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Cross-modal taste and aroma interactions: Cheese flavour perception and changes in flavour character in multicomponent mixtures

Jun Niimi [a,*], Amy R. Overington [b], Patrick Silcock [a], Phil J. Bremer [a], Conor M. Delahunty [c,1]

[a] Sensory Science Research Centre, Department of Food Science, University of Otago, Dunedin, New Zealand
[b] Fonterra Research and Development Centre, Palmerston North, New Zealand
[c] CSIRO Preventative Health Flagship, Adelaide, SA, Australia

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ABSTRACT

The effect of cross-modal sensory interactions between cheese aroma and cheese taste on both cheese flavour intensity and cheese flavour character were investigated. Cheese aroma consisted of a mixture of ten aroma compounds, whilst cheese taste was constructed with the five basic tastes in water solution. Interactions were investigated using a combination of a high resolution design (HRD) and central composite design (CCD). The HRD was 2 aroma $\times$ 5 NaCl $\times$ 5 lactic acid levels. The CCD was constructed based on a 2^3 factorial design that covered the HRD space. Both HRD and CCD gave a total of 57 samples. A panel of experienced assessors ($n = 8–10$) evaluated cheese flavour intensity relative to reference. In addition, samples were sorted based on similarity of flavour character. Fourteen samples were selected for free choice profiling and analysed using generalised procrustes analysis (GPA). Cheese flavour intensity was non-linear and dependent on both taste level and aroma level. The status of flavour character being cheese-like was dependent on taste levels, where either NaCl or lactic acid at a high or low level altered the flavour character to being atypical of cheese. A cheese-like flavour character was maintained across a wide range of NaCl concentrations, but only across a narrow range of lactic acid concentrations. Aroma level changed the character of cheese flavour. Overall, the balance in concentration of both tastes and aroma levels was important in maintaining cheese flavour character as cheese flavour intensity was modified.

1. Introduction

The perception of cheese flavour during consumption results from the stimulation of multiple chemosensory modalities including taste and aroma. For a flavour to be perceived as cheese, all contributing flavour components should be present in appropriate proportions to each other, as postulated in the component balance theory (Mulder, 1952). The theory also applies to perception within modalities of aroma and tastes. A balanced mixture of volatile compounds will give a cheese aroma (Delahunty, Crowe, & Morrissey, 1996; Zehentbauer & Reineccius, 2002) with non-volatile compounds providing cheese taste (Andersen, Ardö, & Bredie, 2010; Engel, Nicklaus, Salles, & Le Quéré, 2002; Niimi et al., 2014b; Salles et al., 2000; Toelstede & Hofmann, 2008). Change in the levels of volatile or non-volatile constituents can shift the balance of components and alter the perceived flavour.

Flavour perception is complex and occurs during the simultaneous stimulation of a number of the senses. When different senses are stimulated concurrently and perceptually interact with each other, the perceived flavour that results can be regarded as cross-modal sensory interaction (Delahunty & Drake, 2004). Interactions between a single taste and aroma have been intensively researched. Aroma was shown to influence the basic tastes of sweetness, saltiness, umami, sourness, and bitterness, and also vice versa (Forde & Delahunty, 2004; Fujimaru & Lim, 2013; Green, Nachtigal, Hammond, & Lim, 2012; Kuo, Pangborn, & Noble, 1993; Lim, Fujimaru, & Linscott, 2014; Niimi et al., 2014a). Cross-modal sensory interactions also occur between complex mixtures of tastes and aroma and can result in larger interaction effects than occur for mixtures of single tastes and aroma, as reported for enhancements in saltiness in cheese (Nasri, Septier, Beno, Salles, & Thomas-Danguin, 2013), strawberry flavour (Pfeiffer, Hort, Hollowood, & Taylor, 2006), citrus flavour (Hewson, Hollowood, Chandra, & Hort, 2008), and cheese flavour (Niimi et al., 2014a).

* Corresponding author at: Wine Science, School of Agriculture, Food, and Wine, University of Adelaide, Urrbrae, SA, Australia.
E-mail address: jun.niimi@adelaide.edu.au (J. Niimi).
[1] Current address: Symrise Flavour & Nutrition, 226 Pandan Loop, Singapore.

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Further, NaCl, lactic acid, and aroma were among the important contributors to cheese flavour intensity in a mixture of cheese taste and cheese aroma (Niimi et al., 2014c). Large interaction effects with mixed tastes in model systems as seen across a range of food categories and beverages, suggests that these effects are universal. Using mixed tastes may provide a better understanding of the cross-modal sensory interactions taking place during the consumption of food and beverages.

Cross-modal interactions between taste and aroma have been studied based on the presence/absence of stimuli, but reports on interactions based on a range of stimulus levels are comparatively sparse. Where variations in stimulus levels have been tested, changes in magnitude of enhancement of flavour intensity were observed across levels and there was evidence that the effects are non-linear. In particular, tastant concentrations above a certain level result in small magnitudes of flavour enhancement, as reported for strawberry and citrus flavour intensities (Hewson, Hollowood, Chandra, & Hort, 2009; Hewson et al., 2008; Pfeiffer et al., 2006). These authors have shown that the perception of flavour was non-linear and was characterised by having maximum enhancements at optimum concentrations of taste. A similar optimum interaction effect was seen with a mixture of tastes with aroma for the enhancement of cheese flavour intensity (Niimi et al., 2014a). The cross-modal sensory interaction effects between cheese taste and cheese aroma towards flavour perception in a complex mixture of five basic tastes and cheese aroma is poorly understood, despite having important implications to industries who seek to utilise cross-modal sensory interactions as a means to accentuate flavour intensity or manipulate ingredient concentrations while maintaining constant flavour intensity.

The reason why potential changes in flavour character due to cross-modal interactions are poorly understood is in part due to the challenge of measuring changes in flavour character without interfering with cross-modal sensory interactions, as both synthetic and analytic cognitive processes are required. A synthetic cognitive process enables cross-modal sensory interactions to be measured because of its holistic nature (Prescott, 1999); however, this comes at the cost of detailed flavour profiles. Conversely, an analytic cognitive process enables a series of samples to be profiled, but at the cost of a reduced likelihood of cross-modal interaction effects emerging due to possible over-partitioning of flavour attributes (Batenburg & van der Velden, 2011; Prescott, 2012). An ideal method would enable the flavour character of a product to be determined while maintaining the synthetic process to minimise the interference with cross-modal sensory interactions.

The objective of the study was to determine and model cross-modal interactions between NaCl and lactic acid in a model cheese flavour, when NaCl, lactic acid, and aroma levels were varied. Effects were determined for both cheese flavour intensity and cheese flavour character. In the current study, a stepwise approach was used that first determined cheese flavour intensity, followed by sorting of samples by flavour character, and finally evaluation of selected samples by free choice profiling (FCP) to determine interaction effects and flavour character.

2. Materials and methods

2.1. Materials

The taste types used to represent pure taste characters of sweetness, saltiness, umami, sourness, and bitterness were sucrose (Chelsea Sugar, Auckland, New Zealand), sodium chloride (NaCl, >99.8%), monosodium glutamate [MSG; produced with sodium hydroxide (98%) and l-glutamic acid (98.5%)], DL-lactic acid (85%), and caffeine (the last four compounds sourced from Sigma Aldrich, Sydney, NSW, Australia), respectively. Aroma compounds were 2-butanone, 2-heptanone, 2-nonanone, diacetyl, ethyl butanoate, butanoic acid, methional, 3-methylbutanal (Givaudan Australia Pty Ltd., Sydney, NSW, Australia), ethyl hexanoate, and 3-methylbutanoic acid (Sigma Aldrich). All samples were prepared using filtered water.

2.2. Experimental design

To determine the cross-modal interactions between tastes and aroma, two experimental designs were merged. The first was a high resolution design (HRD) consisting of $5 \times 5 \times 2$ levels of NaCl, lactic acid, and aroma, respectively. Taste concentrations used in the design were obtained by adjusting the base cheese taste (Niimi et al., 2014b). Five levels of NaCl and lactic acid were obtained varying in concentration increments of ±0.125 log and ±0.2 log, respectively from the centre concentrations. This gave a full concentration range of 0.5 log and 0.8 log differences for NaCl and lactic acid, respectively (Table 1). The stimulus ranges were chosen as previous in house trials within our laboratory showed noticeable differences in flavour intensity. The increments in taste were chosen to obtain a detailed "map" of changes in flavour intensity by cross-modal interactions. Ten aroma compounds typically found in cheese were used, which in combination gave a cheese aroma (Niimi et al., 2014a). The two levels of aroma used for this design were obtained by adjusting the entire aroma mixture by ±0.5 log from the centre concentration (Table 2). Two aroma levels were chosen to give a wide variation in flavour intensity while limiting the samples to a manageable number for evaluation. The HRD gave a total of 50 samples.

The second design was a central composite design (CCD) based on a 2^3 factorial design varying in NaCl, lactic acid, and aroma, where the factorial ranges from the centre concentration were ±0.25 log, ±0.4 log, and ±0.5 log, respectively. The CCD covered the entire range of the HRD space, with additional samples that were axial levels of each variable from the centre of the design. The axial levels extended each variable concentration by $1.68\times$ of the factorial range from the centre, thus levels of NaCl, lactic acid, and aroma extended by ±0.42 log, ±0.7 log, and ±0.84 log, respectively. These levels were equidistant and enabled the design to be rotatable, while accounting for data non-linearity (Montgomery, 2001). The CCD consisted of 15 samples, with seven being unique to the design (six axial samples and a centre sample). The total sum of samples in the HRD and the CCD designs was 57 (Fig. 1). The combination of the two particular designs was used in order to compare the raw measurements of cross-modal sensory interactions to modeled measurements derived from an optimisation design. In particular, two designs were used to give an indication of modelling reliability for cross-modal sensory interactions as a non-linear phenomenon.

2.3. General sensory procedures

A panel of experienced sensory assessors ($n = 8$–10) participated in evaluation. These assessors had been screened in accordance with ISO standards (8586-2) and previously trained in the use of scales with a range of food products and basic taste discrimination. Assessors have had previous experience in the evaluation of food products using descriptive analysis and the level of experience ranged from 1 year to 10 years. No specific training was performed for the current study to ensure that the assessors maintained a synthetic cognitive approach (Prescott, 1999). The age of assessors ranged from 30–70 and the mean age was 49. The first panel for the flavour intensity evaluation consisted of one male and nine females, and the second and third panels for the sorting and FCP consisted of nine females.