup, 8% of tapioca orange, 8% of candied orange,4% of gold sugar and 2.8% of white sugar
LPS-TaBlue-Pra	5% of strawberry syrup, 5% of lemon syrup, 5% of peach syrup, 8% of tapioca blue and 6% of Pralin
LPS-TaRed	5% of strawberry syrup, 5% of lemon syrup, 5% of peach syrup, 8% of tapioca red

Table 1: Dairy products' recipes

Procedure

Participants received about 4cl of each of the eight desserts presented in 10cl white plastic cups coded with three digit numbers. The eight desserts were presented in random order and were assessed monadically. Participants were asked to taste the dairy products and rate liking, harmony, and complexity on 11-point rating scales. Ratings were converted into scores from 0 (low level) to 10 (high level).

Model testing

Figure 5 shows the range of products' complexity and harmony within product's set. Various combinations of complexity and harmony levels were reached. However, compared to an optimal matrix, represented in orange in the graph, combinations of low level of complexity and low level of harmony as well as combinations of high complexity and high harmony levels failed to be reached suggesting that complexity and harmony could be covariate variables.

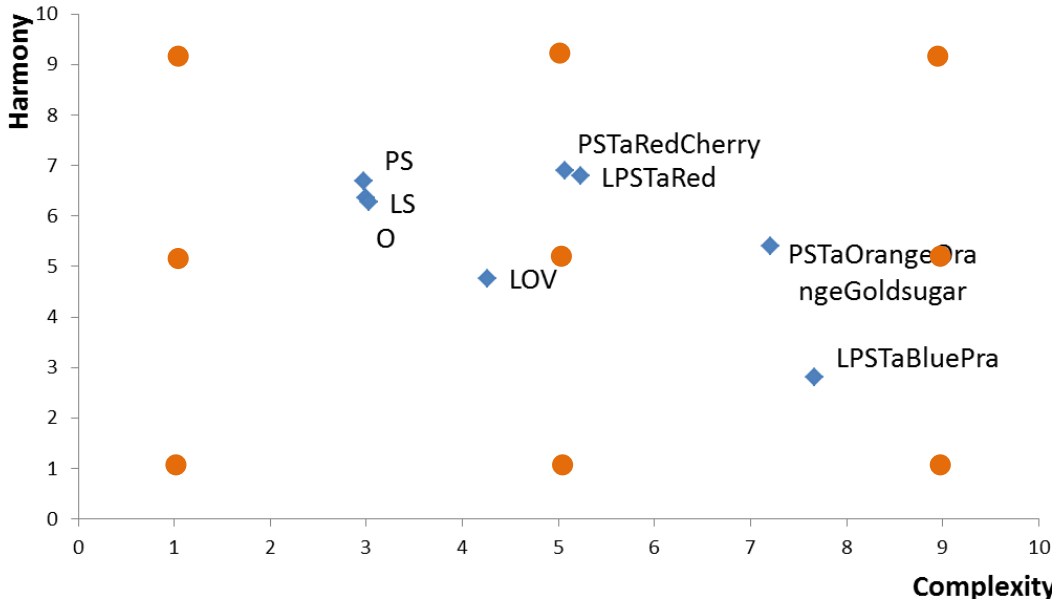

Figure 5 : Range of products' complexity and harmony combinations. Optimal matrix (orange) and experimental data (blue)

A multiple linear regression was performed on these experimental data (NemrodW software). The model was refined compare to Eq.1 by adding an interaction terms between Complexity and Harmony, leading to Eq.2.

$$\text{(Eq. 2)} \qquad \text{Liking} = a + b\text{Harmony} + c\text{Complexity} + d\text{Complexity}^2 + e\text{Harmony}*\text{Complexity}$$

4.3. Results

The regression analysis carried on experimental data shows the model is significant ($F_{4;3}$ =324 ;*P*=0.028). The multiple linear regression (Eq.3) confirms that "harmony" (*P*<0.0001) is positively and significantly related to liking. Complexity is related to liking according to a quadratic relationship as both "complexity" (*P*=0.001) and "complexity^2" (*P*=0.03) are positively and significantly related to liking. The interaction between harmony and complexity also reaches significant level (*P*=0.04).

$$\text{(Eq.3.)} \qquad \text{Liking} = 4.549 + 2.17\ \text{Harmony} + 0.846\ \text{Complexity} + 0.487\ \text{Complexity}^2 - 0.407\ \text{Harmony}*\text{Complexity}$$

Figure 6 represents experimental points the two-dimensional space according to complexity (x-axis) and harmony (y-axis) levels. The liking values predicted from Eq. 3 were represented on the z-axis, defining a "liking surface". Iso-liking curves (in blue) represent all harmony – complexity level combinations leading to the same predicted level of liking.

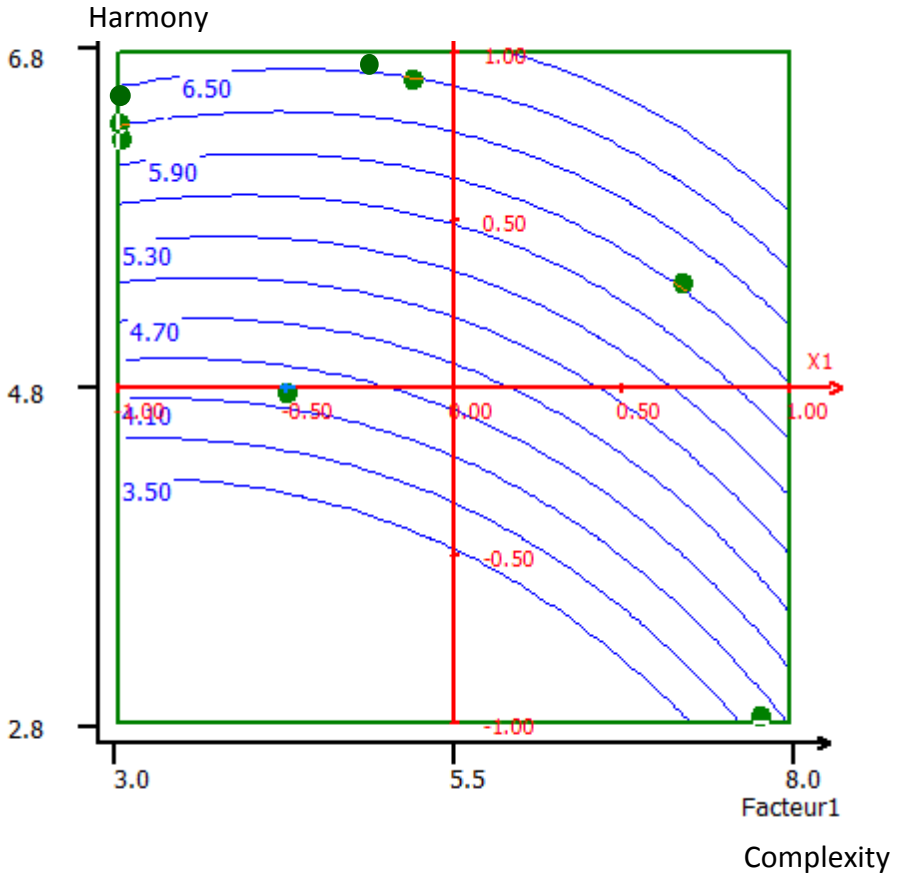

Figure 6 : Predicted iso-liking curve (in blue) according to the level of complexity and Harmony. Green points represent the eight tasted products that were used to test the model.

When compared to the theoretical representation (Figure 4), the experimental data failed to validate our model. The theoretical model stipulated that when complexity level is kept constant, liking monotonically increases with harmony. This also stands for predicted data on Figure 6. The model also stipulated that when harmony level is kept constant, liking first increases with complexity up to a maximal value and then decreases. Such relationships were only partially demonstrated. However, for a constant level of harmony, liking is first constant and then increases with complexity as expected.

4.4. Discussion

The objective of this work was to test whether the combined effect of harmony and complexity may predict liking. This model assumed that when harmony level is kept

constant, liking first increases with complexity up to a maximum and then decreases. When complexity level is kept constant, liking monotonically increases with.

The experimental data did not allow for fully validating this theoretical effect of harmony and complexity on liking. Nevertheless, this lack of validation not necessarily calls this model into questions. The experimental design may explain it.

First, as the experimental points didn't cover the whole range of combinations between harmony and complexity level, the prediction of liking is not optimal. Optimal matrix such as 3^k full factorial design or composite matrix, allow for the best estimation of regression coefficients of the model. The most important property of this design is orthogonality between factors. We did not succeed to create such a data set (Figure 5) especially because the combination of low complexity and low harmony level seems difficult to obtain in food domain. These two properties are probably somehow related. The fact we failed to reach combinations of high complexity and high harmony may be explained by our limited abilities to create sophisticated food products from dairy products. Chefs' expertise would be required here to create such products, from a larger set of ingredients.

Overall, experimental data seems compatible with the theoretical model we first developed. Results suggest our experimental products only covered a fraction of the whole space (Figure 7) with complexity levels lower than the optimum level of liking.

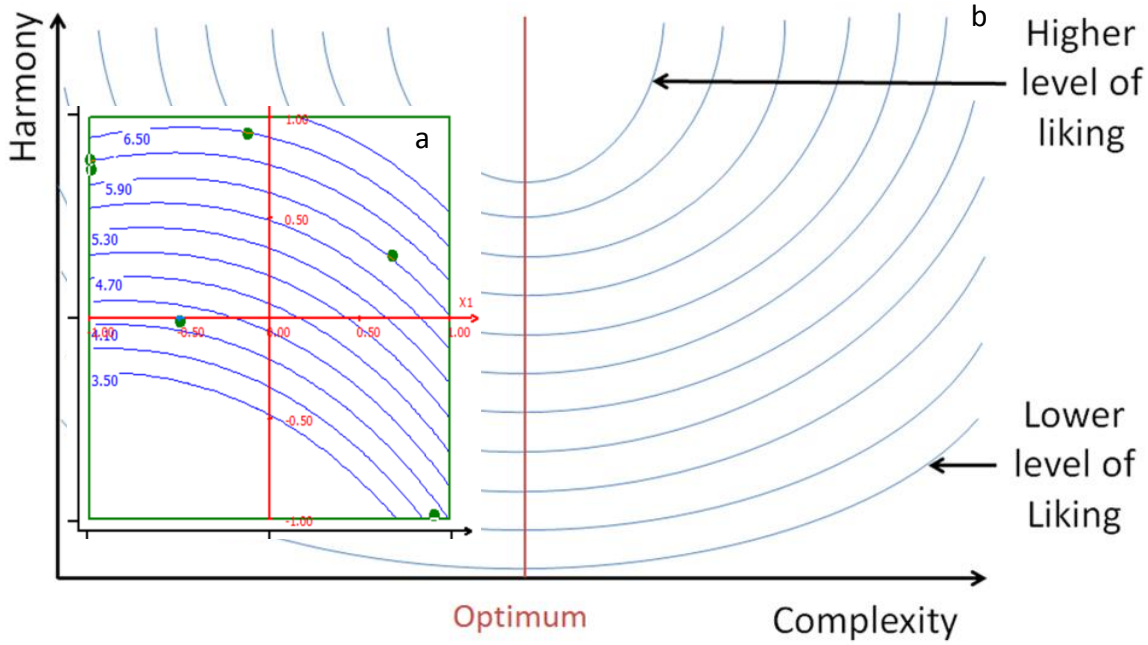

Figure 7 : Adequacy between experimental predicted iso-liking curves (a) and theoretical predicted iso-liking curves (b) according to according to the level of complexity and Harmony.

In food domain, studies investigating the theoretical inverted U-shaped relationship between complexity and liking also failed to reach over-optimal levels. Giacalone et al. (2014) investigated consumers' hedonic response to different beers in light of Berlyne's collative-motivational model. They studied the relationships between liking and three collative properties including complexity. After having tested different set of beers, they demonstrated that complexity had a positive effect on the hedonic response. The authors suggested that they failed in spanning the spectrum of complexity sufficiently enough to activate the minimum rejection threshold from which the relationship with liking is reversed. The same problem may explain our results. The created products probably not reach the rejection threshold of complexity.

In a tentative to address the span complexity issue, we tried to create a larger range of combination of harmony and complexity levels in designing several pairings between dairy products and soft drinks. However, we failed in covering a large range of pairings' complexity and harmony combinations (see Figure 8). Actually harmony and complexity were strongly correlated. Such a set of stimulus do not allows for testing the theoretical model and the combined effect of both properties on liking.

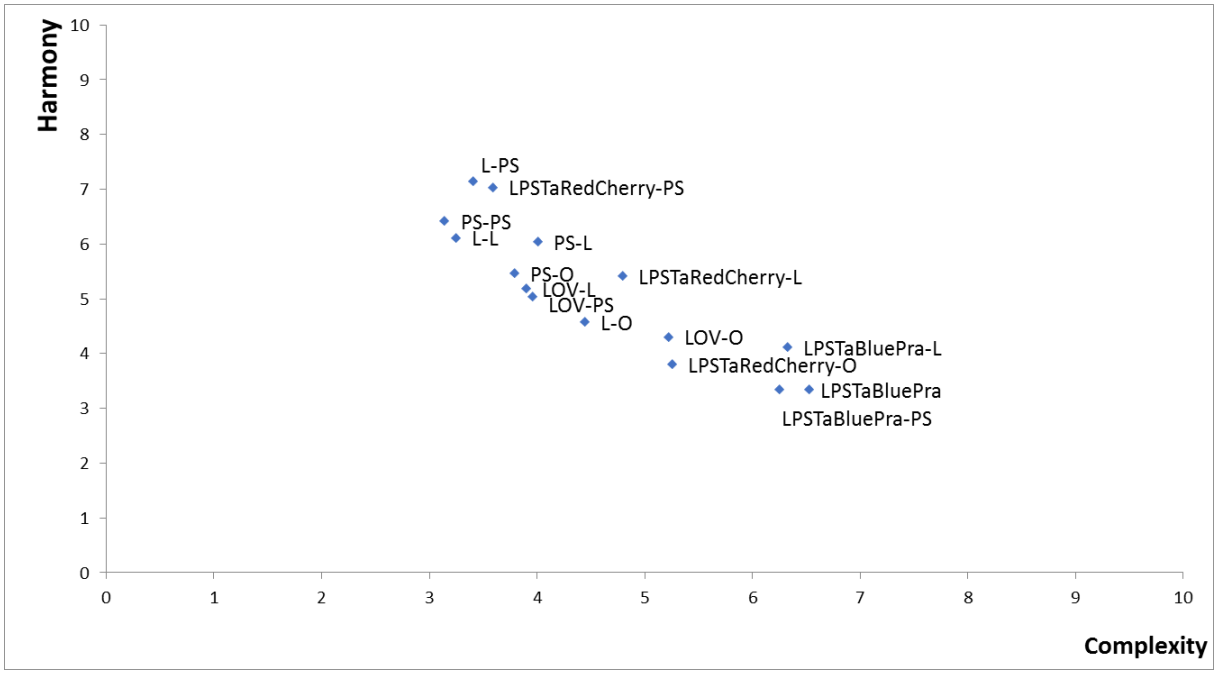

Figure 8 : range of pairings' complexity and harmony combinations

Another explanation should be that the statistical methodology used to test the model was not the most accurate one. We used a multiple linear regression base on an a priori equation based on hypothesis. Structural equation modelling (SEM) is a data analysis technique that enables researcher to answer a set of interrelated research questions in a single, systematic and comprehensive analysis by modelling the relationships among independent and dependant variables. This methodology designates a diverse set of mathematical models, computer algorithms, and statistical methods that align a network of concepts to experimental data (Kaplan, 2009). Such methodology were used in food behaviour domain to model the present food variety seeking score of children according to different variable such as age, gender and neophobia (Nicklaus, Boggio, Chabanet, & Issanchou, 2005). This methodology may be used with our data to visualize the most suitable model for explaining the relationship between liking, complexity and harmony. This methodology could account for the covariation we observed between complexity and harmony for instance. Moreover, other variables, also known to modulate liking, such as familiarity or intensity balance should be integrated in the tested models.

4.5. Conclusion

The results demonstrate that liking may be explained by the combine effect of harmony and complexity. Even though experimental data failed to validate the theoretical model they are still compatible with the idea of a positive linear relationship of harmony with liking and an inverted U-shaped relationship between complexity and liking. Further work is needed to fully understand the effect of complexity and harmony on liking.

5. Chapter's Conclusion

Chapter 5 first aimed at investigating whether aromatic similarity between food and beverage leads to a good match and to contribute to the identification of the underlying perceptual mechanisms.

The results highlighted that perceived **aromatic similarity between food and beverage contributes, in some extent, to the hedonic judgment of their association**. However, the results also highlight that aromatic similarity level between food and beverage is not the main characteristics predicting match liking. As the different variants of the tasted match were not equally liked when tasted alone, the hedonic valence of the match was largely dependant of products' liking. According to the experimental design, one beverage was tasted with different foods. The food the best liked was the one leading to the better match. This relationship was also highlighted by Bastian et al. (2010); Donadini and Fumi (2014); Donadini et al. (2012, 2013); Donadini et al. (2015); Harrington et al. (2008); Harrington and Seo (2015). Moreover, when looking at individual results, 25% of the participants scored the pair with the lower level of aromatic similarity higher than the pair with the higher level of aromatic similarity. We suggested that even if other collative properties, such as familiarity and intensity balance were kept constant over pairings, this was probably not the case for every individual. Thus the pair liking may also depends on the relative level of match familiarity and balance of intensity.

Results also demonstrate that the role of aromatic similarity on match liking is due to the modulation of collative properties such as harmony and complexity. More precisely, a higher level of aromatic similarity between food and beverage can promote good match in creating a more homogeneous multidimentional percept, perceived as more harmonious and less complex than a pair of products having a lower level of aromatic similarity.

Based on the relationship between harmony and liking on the one hand and complexity and liking on the other hand, we suggested a model accounting for the impact of aromatic similarity on liking. Althought the tentative validation study failed to fully demonstrate the

model, experimental data are still compatible with this model. It would be necessary to implement another modeling approach such as SEM to better describe this phenomenon.

The modulation of pairing perception according to aromatic similarity was observed with pairings that contrasted highly in similarity level (lemon syrup based soft drink – aromatized dairy product) whereas only one modulation, either increasing harmony and homogeneity or decreasing complexity was observed with pairings moderately contrasting in similarity level (beer – verrine). These observed differences between the two studies may be explained by the products' composition in terms of sensory properties that characterized the products' flavor. Indeed, contrary to flavoured dairy products and soft drinks where the added aromas minly contributes to the products' flavors, beer and purée are complex products with various sensory properties that characterize their flavors. This leaves room for attentional modulation in stimulus perception (Keller, 2011; Marks, 2003). In pairing perception, consumers' attention may be focused on other characteristics than the shared aroma decreasing the perception of aromatic similarity. To verify this hypothesis **we wonder whether the effect of aromatic similarity on match harmony, complexity and thus liking may be reinforced if the taster' attention is focused on the product' aromas of interest that leads to different level of aromatic similarity.**

Descriptive food labels may tune attention toward the mentioned characteristics in the stimulus (Spence & Piqueras-Fiszman, 2014). In line with this idea, the aim of the next chapter was therefore to investigate whether providing products' labels explicitly referring to the aroma, would modulate the effect of aromatic similarity on beers-purées match perception.

Chapter 6: Products' labels and aromatic similarity in food and beverage pairing.

1. Introduction

The level of aromatic similarity between two products modulates perception of their association as a pair. A food – beverage pairing with high aromatic similarity is in some extent, better liked, perceived as more harmonious and less complex than a pair with a lower level of aromatic similarity. Such modulations were clearly shown when the shared aroma was practically the only property that determines the products' flavors. However, with more complex products in which the shared aroma was a note among others sensory properties, these modulations are not systematically demonstrated. Attention that could be tuned toward properties other than aromas may explain such differences. Indeed, in pairing perception, consumers' attention may be focused on other characteristics than the shared aroma decreasing the perception of aromatic similarity between food and beverage. In this case, other pairing' characteristics may influence its hedonic valence.

Descriptive food labels may tune attention toward the mentioned characteristics in the stimulus (Spence & Piqueras-Fiszman, 2014). In line with this idea, the aim of this work **is to investigate how providing products' label referring to the aromas leading to the pair' aromatic similarity level would reinforce the effect of aromatic similarity on match liking and perception.**

Our hypothesis is that providing products' name explicitly mentioning the shared aroma would reinforce the effect of aromatic similarity on match harmony and complexity perception as well as on match liking.

To investigate this hypothesis, the same beer and potatoes purée pairings that those used in the previous chapter were prepared. Two studies were implemented to test, in one hand, pairings between lemon beer and two different potatoes purées (with lemon or smoke aroma), and in another hand, to test pairings between smoke beer and lemon or smoke potatoes purée. In the two studies, pairings were tasted in blind condition and in informed condition. In informed condition, participants were provided with products' label referring to the aroma of interest (smoke or lemon). The level of aromatic similarity between the two

products was therefore indirectly mentioned to the tasters. In the two conditions, each pairing were tasted monadically and rated for their level of liking, harmony and complexity. Results resulting from the pairs' evaluation realized in blind condition were compared with those resulting from the chapter 5. Then the pairings perception was compared between blind and informed condition.

Because laboratory is not fully representative of actual contexts of consumption of beer and food pairing, it should be necessary to investigate this question in more ecological contexts of consumption. However, the within subject design implemented in the two studies is not appropriated to such contexts. An in-between subject design appears as being more appropriate and more representative of an actual context of consumption. However, before to implement the same studies in an ecological context of consumption, it is necessary to verify that in-between subject design may allow observing significant differences. To this end, a third study based on the same methodology used in the two first studies was implemented. The only difference is that an in-between subject design was used. The results of this study were analysed along with the results of the two other studies.

This work is presented in the article 3, in writing.

2. Effect of products' labels refering to products' aroma on the effect of aromatic similarity in food and beverage pairing (Article 3)

Title: Effect of products' labels refering to products' aroma on the effect of aromatic similarity in food and beverage pairing.

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Abstract: Aromatic similarity is a basic principle to match food and beverages. A higher level of aromatic similarity between food and beverage promotes good match in increasing harmony and decreasing complexity. However, in complex stimulus such as food and beverage pairing, taster's attention may be focused on other aspects than aromatic characteristics that in turn lead to a decrease in perceived similarity. The aim of this work was to investigate whether providing product labels referring to the aromas would modulate the effect of aromatic similarity on match perception. We hypothesized that labels will reinforce the effect of aromatic similarity on match perception by increasing harmony and decreasing complexity.

Two beers flavoured with lemon or smoky aroma and savoury potato purées flavoured with either the same aroma or another aroma were tested. They lead to pairings with two contrasted levels of aromatic similarity. Pairings were assessed by two groups of 36 participants in a within experimental design (one for each beer). Participants rated each match for liking, harmony, complexity, intensity balance and familiarity in two experimental conditions (blind vs informed).

Results confirmed in some extent our hypothesis. Product labels increased the discrepancy in complexity between the two contrasted levels of aromatic similarity for both lemon and smoke beers. They also increase the discrepancy of harmony between the two contrasted levels of aromatic similarity for smoke beer. Product label had no effect on the liking of pairings whatever the beer.

Laboratory condition is not representative of ecological context of consumption. But an actual consumption situation generally implies that each participant assessed only one pair in only one experimental condition. The secondary objective of this work was to check whether an in-between subject design would lead to the same results of a within subject design. Results fail to show any effect of aromatic similarity on pair assessments. This highlights that participants need to compare pairs and that aromatic similarity effect seems somehow context-dependant.

Keywords: Food and beverage pairing, aromatic similarity, products label, perception, hedonic evaluation.

1. Introduction

Beer increasingly appears to be a good companion for food. Number of recommendations in terms of food and beer pairing are currently available in culinary literature. Generally, they provide examples of matches with given products. Some references provide not only different examples but general guidelines to match different food and beer categories. For example, fruit beers are recommended as companion to desserts, white meat, seafood and cheeses whereas IPA beers are recommended as companion to spicy food, pizza, pasta and cheeses.

Some experts offer guidelines to match products. Food and beverage can be matched according to similarity (finding similar sensory characteristics in the two products (aromas, taste, texture...) or contrast (matching product with various sensory characteristics) while the balance in intensity (neither the food, nor the beverage has to dominate the match) is met. The beverage may also have a role of palate cleanser (Herz & Conley, 2015; Maresca, 1994; Pierre, 2014).

The notion of similarity often involves aromas and is widely mentioned in culinary literature. For example, a blond Leffe paired with a fruit salad with a vanilla ice cream create a good match because of the vanilla aroma shared by the dish and the drink. This principle of aromatic similarity in food and beverage pairing was only scarcely investigated (Eschevins, Giboreau, Allard, & Dacremont, 2018). The authors hypothesized, according to information available in the literature about visual modality (Aitken, 1974; Berlyne & Boudewijns, 1971; Schloss & Palmer, 2011), that the higher the aromatic similarity between food and beverage,

the more harmonious and liked, and the less complex the pair. They tested their hypothesis with two types of pairings: Pairings of flavoured dairy products and soft drink, and pairing of flavored beers and savory savoury potatoes purées. They created two contrasted aromatic similarity levels either high or low. For pairings between flavoured dairy products and soft drink, the aromatic similarity modulated the pairing perception in line with the hypothesis. Concerning flavoured beers and savory purées, the authors demonstrated that the match with the higher level of aromatic similarity was either perceived as more harmonious (with lemon beer) or less complex (with smoky beer) than the match with a lower aromatic similarity level. One possible explanation of the discrepancy between the two pairs of products lies in the different contribution of the added aroma in the global products' flavors. In soft drink and dairy products the added aromas were the main characteristics determining the products' flavours whereas in beers and potatoes purée, considered as more complex products, the added aromas contributed with number of other sensory properties (aroma, taste, texture) to products' flavour. In complex products, consumers' attention may be focused on other characteristics than the shared aroma that would decrease the perception of aromatic similarity. The shift of attention toward different modalities depends on expectations (Keller, 2011; Spence, Kettenmann, Kobal, & McGlone, 2001). Tasters' expectations toward food product may be changed by providing food labels (Piqueras-Fiszman & Spence, 2015). In line with this idea, the aim of this work was to investigate whether providing products' names explicitly referring to the added aroma will reinforce the effect of aromatic similarity in match perception. Tuning attention toward the shared aroma would increase perceived similarity leading to an increase in harmony and a decrease in complexity, that in turn will increase liking.

To adress this issue, the same savoury beers and potatoes purées that those used by Eschevins et al. (2018) were used. Each beer was paired with one potatoes purée sharing the same aroma (high similarity level) and one potatoes purée with the other aroma (low similarity). Pairs were assessed in two experimental conditions: blind vs. informed conditions. In the informed condition, the product names provided to participants explicitly mention the added aromas (e.i.: a beer with lemony notes).

Our hypothesis is that product labels referring to the added aroma will reinforce the effect of aromatic similarity on match perception by tuning attention toward the shared aroma. It is then expected that aromatic similarity would increases liking, harmony and decreases

complexity. This effects should be more pronounced in the informed compare to the blind condition.

Because laboratory setting does not represent actual consumption experience, it would be necessary to conduct such experiments in a more ecological context. However, a more ecological condition requires that each participant tastes only one combination in a unique experimental condition. To check the impact of experimental design on results, we compare a within subject design to a in-between subject design.

2. Materials and Method

2.1. Participants

One hundred and eighty nine participants (101 women and 88 men aged from 18 to 74 years) were recruited in Dijon and vicinities. They volunteered to participate in the experiment; they gave their written, informed consent, and received snack and sweet treats as reward. Alcohol tests were carried out before and after the session. All participants started the session with a 0.0 blood alcohol level. Participants were randomly assigned to one the six experimental groups. For the within-subject design, one group of thirty six participants (24 woman and 12 men aged from 21 to 73 years old) tasted pairings with smoke beer and one group of thirty six participants (20 women and 16 men aged from 19 to 60 years old) tasted pairings with lemon beer. The remaining subjects were split out into four groups of twenty eight, thirty, twenty nine and thirty for the between-subject study.

2.2. Products

The beers and food used in this study were the same than those used by Eschevins et al. (2018).

Two flavoured beers were prepared by adding smoky aroma (0.12%, aromefume115, Selectarôme) or lemon aroma (0.004%, aromecitron115, Selectarôme) to Stella Artois (0.25 L glass bottle, 5.0% alcohol, ABV). Flavoured beers were prepared half an hour before each session and kept at 4°C +/- 2°C in a covered glass container before serving.

Savoury potato purées were aromatized with the same aromas as the ones used for the beer (smoky or lemon). Thus, aromatic similarity between beer and purée was either high (smoky

beer with smoky purée, lemon beer with lemon purée) or low (smoky beer with lemon purée, lemon beer with smoky purée). Another aromatized purée (cheese) was included in the experiment as distractor intended to conceal the experimental design.

Purée were prepared with 42 g of instant mashed potato (Mousline l'originale, Maggi) added to 600 mL of hot semi-skimmed milk (Lait de montagne, Carrefour) with two leaves (3.78 g) of edible gelatine (Vahiné) soaked in cold water for a few minutes, and 2 g of salt. Then, the mixture was aromatized by adding either 0.160 mL of lemon aroma (aromecitron115, Sélectarôme), 3 mL of smoky aroma (aromefume115, Sélectarôme), or 15g of Comté cheese (Président). The mixture was stored in the refrigerator overnight. One hour before tasting, mixtures were poured into verrines (crystal clear plastic cups) and kept at room temperature.

2.3. Procedure

For the within-subject design, participants attended one three steps session. The first step was dedicated to the evaluation of product liking when tasted alone. Participants received all products (1 beer and 3 purées) in a random order and assessed their liking on 11-points rating scale anchored from "I don't like at all" (score 0) to "I like very much" (score 10). Participants were asked to take some unsalted biscuits and water between each products.

In the second step, participants received all possible beer-purée pairs (1 beer x 3 purées) in a random order in blind condition. For each pair, they were instructed to take a sip of beer, a spoonful of purée, a second sip of beer, and a second spoonful of purée, and to assess the pairing in terms of liking, harmony, and complexity on 11-points rating scales (Eschevins et al., 2018). Intensity balance and familiarity were also rated to check that pairings did not differ on these two properties.

Ratings were converted into scores from 0 to 10, except for balance intensity, that was converted into scores from −5 to +5, with 0 representing an exact balance. The third step was the same that the second one but information on the aromas added in each product of the pair was given to participants. For beers the labels were either "a beer with lemon note" or "a beer with a smoked note". For potato purées the labels were either "a potato purée with lemon note" or "a potato purée with smoked note".

Participants were asked to take some unsalted biscuits and water between each pair.

For the in-between subject design study, each participant tasted only one pair in only one of the four experimental conditions (see Table 1) instead of assessing all four conditions as in the within-subject design.

	High similarity	**Low similarity**
Blind condition	Lemon beer - lemon purée N = 28	Lemon beer- smoke purée N = 30
Informed condition	Lemon beer-lemon purée N = 30	Lemon beer-smoke purée N = 29

Table 1: Experimental conditions

3. Statistical analysis

The data were analysed with XL-STAT (Addinsoft, USA) software.

The difference in liking, harmony, and complexity scores between pairs with high aromatic similarity and low aromatic similarity were analysed with one-tailed paired t-tests according to our hypotheses about aromatic similarity impact. Intensity balance and familiarity scores for similar vs. non similar pairs were analysed with two-tailed paired t-tests. For the in-between subject design, independent t-tests were performed.

4. Results

4.1. Aromatic similarity and consumers' judgement of pairings tasted in blind condition. Comparison with (Eschevins et al., 2018)'s experiment.

Figure 1 shows the differences between mean scores of high aromatic similarity and mean scores of low aromatic similarity for match liking, harmony and complexity for pairings with lemon and smoked beers (mean scores are presented Appendix 1). Results from the previous experiment (Eschevins et al., 2018) and from the present study (within Subject design) are represented on the graph.

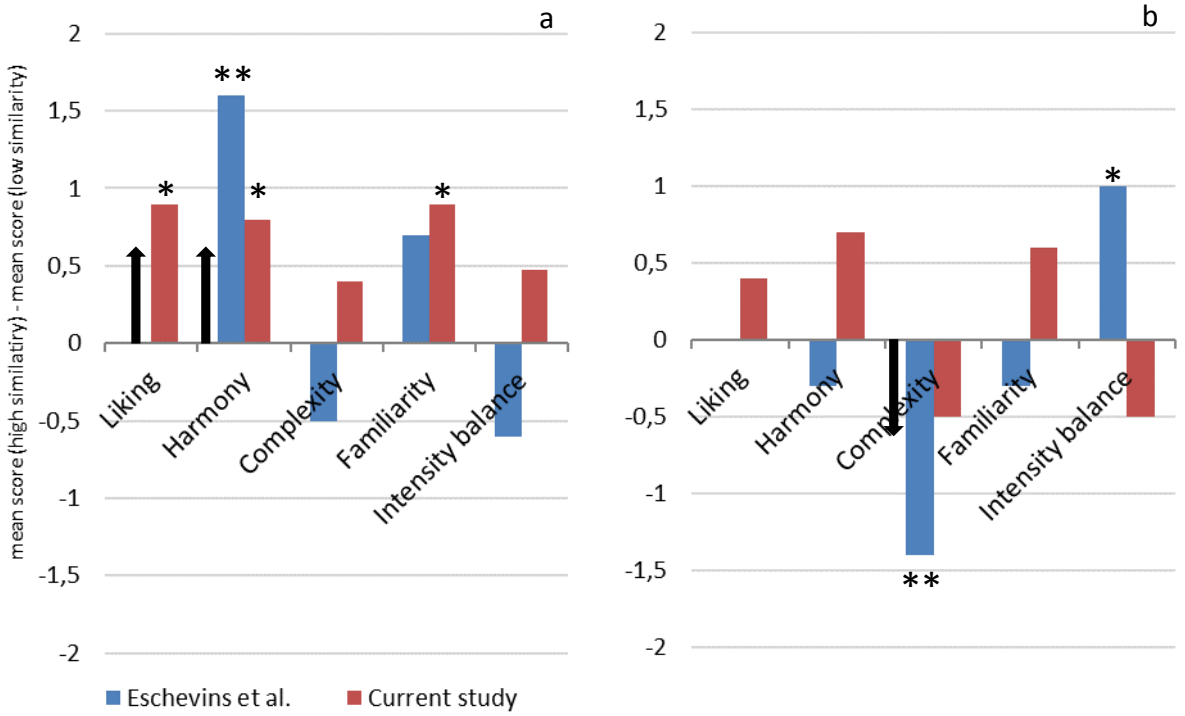

Figure 1: Effect of aromatic similarity increase on match liking, harmony, complexity, familiarity and intensity balance for pairings with lemon beer (a) and smoked beer (b) tasted in blind condition. Comparison between the current study (N=36) and the study of Eschevins et al. (2018) (n=47). Black arrows show the theoretical effect of aromatic similarity on match perception according to the results of Eschevins et al. (2018) * P<0.1, ** P<0.05.

For pairings with lemon beer, both studies highlight in some extent that an increase in aromatic similarity leads to a better liked and more harmonious match. There is no significant effect on match complexity and intensity balance. In the current study, aromatic similarity slightly increases familiarity. For pairings with smoked beer, the current study does not demonstrate any significant effect of aromatic similarity. Although a decrease in complexity is obtained, its amplitude is much smaller than in the previous study and fail to reach significance.

Overall, results of the present study seem consistent with the study of Eschevins et al. (2018) at least for the lemon beer pairings.

4.2. Modulation of aromatic similarity effect by product labels referring to the added aromas (within subject design)

Figure 2 shows the difference between mean scores of high aromatic similarity and low aromatic similarity pairings for liking, harmony, complexity, familiarity and intensity balance when pairings were tasted in blind or informed condition through a within subject design. Mean scores are presented Appendix 1.

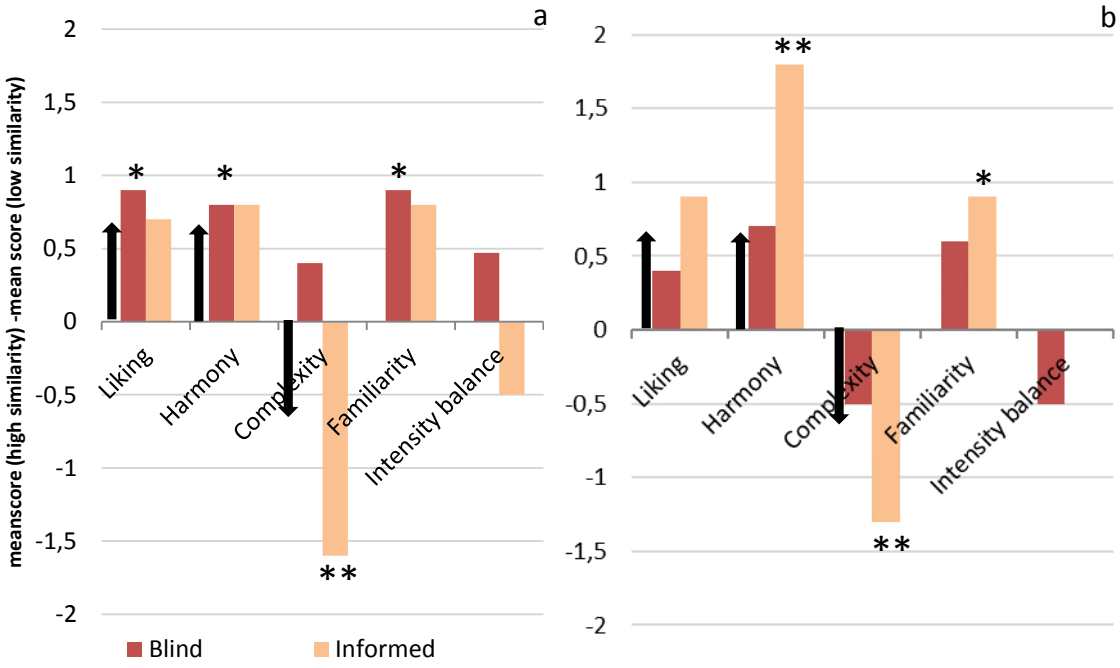

Figure 2: Effect of products' labels on the discrepancy of liking, harmony, complexity, familiarity and intensity balance between high and low aromatic similarity for pairings with lemon beer (a) (n=36) or smoked beer (b) (n=36). Within subject design. Black arrows show the theoretical effect of an increase of aromatic similarity on match perception. * P<0.1, ** P<0.05

For parings with lemon beer, labels significantly increase the discrepancy between high and low aromatic similarity in terms of complexity. The negative value means that the pair with high aromatic similarity was perceived as less complex than the pair with low aromatic similarity. This result is in line with our hypothesis. An increase in liking and harmony is induced by aromatic similarity in the blind condition. This effect is reproduced in a similar extend in the informed condition. For parings with smoked beer, labels increase the discrepancy of harmony and complexity between high and low aromatic similarity. In line

with our hypothesis, an increase in aromatic similarity increases harmony and decreases complexity. Although a slight increase in liking is also observed, it fails to reach significance.

4.3. Modulation of the effect of aromatic similarity in match perception by the provision of products' labels referring to the added aromas (In between subject design).

Figure 3 shows the difference between mean scores (see Appendix 1 for mean scores) of high aromatic similarity and low aromatic similarity for liking, harmony, complexity, familiarity and intensity balance when pairings with lemon beer were tasted in blind or informed condition through a in between subject design.

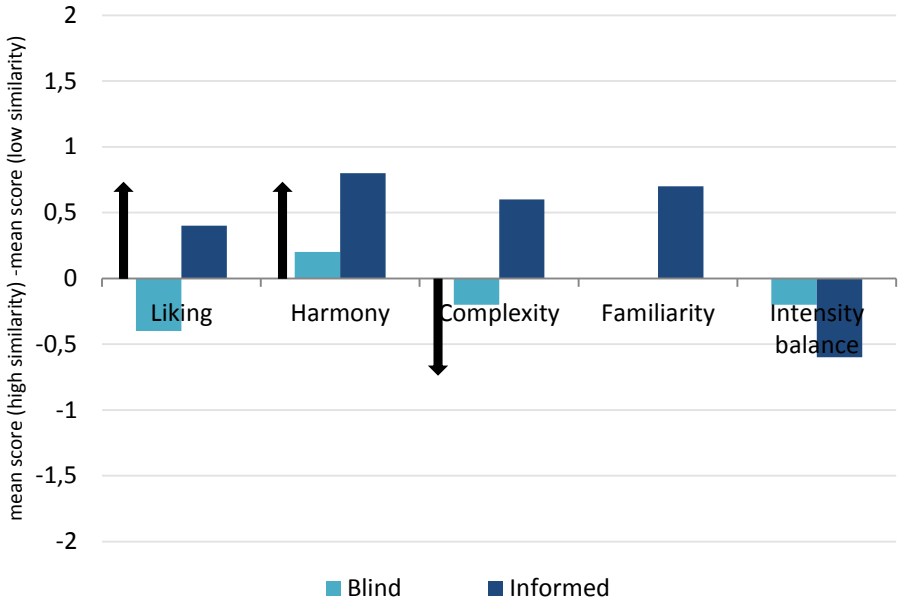

Figure 3: Effect of products' labels on the discrepancy of liking, harmony, complexity, familiarity and intensity balance between high and low aromatic similarity for pairings with lemon beer. In-between subject design study.

When pairings are tasted in an in-between subject design, similar and non similar pairs get roughly the same mean scores (blind condition) and labels showed no significant effect.

253 5. Discussion

254 5.1. Modulation of the effect of aromatic similarity in match perception by the
255 provision of products' labels referring to aromas controling aromatic similarity
256 between food and beverage

257 The main objective of the present work was to explore how labels referring to aromas
258 controling aromatic similarity between food and beverage, modulates the effect of aromatic
259 similarity on match perception and liking. We adressed this issue by comparing pairings with
260 contrasted levels of aromatic similarity, i.e. pairs of products sharing or not some aromatic
261 notes. The comparison was carried out in two experimental conditions: blind and informed
262 conditions. As the products used in the current work were the same that those tested in the
263 study of Eschevins et al. (2018), we first checked reproducibility of previous results. Overall,
264 results of the present study are in line with those of Eschevins et al. (2018).
265 Aromatic similarity tends, in some extent, to increase liking and harmony for pairings with
266 lemon beer and to decrease complexity for pairings with smoky beer.
267
268 As highlighted by Eschevins et al. (2018), a possible explanation for the non-systematic
269 influence of aromatic similarity on match perception, may be that consumers' attention is
270 not focused on aroma but on other sensory properties. This may decrease the perception of
271 aromatic similarity between food and beverage. Thus, we hypothesized that the effect of
272 aromatic similarity would be reinforced when labels explicitly mentioning the added aromas,
273 are provided to participants. Results support this hypothesis. In informed condition the
274 discrepancies between the two similarity levels increase compared to what is observed in
275 blind condition. This effect was observed for complexity for both lemon and smoked beers.
276 Such an effect is also observed for harmony but only for smoked beer. It is worth mentioning
277 that for lemon beer the effect of aromatic similarity on harmony was already significant in
278 blind condition and thus is equivalent in informed condition.
279
280 To explain these increases of discrepancy when labels are provided, we look after the effect
281 of these labels on each match perception. Labels decrease perceived complexity of the
282 lemon beer-lemon purée match (P=0.053) and increase the harmony of smoke beer and
283 smoke purée (P=0.02) compared to blind condition. Labels also increased the perceived
284 complexity of dissimilar pairs both for lemon beer-smoke purée pair (P=0.012) and smoke

beer-lemon purée (*P*=0.049). Such modulations could be explained by several processes. As hypothesized, labels mentioning aromas may lead participants to focus their attention on these aromas (Piqueras-Fiszman & Spence, 2015). This would modulate similarity perception and then reinforced aromatic similarity effects. But, information may also create expectations that in turn modulate match perception (Yeomans, Chambers, Blumenthal, & Blake, 2008). In this case, the effect is not directly due to perceived aromatic similarity of beer-purée pair. Further work would be needed to identify which mechanisms are at work.

For lemon beer, labels did not reinforce the perceived harmony of similar pair. This could be explained by the fact that lemon aroma is quite easy to identify in beer. By contrast smoky aroma may be more difficult to identify in beer and providing labels did help to spot the share aroma. This difference of aroma identification should be explained by the different levels of familiarity of these aromas in association with beer. Lemon and smoky aromas both suit potato purée and found in classical French dishes such as potato purée with fish and a lemon cream sauce or potato purée with smoked sausage. By contrast, lemon aroma is more familiar in beer (white beer and flavored commercial beers) than smoky aroma (smoked beers) and maybe less easy to identified. Thus, product labels could also help taster to identify the aromas leads to increase familiarity. This is supported by our results as labels indeed modulates familiarity assessments for pairs with smoke beer but not for pairs with lemon beer (Figure 2).

5.2. Is in-between subject design appropriated to assess the effect of products' label on match perception?

A secondary objective of this work was to verify if an in-between subject experimental design could be used to study effect of aromatic similarity in a more ecological setting.
Results show no effect of similarity on harmony, complexity and liking. Information on added aromas did not have any impact. One potential explanation is that participants have no comparison point to anchor their ratings. Indeed, collative adjective is related to the verb "to collate". According to the Larousse definition is means "To examine and compare carefully in order to note correspondences and divergence". Thus, collative properties such as harmony and complexity may be characteristics that need comparison between stimuli.

Moreover, mean scores for liking and harmony are higher in the in-between subject design compared to the within subject design. This could be due to a primacy effect often observed in consumer tests: liking of the first sample of the serie is overestimated.
Hence, the implementation of such study in a more ecological context of consumption seems to be more challenging that first expected.

Overall, this work highlights that aromatic similarity effect seems somehow context-dependant at least in the amplitude of the observed effects. This would explain why we did not observe the exact same results that those of Eschevins et al. (2018) in the present study. In both studies the pairs of interest are the same but the distractors pairs are different (cardamom purée and roasted chicken purée instead of cheese purée).

6. Conclusion

The present study demonstrated that labels explicitly mentioning the shared aroma, and indirectly informing about aromatic similarity between beer and purée reinforced the effect of aromatic similarity on match perception through top-down processes. However, results does not allow for determining the underlying process at work. The information could allow participants to focus attention on the shared aroma and thus increase the perceived similarity. Information could also create expectations well-known to modulate perception. Further studies are needed to identify the nature of these processes. This work also highlights that the amplitude of the effect seems context-dependent and that an in-between subject design is not suitable to bringing to light aromatic similarity effect on match perception. This means that strategies to study such effects in an ecological setting and more natural condition of consumption need to be carefully designed.

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388 **Appendix 1**: Mean scores for liking, harmony, complexity, familiarity and intensity balance.

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Study design	Experimental conditions	Liking	Harmony	Complexity	Familiarity	Intensity balance
Within subject design	High sim-blind-Lemon B	5.33	5.19	5.52	3.92	5.06
	High sim-informed-Lemon B	5.78	5.22	4.53	3.92	5.56
	Low sim-blind-lemon B	4.47	4.36	5.14	2.97	5.03
	Low sim-informed-Lemon B	5.11	4.44	6.14	3.14	6.06
	High sim-blind-Smoke B	5.06	5.53	4.33	3.81	5.28
	High sim-informed-Smoke B	5.78	6.47	4.08	4.97	5.92
	Low sim-blind-Smoke B	4.56	4.75	4.75	3.22	5.78
	Low sim-informed-Smoke B	4.86	4.67	5.43	4.03	5.92
In between subject design	High sim-blind-Lemon B	6.89	7.11	4.92	4.19	4.66
	High sim-informed-Lemon B	6.77	6.63	4.66	4.27	4.53
	Low sim-blind-lemon B	6.93	6.87	4.55	3.85	5.05
	Low sim-informed-Lemon B	6.38	5.83	4.06	3.59	5.10

390 **Mean scores of liking, harmony, complexity, familiarity and intensity balance for each pairings tasted in blind**
391 **or informed condition. The two study designs are presented.**

3. Conclusion

The study presented in chapter 6 mainly aimed at investigating how providing products' label referring to the aromas leading to the pair' aromatic similarity level would reinforce the effect of aromatic similarity on match liking and perception.

The results of this last chapter showed that **the provision of products' labels increases significantly the discrepancy of complexity between high and low aromatic similarity of matches with both lemon and smoke beer. Products' labels also significantly increase the discrepancy of harmony between high and low aromatic similarity matches with smoke beer. No effect was demonstrated on liking.** Several reasons may explain the observed differences between pairings with lemon of smoke beer.

First, the number of participants may be not high enough (N=36) to observe statistical significance for each parameters. The same study should be implemented with a higher number of participants to make the statistical test more powerful.

Secondly, the selected aromas were certainly not equally familiar in beer for the consumers. Lemon aroma is a characteristic commonly encountered in beer for consumers. Number of commercial beer promotes their lemon characteristic (white beers, flavored commercial beers). Even if smoke aroma may also be encountered in smoked beers, such products are less common for standard consumers. It should be interesting to select consumers according to their knowledge about beer to be sure they are also familiar with smoked beers. Another possibility should be to select another aroma often encountered in beer and with potatoes purée.

Nevertheless, the results of this chapter show that **products' labels referring to the aromas involved in the level of aromatic similarity between food and beverage reinforced the effect of aromatic similarity on match perception.**
Such modulations may be explained by several processes. Providing products' name explicitly mentioning the aromas of interest, may lead the participants to focus their

attention on these aromas (Piqueras-Fiszman & Spence, 2015) and thus increase (when the same aromas are mentioned in beer and purée) or decrease (when two different aromas are mentioned in purée and beer) perceived aromatic similarity level. Information may also create expectations that may influence the match perception independently of the perceived aromatic similarity of beer-purée pair (Yeomans, Chambers, Blumenthal, & Blake, 2008).

This chapter also highlights that the implementation of in-between subject design, more appropriate to ecological context of consumption, not allow highlighting the effect of aromatic similarity on match perception. Special care need to be considered about the experimental design to implement in such ecological contexts of consumption.

Chapter 7: General discussion

Over the past years, research in food and beverage pairing intended to identify determinants of a good match, especially in the sensory evaluation domain. They highlighted that food and beverage pairing, whatever the beverage, is under the influence of product sensory properties, as well as individual preferences. Few works aimed at understanding the underlying perceptual mechanisms, although this is key to understand what leads to a good match. Within this context, the main objective of this work was to contribute to the understanding of what makes beer and food pairing in identifying pairing principles and their underlying mechanisms.

The discussion part first presents how this work contributes to the understanding of pairing principles for beer. The second part focused on how this work contributes to the identification of mechanisms that underlie the principle of aromatic similarity.

1. Contribution to the understanding of pairing principles for beer.

This work allows identifying several pairing principles that may govern a match between food and beverage. Differences and commonalities between pairing with beer or wine were highlighted. Beyond the identification of pairing principles, this work also highlight that a match may reach different goals that influence the pairing principles to use. All these points are discussed in this section.

1.1. Determinants of food and beverage pairing

The first experiment (chapter 4) studied pairing principles used by experts from self-confrontation interviews based on case tests with sommeliers and beer experts. A discourse analysis leads to identify e**ighteen pairing principles. These pairing principles are related to three categories:**

(1) A perceptual category related to sensory characteristics such as aroma, taste, texture. Perceptual principles aim at modulating sensory properties of each product by the presence of the other one. Identified principles are: "balance of intensity"; "balance of quality", "harmony", "similarity", "culinary practices", "creation of off-flavor", "rinsing effect", "decrease of sensory property", “enhancement of sensory property";

(2) A conceptual category related to extrinsic properties ("geographical identity", "quality level")**, context of consumption** (“moment of the meal”, “specific situation”, “season"), and **norms** ("norms").

(3) An affective category related to consumers’ preferences ("individual preferences") **and emotions** ("surprise").

The perceptual dimension of a match is already widely emphasized in the culinary literature (Harrington, 2008; Pierre, 2014), and appears to be the major determinant of match liking together with individual product preferences (Bastian et al., 2010; Donadini et al., 2012, 2013; Harrington et al., 2008; Harrington & Seo, 2015; Tuorila, HyvÖNen, et al., 1994) (see Chapter 2).

We confirmed some pairing principles. For examples, the principle of **"balance in intensity"** was identified as pairing principle in both expert literature (as reported by Harrington (2008) and Paulsen et al. (2015)) as well as scientific literature (Bastian et al., 2009; Donadini & Fumi, 2014; Donadini et al., 2012, 2013; Donadini et al., 2008; King & Cliff, 2005; Paulsen et al., 2015). The same observation holds for **"rinsing"** principle. Harrington (2008) reported that *"fatty food requires a wine that cuts through the fat (acidic, fruity or tannic)".* This principle was also investigated in the scientific literature (Peyrot des Gachons et al., 2012). Modulation of product sensory properties was identified as determinant of match liking. This was widely demonstrated in the scientific literature (Donadini & Fumi, 2014; Donadini et al., 2013; Donadini et al., 2015; Galmarini et al., 2016; Harrington & Hammond, 2009; Madrigal-Galan & Heymann, 2006; Nygren et al., 2001; Nygren et al., 2003a, 2003b; Peyrot des Gachons et al., 2012). This may be related to the notions of **"enhancement and decrease of sensory property"** identified in this work. Finally, Harrington (2008) and Paulsen et al. (2015)

reported from expert literature that *"Food and wine flavor types can be matched using similarity or contrast".* We also identified this principle in this study. Furthermore, we found that it is one of the widely used one by experts.
In culinary literature, some specific recommendations are provided such as *"Food sweetness level should be less than or equal to wine sweetness level" or "Spicy food should be paired with off-dry, acidic white wines".* Principles we identified from experts' discourse analysis, are more generic and do not refer to specific sensory quality. For instance, the second statements may relate to what we called "balance of quality" or "rinsing effect" according to what experts reported when explaining why such association would work.

Although number of the perceptual pairing principles we identified were already known, our work also brings out new piece of information. This is the case for the **"culinary practice"** principle. It refines the notion of contrast largely mentioned in the literature. The principle of contrast consists in matching products with different sensory properties that "go well together". But, why do they go well together? Our work provides some cues such as associating properties in a way that **mimics culinary practices**. Associations that are often encountered in gastronomic practices (such as fish and lemon juice) become familiar through associative learning and thus are liked and perceived as harmonious. Thus, such aromatic associations can be use in the context of beer-food pairing.
Another contribution of our work streams from experts' answers to the question: "What would be a bad match and why? Having asked experts to explain why an association does not work highlights new principles such as **"creation of off-flavor".** This issue orientates the final choice at an early stage by dismissing some products or some category of product. This is helpful guidelines usually not mentioned in the culinary literature.

Contrary to the perceptual dimension of the match, widely mentioned in the literature, the contribution of conceptual and affective dimensions to the match are not so often highlighted or even more discussed. To the best of our knowledge, only the notion of "geographical identity" consisting in matching two products related to the same area is suggested as conceptual pairing principle (Pierre, 2014). In that sense, this work offers a larger view of what makes a good match. **It largely expends information available in**

culinary and scientific literature, especially in highlighting strategy to match products related to contextual, traditional, symbolic and emotional aspects. All of them have to be taken into account for a global understanding of food and beverage pairing.

As previously discussed, social aspects emphasized by Pettigrew and Charters (2006) as a match objective for consumers was not highlighted in our study. Our methodological approach may not allow highlighting this social aspect of the match. A perspective to refine the present study would be to investigate how social surrounding may affect food and beverage pairing principles. Scenario depicting situations with family members, friends, colleagues or even unknown people may elicit different strategies to match food and beverage. As reported by Pettigrew and Charters (2006), "*the social dimension of food and alcoholic beverage pairing has both an experiential element, in the stimulation of conviviality and friendship, and a symbolic dimension, in the messages drinkers convey to others and themselves*." Thus, depending on the social surrounding, the intended message could be different and thus orients toward different pairing strategies in terms of products but also in terms of principles.

When experts explained why a given association would match, they often mentioned more than one principle. Thus, it seems that pairing principles are used in combination. For example, one expert suggested matching Hoegaarden beer with a dish made of veal meat, mushrooms, cream and Plantin banana purée. The association would match because of both "decrease of sensory property" and "increase of sensory property". Both modulations may be encountered in the same match. Such combined effects were already mentioned by Madrigal-Galan and Heymann (2006), Donadini and Fumi (2014) and Nygren et al. (2001). However, as both principles refer to some carry-over effects, it seems quite natural they may occur concomitantly. But other principle associations are more complex such as Hoegaarden beer with fruit pie for which the principles of similarity, culinary practice and balance in intensity were mentioned all together. A last example is a match between Hoegaarden beer and smoked salmon. The expert mentioned the principle of culinary practice (associating lemon note and fish) and the moment of consumption (both products suit the idea of

aperitif at social event). Thus the idea is that perceptual principle can be combined together as well with other conceptual and/or affective principles.

Potentially, all combinations of pairing principles are possible. To our thinking, perceptual and conceptual pairing principles may be easily combined because they considered different dimensions of the match. However, among conceptual and affective principles our thinking is that "norms" and "surprise" principle may not be encountered in the same match because they seemed to be opposed. The notion of norms is related to a match that is widely known whereas the notion of surprise is related to an association that is not often encountered. Among perceptual principles, the principle of rinsing could leave little room for other principles. Although underlying mechanisms are diverse according to the specific nature of food and/or beverage, the objective is to preserve sensory characteristic of products over time.

Further work would be needed to understand how pairing principles combined and determine whether some principles associations are more desirable than others. Moreover, our work may be used as basis to create new tool to describe food and beverage pairings. This tool could be provided to consumers to help them to select proper pairings according to what they want to reach with the match.

1.2. Pairing with beer or wine: Differences and commonalities

Pairing principles elicited with wine and beers were compared. The results highlights that **matching food with either wine or beer seems to follow the same rules.** All the identified perceptual, conceptual and affective pairing principles were mentioned for both products.

However, some differences in the occurrence of pairing principles usage were brought out. **“Norms” and “geographical identity” were more often mentioned with wine than with beer. By contrast, the notion of “surprise” was mentioned more often with beer than wine.** As discussed in the paper presented in chapter 4, possible explanations for such difference may be that whereas wine is part of the French culture and history, pairing food

with beer is a relatively new trend in France. Offering beer as a companion to food may be a first source of surprise for French consumers. Moreover, the region of production of wine is an important characteristic of the beverage but it is currently less advertised for beer.

The selected products may also provide possible explanation. Beers were industrial Belgian beers certainly not considered as being linked to a specific production area for French experts. By contrast, wines were AOC (Appellation d'Origine Controlée) wines with a strong regional identity. One possible experimental perspective could be to conduct a similar experiment with craft beers to see whether this "geographical identity" principle is really product-dependant.

The principle of "norms" better fit for wine and food pairing than for beer and food pairing because considering beer as companion to food is a relatively new trend for French consumers. The only normative pairings with beer were pairings with sauerkraut or Belgian food specialty. These food specialty are both related to country were beer is more anchored in meal culture.

To complete this comparison**,** pairing principles used to create a match between wine and food may also be applied to create a match between beer and food. Perceptual pairing principles appear as being easily transferable from wine to beer. As alcoholic fermented drinks, wine and beer sensory properties are rather comparable. Then the same perceptual principles may be followed to create a match. Conceptual pairing principles may also be used for pairing with beer but may depend on the considered beer type (industrial or craft beer). Craft beer in France tends to be related to its specific region of production whereas industrial beers are more related to a specific country. However, offering beer as a companion to food appears as being an interesting novelty for consumers to be positively surprised.

1.3. Food and beverage pairing: not only one goal

As highlighted in the previous sections, food and beverage pairing may be created through a number of pairing principles. The culinary and scientific literatures provide diverse recommendations to choose products that would match. The present work listed pairing principles some already well-known and others not so often mentioned in the literature. Another aspect highlighted by the present work is that associating food and beverage may address different goals. From experts' discourse, we identified three main goals for a match: **(1) To create a unified experience of the two products, (2) to highlight one of the two products or (3) to preserve characteristics of each product over repeated time. A few works also mentioned some diversity in match objectives**. Harrington (2008), Nusswitz (1991) and Herz and Conley (2015) reported that the main goal to reach in associating food and beverage is to make two things greater than the sum of their parts. The idea is to create a new experience of the two products that can only be reached with their association. However, associating two products not always aims at creating a "perfect" match. Harrington (2008) also reported that food and beverage may be associated to "refresh" the palate from the food. In the same line, Maresca (1994) stated that the match may aim at *"giving the food and [beverage] equal importance",* (2) *"highlighting the food", or "highlighting the [beverage]".*

In the scientific literature, authors usually do not explicitly state what kind of pairing they are exploring; what is the objective tested pairings should reach. However, the experimental design implemented in some study suggests that one match objective is favor. For examples, Paulsen et al. (2015) who studied beer and soup pairings, asked participants to rate each pair on dimensions such as complexity, harmony, intensity balance. These assessments, therefore, are rather in line with the idea of considering pairing as a whole where the two products have to be considered simultaneously. On the contrary, Galmarini et al. (2016) investigated how eating cheese modulated the description and liking of wine. Participants were instructed to assess one product whereas another product was presented before (or not). In this case, the objective of the match is either to lubricate the mouth to enjoy wine over repeated sipping or even to enhance the wine experience, but clearly not to create a unique percept.

In other words, matching food and beverage may aim at (1) enjoying the association of the two products in a way that goes well beyond what could be achieved by tasting only one or the other, (2) highlighting one of the two products and enhance its features, or (3) refreshing the mouth allowing for an optimal experience of each product over repeated and alternated tasting.

The key idea streaming from this differentiation of pairing goals is that some pairing principles may be more or less relevant according to the targeted objective. Another consequence is that there are methodological issues for food – beverage paring studies. Both the way products are tasted and the nature of the dimensions assessed by participants (beyond liking) have to be in agreement with the targeted objective.

1.4. Match goals orientate the use of pairing principles

As associating food and beverage may target different goals, the main idea is to know which principles need to be applied to reach the desired objective.

If the aim of the match is to enjoy the association of the two products as a whole, all dimensions of the match should be considered. On a perceptual point of view, to create a unified experience, pairing principles such as "similarity", "culinary practice", or "quality balance" may be of most relevance. However, as demonstrated in chapter 4, a match also involved characteristics related to the context of consumption. The interactions between a product, an individual and an environment defined a “product experience in context” (Sester, 2013). According to Hekkert (2006) this includes “*the degree to which all our senses are gratified (aesthetic experience), the meaning we attach to the product (experience of meaning), and the feelings and emotions that are elicited*”. Pettigrew and Charters (2006) are in line with this view when reporting that consumers' expectations on food and beverage pairing could be (1) flavors synergy, meaning the association leads to a pleasant sensory experience; (2) psychological state facilitator (positive emotions) and (3) a social and symbolic role as the match convey messages about social sophistication. Thus, it seems that

beyond the goal intended for the match, the meaning assigned by consumer matter. When the aim is to create a unique percept, the emphasis could be put on the sensory, affective, or social dimensions of this experience by favoring one kind of principles. For instance, when the emphasis is on the social dimension of the experience, conceptual principles such as contextual aspects ("season", "specific situation", "moment of meal") and appropriateness in its symbolic dimension ("geographical identity", "quality level") could be even more important that perceptual principal. This should be moderated because some basic perceptual principles such "intensity balance" or avoiding " Off-flavor" could be prerequisite ones.

According to the aim of the match, the relative importance of principles may variate. For instance "balance in intensity" that could be a prerequisite for the match as a whole could be not that important whenever the objective is to highlight one products. In this case, the highlighted product should slightly dominate the intensity of the other product. To highlight one product, is seems important to enhance its sensory quality either increasing the intensity of some positive properties or reduce some negative ones. However, some symbolic or conceptual aspects could also have an effect. For instance, playing with the "quality level" principle could enhance the product of interest. It could be associated with another less qualitative product to create a contrast effect (leading to increase the perceived level of quality) or associated to a slightly more qualitative product to create an assimilation effect (also leading to increase the perceived level of quality).

Finally if the aim of the association is to refresh the mouth allowing for an optimal experience of each product over repeated an alternated tasting, the principles of "rinsing" is clearly the one. This was well demonstrated by Peyrot des Gachons et al. (2012) who investigated the effect of two rinsing solutions (water and tea) on the perception of the fattiness of dried meat in a multiple sips experimental design. They demonstrated that rinsing solution may avoid the increase of food fattiness perception after multiple sip. This consideration was also mentioned by the consumers as one of the possible objective of a match (Pettigrew & Charters, 2006). Galmarini et al. (2016) also demonstrated this type of effect with wine and cheese pairing, the cheese allowing for preventing an increase in wine astringency after multiple sips.

To sum up, this work identified pairing principles for wine or beer and food pairing that can lead to different pairing goals. However, further research are needed to better identify pairing principles that lead to one or the other of these goals and how to use them accordingly. A first approach to answer such question is to investigate mechanisms that underlie the pairing principles. In line with this statement our research on underlying mechanisms focused on aromatic similarity.

2. Mechanisms underlying aromatic similarity

2.1. Aromatic similarity and liking

Chapters 4, 5, and 6 have **shown that aromatic similarity generally leads to a good match**. Chapter 4 highlighted that, according to experts (sommeliers and beer experts), associating two products that share one or several aromas is an easy way to create a match. This pairing principle also works for other properties such as taste or texture but aroma was the most often mentioned sensory property to match products. This pairing principle was one of the most often mentioned by experts. Results of chapters 5 and 6 experimentally confirm this principle. However, chapter 5 also highlighted that aromatic similarity between food and beverage is not the main characteristics predicting match liking. As the different variants of the tasted match were not equally liked when tasted alone, the hedonic valence of the match was largely dependent of products' liking.

2.2. Aromatic similarity leads to a good match through the modulation of perceived harmony and complexity.

Chapters 5 and 6 showed that the role of aromatic similarity on match liking is due to the modulation of collative properties such as harmony and complexity. More precisely, **a higher level of aromatic similarity between food and beverage creates a more homogeneous**

percept, perceived as more harmonious and less complex than a pair of products having a lower level of aromatic similarity.

The effects of harmony and complexity on liking are generally considered separately in the literature (Choi et al., 2015; Giacalone et al., 2014). However, chapter 5 highlights that both harmony and complexity need to be considered together to explain modulation of liking by similarity. Even if this work failed to demonstrate how these two variables are combined, the second part of chapter 5 provides evidences of a combined effect of harmony and complexity. On an experimental point of view, their joint effect is difficult to study because harmony and complexity levels cannot be set directly. We only manipulated stimuli that in turn changed the harmony / complexity perception. Moreover these two properties may covariate in some extent as we did not succeed to create stimuli with both low harmony and low complexity. Another aspect is that we measured harmony / complexity at group level (computing mean values) but inter-individual differences could account for some results. Changes in the stimuli may not have the same effect on perceived harmony / complexity for everybody. Furthermore, the same perceived level of complexity may not modulate liking in the same way for everybody as is depend on the optimal complexity level which also variate from one individual to another.

Other properties such as familiarity or novelty, for instance, are known to modulate liking (Giacalone et al., 2014). Even though we try to keep the familiarity level constant across pairings at the group level, some slight variations were still observed. The effect of these variables would need to be considered all together to explain liking. Modelling approaches are promising to investigate the relationship between several variables and liking by identifying their relative contribution to liking and taking into account some links among them.

2.3. Dimensions of aromatic similarity

In chapter 5 and 6, aromatic similarity was considered as the perceived sensory similarity between the aromatic profiles of the two products. In chapter 6, we showed that labels referring to product aroma reinforced the effect of aromatic similarity on match perception. Several processes may explain such modulations. Providing labels mentioning the aroma of interest, may lead the participants to focus their attention on these aromas (Piqueras-Fiszman & Spence, 2015) and thus, increases (when the same aroma is mentioned in beer and purée) or decrease (when two different aromas are mentioned in beer and purée) the level of similarity. Information on aroma may also create some expectations that in turn influence the match perception (Yeomans et al., 2008). To identify which process is at play, it would be interesting to measure expectations on match perception induced by labels and compared with labels effects when tasting pairings. Another way could be to provide labels either referring to the same aroma or to two different aromas in association to the same pair of products, for instance beers and potato purées that were not flavoured. The disjunction of similarity at the semantic level (labels) and at the sensory level (aromatic compounds) may help to see how they influence match perception.

This raises the issue of similarity in food and beverage pairing. This perceived similarity may results from a sensory similarity (e.i. two products sharing an aroma or an aromatic note) but also from a semantic or conceptual similarity (e.i. product labels). To go further it would be interesting to investigate how the conceptual similarity between two products may reinforce the perceived aromatic similarity of the match. To this end, two products chosen for their level of aromatic similarity would be presented as coming from the same region or from two different areas. Assessing the impact of such information on overall similarity, match liking and other collative properties of interest (harmony, complexity, and familiarity) may help to tackle this issue. This type of study design may allow understand how semantic, conceptual and perceived similarity are organised in pairing.

Chapter 8: General Conclusion

Enthusiasm for beer has reached a level that pushes the beer producers and gastronomy professionals to offer new alternatives for beer consumption. Even though only 11% of French people consume beer at meal, pairing beer and dishes emerges as a new trend in France (Pierre, 2014) and beer is more and more suggested as companion to food. Within this context, beer promoters or gastronomy professionals need to follow this raising trend in offering to customers, high-quality advices in terms of beer and food pairing. The first information resource is the culinary literature such as books or websites that provides number of recommendations. However, usually, no explanation is given about why the association creates a good match. Somme experts try to go further in offering guidelines to create a match. However, it is sometimes difficult to distinguish shared knowledge from personal opinions.

Within this context, the main objective of this PhD work was to contribute to the identification of what makes a beer-food match and to contribute to the understanding of mechanisms that underlie pairing perception.

This work first highlighted that there are several ways to match beer and food and the pairing may target different objectives:

(1) **Enjoying the association of the two products in a way that goes well beyond what could be achieved by tasting only one or the other;**
(2) **Highlighting one of the two products by enhancing its features;**
(3) **Refreshing the mouth allowing for an optimal experience of each product over repeated and alternated tasting.**

Depending on the objective, different strategies may be implemented. This work highlighted that beer and food pairing may be governed by several principles related to **perceptual** (modulation of product sensory properties), **conceptual** (extrinsic product characteristics, context of consumption, and norms) and **affective** (individual preferences and emotions) categories. Some of these pairing principles may be more or less relevant according to the targeted objective. The principle of **aromatic similarity** induces a blending effect of the flavor of the two products. It orientates the pairing toward create an association where the two products are enjoyed as a whole. Indeed, aromatic similarity, in creating a

homogeneous, harmonious and moderately complex multidimensional percept contributes to the building of a good match.

As pairing principles were identified through the discourses of French experts, one of the main questions stemming from this work is to wonder whether they are generalizable to other cultures than the French one. **Do other pairing principles exist in other gastronomic cultures? Do the identified principles apply in the same way from one culture to another?**
As already highlighted in the paper presented in chapter 4, culture may affect the content of the principles. For instance, when considering the principle of "Culinary practices", two flavors that would work in one culture may not be relevant in another. So experts of different cultures, calling upon this same principle, would end up with different pairings according to classical accords in their own culinary culture. Culture may also affect the relative weight of principles used in combination. The principle of "geographical identity" is likely to be more important in a country such as France where products of origin (PDO) are numerous and well established, compared to other countries where the notion of "terroir" is less developed. Ultimately, experts from different cultures may consider principles other than those considered by French experts. Thus, it would be interesting to investigate how experts from other countries justify a match to see whether they mentioned similar or different pairing principles. Then, concerning shared pairing principles, it would be interesting to investigate whether experts from different cultures used the same strategies to match food and beverage.

From an applied point of view, this work suggests that gastronomy professional need to identify their customers' desire in terms of beer and food pairing, to identify which is the objective of the pairing. Alternatively, they may suggest them these different objectives and let them choose which one they want to experiment. The objective orientates the selection of relevant pairing principles.
From a methodological point of view, this PhD work underlines that for studies on pairing, both the way products are tasted by participants and the sensory dimensions assessed by participants (beyond liking), have to be in agreement with the targeted objective. Therefore,

the objective of the match need to be clearly stated in future studies on food and beverage pairing.

From a theoretical point of view, the present work evidences that collative properties such as harmony and complexity mediates the effect of aromatic similarity on pairing. It also highlights that these properties need to be considered in combination to understand their relationships with liking. This work focused on the mechanisms that underlie aromatic similarity but many other pairing principles were identified and need to be investigated to be able to understand food and beverage pairing in its whole. This work suggests that other pairing principles than aromatic similarity may modulate perceived similarity between food and drink, including conceptual principles, and that the same underlying mechanisms could be at play.

To conclude this PhD work testified that there is still long way to achieve the understanding of food and beer pairing. It opens a door to a host of new possibilities of researches.

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ÉCOLE DOCTORALE
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Title : Associer la bière avec un mets : principes d'association, mécanismes sous-jacent et focus sur la similarité aromatique.

Keywords : association bière et mets, principes d'association, similarité aromatique, harmonie, complexité, appréciation.

Abstract : L'association de la bière avec les mets apparait comme une nouvelle tendance en France. Il est donc nécessaire pour les promoteurs de bière et les professionnels de la gastronomie de fournir à leurs clients des conseils de qualité en terme d'accord bière et mets. Au vu de ce contexte, l'objectif de la thèse était d'identifier les principes d'association et de mieux comprendre les mécanismes perceptuels qui les sous-tendent. Les déterminants des accords mets et boissons ont, dans un premier temps, été identifiés à partir du discours d'experts. Les résultats ont montrés que les associations mets et boissons sont régies par des caractéristiques perceptuelles, conceptuelles et affectives, liées à des mécanismes physico-chimiques, perceptuels et cognitifs. Les experts ont souvent mentionné la «similarité aromatique» comme l'un des principaux principes d'association. Ce principe consiste à associer deux produits partageant des arômes similaires. Les mécanismes perceptuels sous-jacents à ce principe ont été investigués. Les résultats ont montrés qu'une similarité aromatique entre un mets et une boisson augmente le niveau d'harmonie et d'homogénéité de leur association et diminue sa complexité. Ces effets peuvent être renforcés en orientant l'attention du dégustateur sur l'arôme partagé. D'un point de vue théorique, cette thèse conclut que l'association bières et mets inclut des dimensions sensorielles avec une recherche d'harmonie, mais aussi des dimensions symboliques et contextuelles. D'un point de vue plus appliqué, cette thèse fournit aux professionnels de la gastronomie, de nouvelles informations concernant les mécanismes perceptifs sous-tendant les principes d'associations.

Title : Matching beer with food: pairing principles, underlying mechanisms and a focus on aromatic similarity.

Keywords : beer and food pairing, pairing principles, aromatic similarity, harmony, sensory complexity, liking.

Abstract : Pairing between beer and dishes emerges as a new trend in France. Beer promoters or gastronomy professionals need to offer high-quality advices in terms of beer and food pairing to their customers. Within this context, the objective of the research was to identify pairing principles and to better understand the underlying perceptual mechanisms. Determinants of food and beverage pairing were first analysed from experts' discourses. Results showed that food and beverage pairings are governed by perceptual, conceptual and affective features, related to physicochemical, perceptual and cognitive processes. Experts often mentioned "Aromatic Similarity" as one of the main pairing principles. This "Aromatic similarity" principle consists in matching two products sharing similar aromas. Underlying perceptual mechanisms were then investigated. Results showed that aromatic similarity in food and beverage generally increases harmony and homogeneity and decreases complexity of the match. These effects can be reinforced by orientating the attentional focus on the shared aroma. From a theoretical point of view, this work concludes that beer and food pairing includes sensory dimensions with the search for harmony, as well as symbolic and contextual dimensions. From an applied point of view, this work provides useful information to gastronomy professionals with recent knowledge on perceptual mechanisms underlying food and beverage pairing principles.

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