Perceptual and Nutritional Impact of Kokumi Compounds

Kokumi Substance as an Enhancer of Koku

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Chapter 13
Perceptual and Nutritional Impact of Kokumi Compounds

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Abstract The chapter first reviews the impact of kokumi compounds on sensory perception, then highlights opportunities to use koku sensations to support product reformulation and to impact energy perception and finally provides an outlook on research gaps and future directions. Many desirable sensory characteristics are enhanced by the addition of kokumi compounds to foods which can have a positive effect on consumer acceptance and product liking. Kokumi compounds impact not only the flavor of foods but also mouthfeel properties that are often associated with the presence of fat and calories. Adding kokumi compounds to reduced calorie soups and broths can enhance the perceived sensory intensity for sensations linked to calorie perception and enhance desirable sensory qualities linked to hedonic appeal. This raises the possibility that enhancement of sensory intensity with kokumi compounds could be applied to support reformulation efforts such as reduced fat or reduced calorie products by impacting how consumers perceive the energy content through sensory properties. Currently findings are limited to measuring expectations of fullness, and would need to be further confirmed through controlled feeding trials to quantity the impact of koku enhancement on energy intake and post-meal satiety to assess whether this could be a viable strategy to support long-term reductions in energy intake.

13.1 Introduction

The taste of food cannot be described by the five basic tastes alone, as there is often an additional complexity that goes beyond simple combinations of sweet, sour, salty, bitter, and umami. For example, mature Cheddar cheese differs from younger Cheddar cheese in primary tastes, but also has distinctive differences in sensory characteristic such as flavor continuity, complexity, and mouthfulness (Drake et al.

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2005; Muir et al. 1997; Rehman et al. 2000; Urbach 1993). Many foods that have been aged, fermented, or cooked at low temperatures for long time have distinctive desirable perceptual properties linked to their flavor and mouthfeel complexity. Although widely recognized in Western cultures, these sensations are poorly defined or described, yet they have been recognized as "full taste" in Japan for many years. The first identification of compounds to produce the koku sensation was described in 1990 by Ueda et al. (1990) who studied the flavoring effects of a water extract of garlic that increased continuity, mouthfulness, and thickness when it was added to umami solutions [monosodium glutamate (MSG), inosine-5′-monophosphate (IMP)] and broths (Chinese style broth and curry flavored broth). The key compounds responsible for this effect were identified as sulfur-containing compounds such as S-allyl-cysteine sulfoxide (alliin) and glutathione (GSH) (Ueda et al. 1990). These compounds distinctively impacted not only flavor complexity and duration, but also contributed to mouthfeel properties such as in-mouth thickness and mouthfulness (Ueda et al. 1990).

The compounds responsible for the koku sensation (termed kokumi compounds) are often produced through heating, fermentation, and aging of a product, which leads to the formation of tri-peptides that alone have low taste activity, but when combined with other tastant compounds can produce an intense flavor response. Kokumi compounds have been isolated and characterized in fermented foods such as kimchi, beer, and fish sauce; aged foods such as aged cheese, salami, wine, and dried scallops; and in slow-cooked foods such as consommés and meat broths. Differences in flavor perception and intensity in these products can be obtained by varying the treatment conditions (e.g., time, heat, fermentation) which can modify the concentration of the formed kokumi compounds (Nishimura 2019). For example, a simple chicken stock can be prepared by boiling chicken meat and bones with various vegetables (e.g., onion, carrots, leeks, celery). Variations in the cooking duration of the chicken soup result in the formation of kokumi compounds at different concentrations since the Maillard reaction between free amino acids and sugars is influenced by cooking duration. To date more than 50 chemical compounds have been identified from a range of different sources (natural and synthetic) that differ in chemical composition and potencies that cause koku sensations. Unlike the basic tastes, there has been confusion on the description and definition of the koku sensation. This has led to a lack of clarity in its perceptual description, since kokumi compounds do not elicit a distinct taste quality of their own, but rather enhance the complexity, continuity, and mouthfulness of other taste sensations.

Though not defined by the same criteria as other taste primaries, perception of kokumi compounds is mediated by an independent taste receptor system and is perceived via the calcium-sensing receptor (CaSR) (Briand and Salles 2016; Maruyama and Kuroda 2019). Some of the most potent kokumi compounds are tri-peptides, of which γ-glutamyl-valyl-glycine (γ-Glu-Val-Gly) is one of the most potent compounds. As with rare sugars and low-calorie sweeteners, kokumi compounds can enhance the sensory complexity and intensity of a mixture without adding significant amounts of calories. As such, kokumi compounds could be used to enhance the body and mouthfeel properties often associated with the presence of fat and energy, and potentially be applied to support reductions in energy density or fat content in foods. Beyond what is sensed in the oral cavity, taste stimuli are likely to play an important role in moderating metabolic kinetics and gastric emptying throughout the alimentary canal. Kokumi tri-peptides potentially play a role in signalling the presence of specific nutrients on the gut-brain axis. The current chapter first reviews the impact of kokumi compounds on sensory perception, then highlights opportunities to use koku sensations to support product reformulation and to impact energy perception and finally provides an outlook on research gaps and future directions.

13.2 Impact of Kokumi Compounds on Sensory Perception

The term kokumi originates from the Japanese words “koku” meaning full and “mi” meaning taste, and is often used interchangeably in conversational Japanese to describe a range of foods as “palatable” (Nishimura 2019). The direct translation of kokumi remains elusive for many English speakers as there is not an equivalent single concept or lexicon for its usage in English. The koku sensation implies a tactile and somatosensory component in addition to the enhancement of taste intensity perception. The original koku sensation was first defined as a rich, mouthful, thick, and delicious sensation (Ueda et al. 1990). Kokumi compounds tend to act as enhancers of other taste qualities such as sweet, salty, and umami, rather than eliciting any specific taste of their own (Briand and Salles 2016; Maruyama and Kuroda 2019; Zhao et al. 2016; Kuroda and Miyamura 2015; Maruyama et al. 2012).

Kokumi compounds have diverse sources, chemical structures, and potencies. A quantitative comparison between kokumi compounds showed marked differences in their koku enhancement potential (Ohsu et al. 2010). Currently, the most potent kokumi peptide identified to date is γ-Glu-Val-Gly. The point of subjective intensity equivalence in a salty-umami solution was estimated to be 12.8 times stronger for γ-Glu-Val-Gly compared with Glutathione (GSH) (i.e., 0.01% γ-Glu-Val-Gly solution had an average perceived koku intensity equivalent to a 0.128% GSH solution) (Ohsu et al. 2010). Compounds that elicit a koku sensation have only a slight flavor of their own in water, yet they have been shown to markedly increase perceived thickness, continuity, and mouthfulness when added to an umami solution or other foods (Ueda et al. 1997, 1994). The umami compound MSG can give koku in that it contributes to mouthfeel, intensity, and continuity, yet kokumi compounds cannot provide the same savory taste as umami in isolation (see review on umami by Yamaguchi and Ninomiya (1998)). Unlike umami, it has been demonstrated that kokumi compounds do not have a distinct taste of their own (Ueda et al. 1990, 1994, 1997; Kuroda and Miyamura 2015; Kuroda et al. 2012) although many kokumi compounds have subtle taste and odor qualities (Kurobayashi et al. 2019). Unlike umami, kokumi compounds arise from a wide range of different chemical compounds and sources, whereas umami is primarily associated with salts of glutamic acid [i.e., monosodium glutamate (MSG), disodium 5′-guanylate (GMP), inosine-5′-monophosphate (IMP), etc.] (Toelstede et al. 2009; Amino et al. 2016).

A kokumi compound is often produced from pre-cursors through heating, fermenting, or aging a product. For example, hydrolyzed soy protein is used to produce "Maillard peptides" by heating (Ogasawara et al. 2006). These "Maillard peptides" have been shown to increase overall taste intensity and give longer taste continuity and mouthfulness in a chicken consommé broth and salty-umami solution (sodium chloride and MSG) in comparison to control samples (Xu et al. 2018). Similarly, a study on taste-active peptides in bovine bone marrow extract found that kokumi compounds enhanced the taste activity of these peptides after Maillard reaction (Xu et al. 2018). Interestingly, 8 out of the 12 produced peptides have been shown to enhance koku sensations when added to beef broths (Xu et al. 2018). Fermentation and aging of certain peptides also influences the expression of kokumi compounds and the koku sensation (Toelstede et al. 2009). A comparative quantitative analysis between a Gouda cheese ripened for 4 weeks versus a Gouda cheese matured for 44 weeks revealed significant differences in perceived mouthfulness, taste intensity, and continuity (Toelstede et al. 2009). The enhancement of koku sensation of the matured cheese was linked to increased concentrations of key kokumi compounds comprising γ-L-glutamyl dipeptides (Toelstede et al. 2009). Similar enhanced koku sensations have been observed in dried herring that underwent a longer drying time which increased concentrations of creatinine compounds (Azad Shah et al. 2013). In fermented sourdough breads, similar effects and compounds have been reported (Tang et al. 2017). The concentration of kokumi compounds can also differ by cultivar type or by food processing condition. Raw onions cultivated from different regions in Japan contained different amounts of kokumi peptides (cycloalliin ranged from 5.6 mg/100 g of onion bulb in Nagano onions to 11.4 mg/100 g in Kagawa onions) (Ueda et al. 1994). When added into umami solutions, these kokumi peptides extracted from different types of onions (raw and cooked) gave different characteristics of koku mouthfeel and flavor, but the panellists were not able to recognize sweet taste qualities in the solutions (Ueda et al. 1994). These findings suggest that the koku sensation was independent from the sweetness of cooked onions (Ueda et al. 1994). For scallops, the concentration of the kokumi tripeptide γ-Glu-Val-Gly depended on the scallop processing conditions (Kuroda et al. 2012). Raw scallops contained 0.08 μg/g γ-Glu-Val-Gly, whereas dried scallops contained 0.64 μg/g and scallop extracts 0.77 μg/g γ-Glu-Val-Gly (Kuroda et al. 2012).

13.2.1 Kokumi Perception and Hedonic Responses

In order for koku to be classified as a basic taste quality, there are a number of specific criteria that must be fulfilled before the sensation can be categorized as a new "taste" sensation (Keast and Costanzo 2015; Mattes 2011; Hartley et al. 2019; McBurney and Gent 1979; Kurihara 2015). Although the proposed criteria vary considerably, perceptual salience and uniqueness of the taste quality and consensus on its description are necessary for a novel sensation to be categorized as a basic taste (Keast and Costanzo 2015; Mattes 2011; Hartley et al. 2019; McBurney and Gent 1979; Kurihara 2015). The relationship between individual measures of taste function (i.e., taste thresholds and suprathreshold intensity perception) from tasting a range of dissolved chemical stimuli can be determined with precision [e.g., detection threshold, recognition threshold, and suprathreshold intensity perception between the five basic taste qualities (Webb et al. 2015)]. This has led to proposed novel "tastes" for compounds linked to the perception of fatty acids (Running et al. 2015), carbohydrate (Lim and Pullicin 2019), metallic (Lawless et al. 2004), and more recently, kokumi (Rhyu et al. 2020; Feng et al. 2016).

The uniqueness of kokumi compounds is that some compounds such as γ-Glu-Val-Gly are consistently undetectable in low concentrations when diluted in water (Kuroda and Miyamura 2015; Ohsu et al. 2010; Kuroda and Harada 2004) whereas some kokumi compounds (i.e., GSH, γ-Glutamyl Peptides such as γ-Glu-Val, γ-Glu-Leu and β-Alanyl Dipeptides) are detectable in comparison to water control solutions (Ueda et al. 1997) due to a slight sour taste (Lee et al. 2010; Dunkel and Hofmann 2009), bitter taste (Shibata et al. 2018a, b), and/or astringency (Shibata et al. 2018a; Dunkel et al. 2007; Yang et al. 2017). These compounds are detectable as astringent in aqueous solutions (Lee et al. 2010). Similarly, kokumi compounds such as creatine, creatinine, and yeast extract compounds are barely detectable in terms of oral intensity perception when diluted in water (Shah et al. 2010; Liu et al. 2015). By contrast kokumi peptides from beef bone marrow are perceivable due to their weak sourness intensity (Xu et al. 2018). However, adding kokumi compounds (i.e., alliin, xycloalliin, MeCSO, GAC, GACSO) into an umami mixture of MSG-IMP or umami-salty (MSG-IMP-NaCl) or sweet-salty-umami (sucrose-NaCl-MSG) mixtures significantly reduced the detection (Ueda et al. 1997) and recognition thresholds (Dunkel et al. 2007) and significantly enhanced the rated koku intensity (Ueda et al. 1990, 1994, 1997; Kuroda and Miyamura 2015; Ohsu et al. 2010; Amino et al. 2016) in comparison to control-base solutions. These threshold concentrations and perceived koku sensations were similar when kokumi peptides were added to a model soup-base chicken broth (Kuroda and Miyamura 2015; Ohsu et al. 2010; Dunkel et al. 2007; Yang et al. 2017), Chinese and curry flavored soups (Ueda et al. 1990), beef broth (Ueda et al. 1997; Xu et al. 2018), Japanese fish-based noodle soups (Azad Shah et al. 2013), reduced-fat cream (Kuroda and Miyamura 2015), and commercial soy sauce (Yang et al. 2017), where their addition was characterized by reduced detection and recognition thresholds and enhanced rated koku intensity, but not basic taste intensity.

Descriptive sensory profiling of chicken consommé containing γ-Glu-Val-Gly showed that umami taste, mouthfulness, and mouth-coating sensations were more intensive than in control consommé (Miyaki et al. 2015) implying that the kokumi peptide γ-Glu-Val-Gly could be used to enhance and improve the flavor of chicken consommé. These sensory qualities have been associated with the perception of higher expected fullness and a higher caloric content in a food (see Sect. 13.3).

Similarly, a distinctive feature of the koku sensation is the temporality imparted by the addition of kokumi compounds as revealed through Time-Intensity sensory profiling (Ogasawara et al. 2006). This has been characterized by an increase in the continuity of savory sensations, longer and more intense flavors, and greater flavor after-tastes. For example, Maillard reaction peptides obtained by enzymatic hydrolysis of soybean protein followed by fractionation have been shown to enhance the flavor and umami sensation and increased the continuity and mouthfulness in umami solutions and consommé soups (Feng et al. 2016; Liu et al. 2016). Similarly, the addition of a mixture of creatine and creatinine to Japanese noodle soups resulted in enhancement of perceived thickness, mouthfulness, and continuity (Azad Shah et al. 2013).

Many desirable sensory characteristics are enhanced by the addition of kokumi compounds to foods which can have a positive effect on consumer acceptance and product liking. The sensory characteristics and consumer acceptability of beef soup with added glutathione Maillard reaction products were compared to soups with added glutathione and MSG (Hong et al. 2010). Glutathione Maillard reaction products and glutathione enhanced beef flavor of soups compared to MSG. Glutathione Maillard reaction products increased other flavors such as green onion, garlic, and boiled egg white flavor. Beef soups containing MSG were preferred and soups with reduced Glutathione Maillard reaction products were the least preferred because of their pronounced metallic and astringent notes. While glutathione Maillard reaction products enhanced both desired and undesired flavor notes equally, additional studies sought to optimize Maillard reaction conditions to generate Glutathione Maillard reaction products without undesirable flavors. In a beef broth (Hong et al. 2010, 2012), Glutathione-xylose Maillard reaction products enhanced the perception of beef flavor intensity. Again, these compounds also enhanced other undesirable flavor notes such as sulfur and chestnut flavors, suggesting a general flavor enhancement by glutathione-xylose Maillard reaction products. The combination of glutathione-xylose Maillard reaction products and MSG displayed a synergistic effect on flavor enhancement of beef stocks indicating that MSG is needed to produce the specific desirable koku enhancement. Salty, umami, and sweet tastes impacted liking of the beef broths the strongest.

13.3 Opportunities for Product Reformulation and Energy Content Reduction Using Koku Sensations

There has been widespread research interest on the impact of savory taste intensity on food intake, satiety, and calorie perception. Previous research has shown that savory taste enhancement using MSG can increase liking and enhance post-meal satiety for vegetable soups in overweight and obese adults (Carter et al. 2011; Masic and Yeomans 2014; Miyaki et al. 2016). Similarly, the addition of MSG to vegetable soups has been shown to decrease subsequent energy intake among a cohort of women with overweight and obesity (Miyaki et al. 2016) and MSG has been shown to increase satiety in adults, although the results have been inconsistent across studies. Addition of MSG/IMP to low-energy soup preloads increased appetite during ingestion and enhanced post-ingestive satiety (Masic and Yeomans 2014). Supplementation of a chicken broth with MSG reduced hunger and desire to snack, but did not affect later energy intake (Carter et al. 2011). Taken together these studies suggest a complex interaction between savory taste intensity and quality, and consumers perception of satiety and later snack intake, with equivocal findings that savory intensity can promote and reduce calorie consumption. A meta-analysis of seven cross-sectional studies demonstrated that regular consumption of savory soups and broths was inversely associated with risk of obesity, though it remains unclear which mechanism is driving these observational effects (Kuroda and Ninomiya 2020).

Kokumi compounds impact not only the flavor of foods but also mouthfeel properties that are often associated with the presence of fat and calories. For example, umami taste, mouthfulness, and mouth-coating sensations were found to be more intense in a chicken consommé containing γ-Glu-Val-Gly kokumi peptides compared to a control consommé without kokumi tri-peptides (Miyaki et al. 2015). These sensory qualities are often associated with the presence of fat, higher calories levels, and greater expected fullness. Hence, when these sensations are imparted using the low calorie but flavor intense kokumi tri-peptides, it creates a potential opportunity to either enhance the expected fullness of a low calorie food, or conceal a reduction in calories to mimic the sensory properties of a full-caloric version of a food, without a loss of hedonic appeal. Adding kokumi compounds to reduced calorie soups and broths can enhance the perceived sensory intensity for sensations linked to calorie perception and enhance desirable sensory qualities linked to hedonic appeal. This raises the possibility that enhancement of sensory intensity with kokumi compounds could be applied to support reformulation efforts such as reduced fat or reduced calorie products by impacting how consumers perceive their energy content through their sensory properties.

The sensory appeal of a food may be compromised during calorie reformulation as reductions of fat or carbohydrate content may result in a loss of mouthfeel, flavor quality, intensity, and duration. Consumers often report that lower calorie or lower fat versions of foods lack sensory intensity, have thin and unappealing mouthfeel properties, and deliver an insipid flavor profile, when compared to their full calorie equivalent products. Preliminary evidence suggests that koku enhancement may offer an effective strategy to support fat reduction and sustained appeal of reduced energy foods. The addition of the kokumi tri-peptide γ-Glu-Val-Gly enhanced the intensities of thick flavor, aftertaste, and oiliness in low fat peanut butter, thereby increasing sensations that were often lacking in the reduced-fat version of peanut butter (Miyamura et al. 2015). In addition to reduced fat peanut butter, koku enhancement using γ-Glu-Val-Gly was also found to enhance the perceived intensity, continuity, mouthfulness, and thick flavor for a series of reduced-fat custard creams (Kuroda and Miyamura 2015). In both cases, the koku enhancement elicited a greater sensory intensity and duration that was linked to increased hedonic appeal for the reduced calorie versions of the test products.

These preliminary findings suggest that koku enhancement could play a role in food reformulations to enhance the sensory perception and hedonic appeal of reduced energy foods. Koku enhancement may also be expected to influence consumer perception of the expected calorie density and satiating properties of foods that vary in this savory/koku dimension. In a study to test this proof of principal, researchers developed a series of beef broths that varied in their savory and koku intensity to test the impact this had on perceived calories, expected fullness, and prospective portion selection (Tang et al. 2020). The energy content of these broths was equivalent, yet they differed considerably in their sensory intensity and koku sensations of mouthfulness, continuity, and savory intensity. Importantly, consumers perceptions of the calorie content and expected fullness differed across the savory- and kokumi-enhanced broths (Fig. 13.1), with the broths that were higher in beef flavor, savoriness, body thickness, mouth-coating, and flavor aftertaste were positively associated with higher calorie ratings and greater expected fullness (Fig. 13.2) (Tang et al. 2020). Conversely, a higher sourness intensity was negatively associated with calorie and fullness expectations (Fig. 13.2).

These findings suggest that savory and koku enhancement may not only promote higher sensory intensity and hedonic appeal, but may also enhance the expected calories and satiating properties of lower-calorie foods by playing on our learned associations between these cues and fullness (Tang et al. 2020). Promoting the intensity and duration of sensory cues typically associated with beliefs of greater satiety could potentially be used to support the development of products that maintain sensory appeal and eating enjoyment, while supporting greater fullness per calorie consumed. Currently findings are limited to measuring expectations of fullness, and would need to be further confirmed through controlled feeding trials to quantity the impact of koku enhancement on energy intake and post-meal satiety to assess whether this could be a viable strategy to support long-term reductions in energy intake.

13.4 Outlook: Research Gaps and Future Directions for Koku and Health

Research to date has demonstrated the potential application of savory and koku enhancement to support sensory and hedonic enhancement of low-calorie or reduced fat foods, and in promoting expectations of calories and fullness through the enrichment of these sensory cues. There may be opportunities to extend this application further in the future, with the emergence of new categories of products that aim to mimic the savory properties of meats. Plant-based meat alternatives play an important role in supporting consumers to make the transition to new protein sources and reduce our reliance on animal production by providing meat enthusiasts an

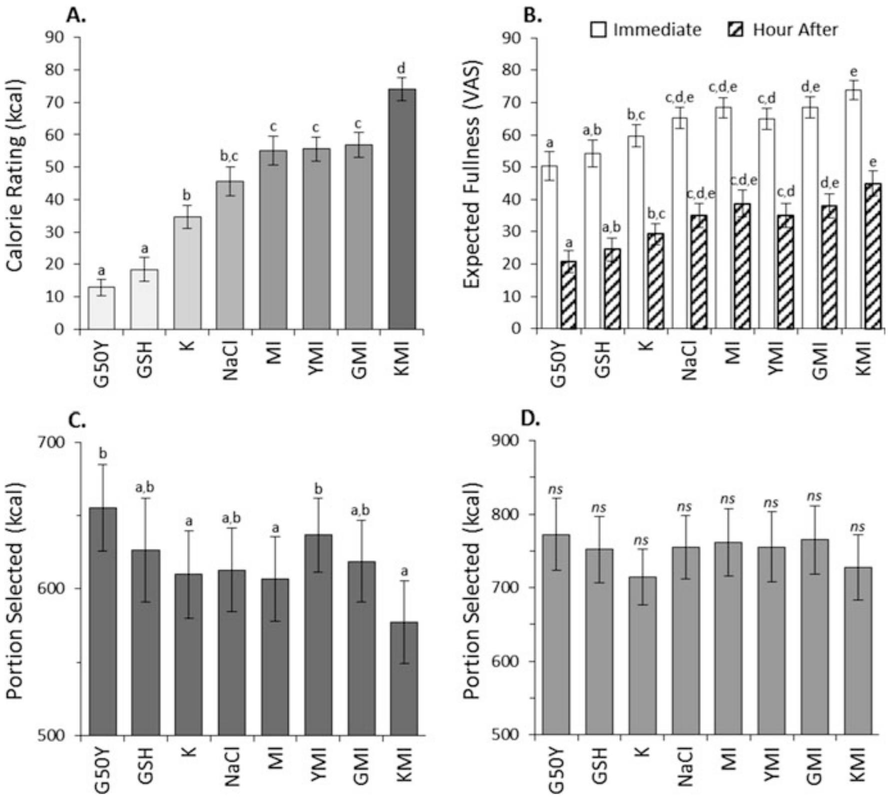

Fig. 13.1 Mean (± SEM) Calorie Rating (**a**) and Expected Fullness (**b**) of broth, and Portion Selection of chicken rice (**c**) and noodles soup (**d**) to accompany broth, across eight savory enhanced broths in increasing calorie rank. Different letters indicate a significant difference at $p < 0.05$, using Bonferroni corrected comparisons to compare broth samples, where "a" always represents the smallest value. Sample abbreviations are **G50Y**; Glutathione +50% yeast extracts, **GSH**; reduced Glutathione, **K**; Kokumax-100-yeast extract, **NaCL**; Sodium Chloride, **MI**; Mono-sodium glutamate (MSG) + inosine mono-phosphate (IMP), **YMI**, Yeast extract with 50% reduced glutathione, + Mono-sodium glutamate + inosine mono-phosphate, **GMI**; reduced Glutathione, MSG, IMP and **KMI**; Kokumax-100 Yeast Extract + MSG, IMP. Figure was adapted from (Tang et al. 2020) (https://doi.org/10.1016/j.foodqual.2020.103897) and used with permission

opportunity to consume plant-based meat alternatives (PBMAs) that mimic the texture and flavor profile of animal meat. Over the past decade, there has been a proliferation of these PMBA products, with rising demand for better quality products of plant origin to mimic the sensory properties of meat. Several significant hurdles remain in capturing consumer appeal for these PMBA products as many current meat replacers either contain excessive amounts of salt or have flavor profiles that fail to closely mimic the quality of meat flavor (Tso et al. 2020; Tso and Forde 2021). An interesting, and as yet unexplored opportunity, that might tackle both issues could be the use of kokumi compounds to enhance savory intensity and mimic the

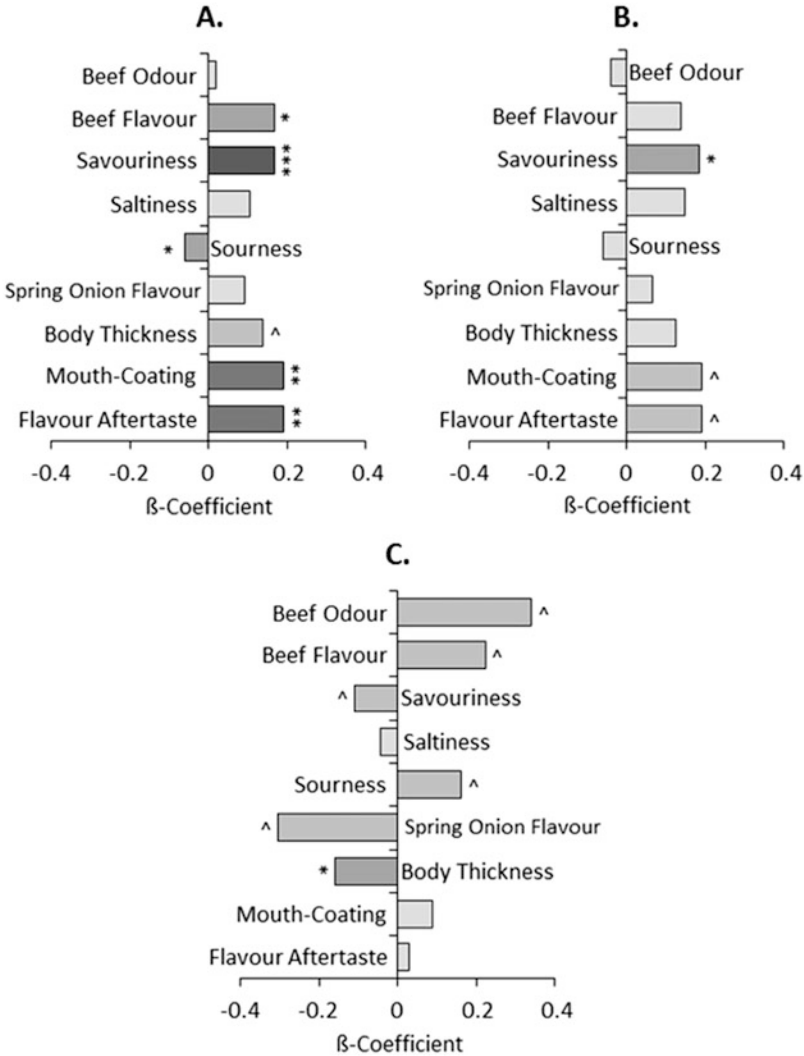

Fig. 13.2 Partial least squares regression (PLSR) of the descriptive sensory profiling data of eight broth samples on (**a**) Calorie Rating, (**b**) Expected Fullness and (**c**) Portion Selection of Noodles Soup to accompany broth, across the eight broths. *** indicates a significance of $p < 0.001$, ** indicates $p < 0.01$, * indicates $p < 0.05$ and ^ refers to reaching significance with $p < 0.10$. Figure was adapted from (Tang et al. 2020) (https://doi.org/10.1016/j.foodqual.2020.103897) and used with permission

flavor release profile of animal meat products. Kokumi compounds have been reported to enhance both saltiness and umami intensity (see Sect. 13.2), two important sensations contributing to meat flavor, and can mimic the experience of fat during consumption by increasing the mouthfulness, mouth coating, and continuity.

Future studies are needed to explore the potential application of koku enhancement to further boost the perceptual properties and sensory appeal of plant-based meat alternatives, without the need for excessive salt addition.

A majority of kokumi compounds identified to date are tri-peptides, especially γ-glutamyl and leucyl peptides (see Sect. 13.2). These compounds are typically found in fermented foods, yeast extracts, and protein hydrolysates, and have kokumi threshold concentrations (modulating threshold) in the order of 0.2–2.0 mM. Recently, a different class of thiamine-derived compounds having a kokumi-imparting ability were identified (Brehm et al. 2019, 2020). These thiamine-derived compounds were identified in commercial process flavors but also in several (roasted) meats. Several of these thiamine-derived compounds have unprecedentedly low kokumi threshold concentrations (0.035–0.08 mM) and are potentially highly potent savory and koku enhancers. Their natural occurrence in roasted meat and low threshold concentrations make these compounds interesting targets for applications in meat alternatives. Furthermore, thiamine is cheap and readily available in food-grade form, facilitating easy and cost-effective synthesis of thiamine-derived kokumi compounds. Future studies are now needed to explore the formation pathways of these thiamine-derived kokumi compounds to maximize yield by optimizing the reaction conditions, and simultaneously explore their sensory properties and potential application as flavor enhancers in plant-based meat alternatives.

Kokumi compounds impact not only the flavor of foods but also mouthfeel properties which are often associated with the presence of fat and calories. The role of koku enhancement in food reformulations to support energy or fat reduction remains a poorly understood area, despite the clear potential for these compounds to support sustained hedonic appeal of lower energy or fat versions of certain foods. Most studies to date have focused on koku enhancement only in liquid food systems, often showing koku enhancement in low viscosity savory broths (Li et al. 2022). Rheological and tribological properties of liquid foods are known to impact mouthfeel sensations such as mouthfulness, thickness, creaminess, smoothness, and lingering of oral coatings, and these sensory properties are often associated with both fat and energy content. Our understanding of the interplay between rheological and tribological properties of liquid foods and the impact of koku enhancement is limited and it is unclear how successfully these koku enhanced calorie perceptions remain in semi-solid and solid foods. A food's texture properties may interact synergistically or antagonistically with koku enhancement and further research is needed to explore the opportunity to apply kokumi compounds to support fat and calorie reduction in solid and semi-solid food systems. Future studies are now needed to determine systematically the effect of food texture properties on koku sensation using a range of kokumi compounds, and demonstrate the efficacy of this approach to support calorie reduction in semi-solid and solid foods.

Finally, there could be potential to reduce some of the calories in a food and compensate for any associated drop in hedonic appeal through the use of kokumi compounds which enhance desirable sensory qualities (see Sect. 13.3). Savory and kokumi enhancers could be used to increase satiating properties by drawing on learned associations between these sensory cues and appetite and fullness.

Promoting the intensity and duration of sensory cues typically associated with beliefs of greater satiety could potentially be used to support the development of products that maintain their sensory appeal and eating enjoyment, while supporting greater fullness per calorie consumed. Studies to date have only focused on consumers expectations and perceptions of calorie content, and measured the expected rather than the experienced fullness of these foods. Future studies should now extend these findings to acute human feeding trials and long-term clinical trials to assess the potential impact of koku enhancement in supporting long-term reductions in caloric intake without a loss of satiety and sustained sensory appeal. Preliminary findings to date suggest a variety of potential perceptual and health benefits for koku enhancement that now require further testing to confirm these applications to support food reformulation, and the protein transition to reduce the current global reliance on products of animal origin.

References

Amino Y, Nakazawa M, Kaneko M, Miyaki T, Miyamura N, Maruyama Y et al (2016) Structure–CaSR–activity relation of kokumi γ-glutamyl peptides. Chem Pharm Bull 64(8):1181–1189

Azad Shah AKM, Ogasawara M, Kurihara H, Takahashi K (2013) Effect of drying on creatine/creatinine ratios and subsequent taste of herring (Clupea pallasii) fillet. Food Sci Technol Res 19(4):691–696

Brehm L, Frank O, Jünger M, Wimmer M, Ranner J, Hofmann T (2019) Novel taste-enhancing 4-Amino-2-methyl-5-heteroalkypyrimidines formed from thiamine by Maillard-type reactions. J Agric Food Chem 67(50):13986–13997

Brehm L, Frank O, Ranner J, Hofmann T (2020) Quantitative determination of thiamine-derived taste enhancers in aqueous model systems, natural deep eutectic solvents, and thermally processed foods. J Agric Food Chem 68(22):6181–6189

Briand L, Salles C (2016) Taste perception and integration. Flavor:101–119

Carter BE, Monsivais P, Perrigue MM, Drewnowski A (2011) Supplementing chicken broth with monosodium glutamate reduces hunger and desire to snack but does not affect energy intake in women. Br J Nutr 106(9):1441–1448

Drake M, Yates M, Gerard P, Delahunty C, Sheehan E, Turnbull R et al (2005) Comparison of differences between lexicons for descriptive analysis of Cheddar cheese flavour in Ireland, New Zealand, and The United States of America. Int Dairy J 15(5):473–483

Dunkel A, Hofmann T (2009) Sensory-directed identification of β-alanyl dipeptides as contributors to the thick-sour and white-meaty orosensation induced by chicken broth. J Agric Food Chem 57(21):9867–9877

Dunkel A, Köster J, Hofmann T (2007) Molecular and sensory characterization of γ-glutamyl peptides as key contributors to the kokumi taste of edible beans (Phaseolus vulgaris L.). J Agric Food Chem 55(16):6712–6719

Feng T, Zhang Z, Zhuang H, Zhou J, Xu Z (2016) Effect of peptides on new taste sensation: Kokumi-review. Mini-Rev Org Chem 13(4):255–261

Hartley IE, Liem DG, Keast R (2019) Umami as an ‘alimentary’ taste. A new perspective on taste classification. Nutrients 11(1):182

Hong JH, Jung DW, Kim YS, Lee SM, Kim KO (2010) Impacts of glutathione Maillard reaction products on sensory characteristics and consumer acceptability of beef soup. J Food Sci 75(8): S427–S434

Hong JH, Kwon KY, Kim KO (2012) Sensory characteristics and consumer acceptability of beef stock containing the glutathione-xylose Maillard reaction product and/or monosodium glutamate. J Food Sci 77(6):S233–S239
Keast RS, Costanzo A (2015) Is fat the sixth taste primary? Evidence and implications. Flavour 4(1):1–7
Kurihara K (2015) Umami the fifth basic taste: history of studies on receptor mechanisms and role as a food flavor. Biomed Res Int 2015:1
Kurobayashi Y, Fujiwara S, Matsumoto T, Nakanishi A (2019) Koku attribute-enhancing odor compounds. In: Koku in food science and physiology. Springer, pp 73–83
Kuroda M, Harada T (2004) Fractionation and characterization of the macromolecular meaty flavor enhancer from beef meat extract. J Food Sci 69(7):542–548
Kuroda M, Miyamura N (2015) Mechanism of the perception of "kokumi" substances and the sensory characteristics of the "kokumi" peptide, γ-Glu-Val-Gly. Flavour 4(1):11
Kuroda M, Ninomiya K (2020) Association between soup consumption and obesity: a systematic review with meta-analysis. Physiol Behav 225:113103
Kuroda M, Kato Y, Yamazaki J, Kageyama N, Mizukoshi T, Miyano H et al (2012) Determination of γ-glutamyl-valyl-glycine in raw scallop and processed scallop products using high pressure liquid chromatography–tandem mass spectrometry. Food Chem 134(3):1640–1644
Lawless HT, Schlake S, Smythe J, Lim J, Yang H, Chapman K, Bolton B (2004) Metallic taste and retronasal smell. Chem Senses 29(1):25–33
Lee SM, Jo Y-J, Kim Y-S (2010) Investigation of the aroma-active compounds formed in the Maillard reaction between glutathione and reducing sugars. J Agric Food Chem 58(5): 3116–3124
Li Q, Zhang L, Lametsch R (2022) Current progress in kokumi-active peptides, evaluation and preparation methods: a review. Crit Rev Food Sci Nutr 62(5):1230–1241
Lim J, Pullicin AJ (2019) Oral carbohydrate sensing: beyond sweet taste. Physiol Behav 202:14–25
Liu J, Song H, Liu Y, Li P, Yao J, Xiong J (2015) Discovery of kokumi peptide from yeast extract by LC-Q-TOF-MS/MS and sensomics approach. J Sci Food Agric 95(15):3183–3194
Liu P, Huang M, Song S, Hayat K, Zhang X, Xia S, Jia C (2016) Sensory characteristics and antioxidant activities of Maillard reaction products from soy protein hydrolysates with different molecular weight distribution. Food Bioprocess Technol 5:1775–1789
Maruyama Y, Kuroda M (2019) Mechanism of Kokumi substance perception: role of calcium-sensing receptor (CaSR) in perceiving Kokumi substances. In: Nishimura T, Kuroda M (eds) Koku in food science and physiology. Springer, Singapore
Maruyama Y, Yasuda R, Kuroda M, Eto Y (2012) Kokumi substances, enhancers of basic tastes, induce responses in calcium-sensing receptor expressing taste cells. PLoS One 7(4):e34489
Masic U, Yeomans MR (2014) Umami flavor enhances appetite but also increases satiety. Am J Clin Nutr 100(2):532–538
Mattes RD (2011) Accumulating evidence supports a taste component for free fatty acids in humans. Physiol Behav 104(4):624–631
McBurney DH, Gent JF (1979) On the nature of taste qualities. Psychol Bull 86(1):151
Miyaki T, Kawasaki H, Kuroda M et al (2015) Effect of a kokumi peptide, γ-glutamyl-valyl-glycine, on the sensory characteristics of chicken consommé. Flavour 4:17
Miyaki T, Imada T, Hao SS, Kimura E (2016) Monosodium L-glutamate in soup reduces subsequent energy intake from high-fat savoury food in overweight and obese women. Br J Nutr 115(1):176–184
Miyamura N, Jo S, Kuroda M, Kouda T (2015) Flavour improvement of reduced-fat peanut butter by addition of a kokumi peptide, γ-glutamyl-valyl-glycine. Flavour 4:16
Muir DD, Banks JM, Hunter EA (1997) A comparison of the flavour and texture of Cheddar cheese of factory or farmhouse origin. Int Dairy J 7(6–7):479–485
Nishimura T (2019) Definition of "Koku" Involved in Food Palatability. In: Koku in food science and physiology. Springer, pp 1–16

Ogasawara M, Katsumata T, Egi M (2006) Taste properties of Maillard-reaction products prepared from 1000 to 5000 Da peptide. Food Chem 99(3):600–604

Ohsu T, Amino Y, Nagasaki H, Yamanaka T, Takeshita S, Hatanaka T et al (2010) Involvement of the calcium-sensing receptor in human taste perception. J Biol Chem 285(2):1016–1022

Rehman S-U, Banks J, Brechany E, Muir D, McSweeney P, Fox P (2000) Influence of ripening temperature on the volatiles profile and flavour of Cheddar cheese made from raw or pasteurised milk. Int Dairy J 10(1–2):55–65

Rhyu MR, Song AY, Kim EY, Son HJ, Kim Y, Mummalaneni S, Qian J, Grider JR, Lyall V (2020) Kokumi taste active peptides modulate salt and umami taste. Nutrients 12(4):1198

Running CA, Craig BA, Mattes RD (2015) Oleogustus: the unique taste of fat. Chem Senses 40(7): 507–516

Shah A, Ogasawara M, Egi M, Kurihara H, Takahashi K (2010) Identification and sensory evaluation of flavour enhancers in Japanese traditional dried herring (Clupea pallasii) fillet. Food Chem 122(1):249–253

Shibata M, Hirotsuka M, Mizutani Y, Takahashi H, Kawada T, Matsumiya K et al (2018a) Diversity of γ-glutamyl peptides and oligosaccharides, the "kokumi" taste enhancers, in seeds from soybean mini core collections. Biosci Biotechnol Biochem 82(3):507–514

Shibata M, Hirotsuka M, Mizutani Y, Takahashi H, Kawada T, Matsumiya K et al (2018b) Thermal treatment of soybean seeds can improve the quality of soymilk by enhancing the extraction efficiency of "Kokumi" taste components. Food Sci Technol Res 24(6):1111–1119

Tang KX, Zhao CJ, Gänzle MG (2017) Effect of glutathione on the taste and texture of type I sourdough bread. J Agric Food Chem 65(21):4321–4328

Tang CS, Tan VWK, Teo PS, Forde CG (2020) Savoury and kokumi enhancement increases perceived calories and expectations of fullness in equicaloric beef broths. Food Qual Prefer 83:103897

Toelstede S, Dunkel A, Hofmann T (2009) A series of kokumi peptides impart the long-lasting mouthfulness of matured gouda cheese. J Agric Food Chem 57(4):1440–1448

Tso R, Forde CG (2021) Unintended consequences: nutritional impact and potential pitfalls of switching from animal-to plant-based foods. Nutrients 13(8):2527

Tso R, Lim AJ, Forde CG (2020) A critical appraisal of the evidence supporting consumer motivations for alternative proteins. Foods 10(1):24

Ueda Y, Sakaguchi M, Hirayama K, Miyajima R, Kimizuka A (1990) Characteristic flavor constituents in water extract of garlic. Agric Biol Chem 54(1):163–169

Ueda Y, Tsubuku T, Miyajima R (1994) Composition of sulfur-containing components in onion and their flavor characters. Biosci Biotechnol Biochem 58(1):108–110

Ueda Y, Yonemitsu M, Tsubuku T, Sakaguchi M, Miyajima R (1997) Flavor characteristics of glutathione in raw and cooked foodstuffs. Biosci Biotechnol Biochem 61(12):1977–1980

Urbach G (1993) Relations between cheese flavour and chemical composition. Int Dairy J 3(4–6): 389–422

Webb J, Bolhuis DP, Cicerale S, Hayes JE, Keast R (2015) The relationships between common measurements of taste function. Chemosens Percept 8(1):11–18

Xu X, You M, Song H, Gong L, Pan W (2018) Investigation of umami and kokumi taste-active components in bovine bone marrow extract produced during enzymatic hydrolysis and Maillard reaction. Int J Food Sci Technol 53(11):2465–2481

Yamaguchi S, Ninomiya K (1998) What is umami? Food Rev Intl 14(2–3):123–138

Yang J, Sun-Waterhouse D, Cui C, Dong K, Wang W (2017) Synthesis and sensory characteristics of kokumi γ-[glu] n-phe in the presence of glutamine and phenylalanine: glutaminase from bacillus amyloliquefaciens or aspergillus oryzae as the catalyst. J Agric Food Chem 65(39): 8696–8703

Zhao CJ, Schieber A, Gänzle MG (2016) Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations–a review. Food Res Int 89:39–47