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Nutrient sensing: What can we learn from different tastes about the nutrient contents in today's foods?

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1. Introduction

Food sensory properties, including taste, are often described as having a nutrient-signaling function that elicits expectations about the food and its nutrient content and in turn affecting the sensory stimulation to eat and food choice and consumption (Lease, Hendrie, Poelman, Delahunty, & Cox, 2016; Boesveldt & Graaf, 2017). Indeed, several essential nutrients are well known for their taste properties (Parke, Birch, & Dijk, 1999); thus, some taste sensations are expected to be associated with the presence of certain essential nutrients or nutritional properties (sweetness and monosaccharides, saltiness and sodium, etc.). To the best of our knowledge, only four studies have been carried out to highlight the relationships between taste and nutrient contents (or nutritional properties, such as energy) in commonly consumed foods (Van Dongen, van den Berg, Vink, Kok, & de Graaf, 2012; Lease et al.,2016; van Langeveld et al., 2017, and Teo et al., 2018). Van Dongen et al. (2012) investigated whether taste acts as a nutrient sensor for 50 foods selected to represent a range of foods commonly consumed in the Netherlands. Linear regression was used to test associations between the taste intensity and nutrient content. The results showed, in particular, that sweet taste was associated with the mono-disaccharide content and that salty and umami tastes were both associated with the sodium and protein contents. Moreover, these associations were more pronounced in raw and moderately processed foods than in highly processed foods. In line with this approach, taste-nutrient relationships were also explored by Lease et al. (2016) for a larger number of foods representing the nutritional and sensory diversity across the whole diet of 4487 Australian children, including foods consumed by Australian adults. The conclusions of their work were consistent with those of Van Dongen et al. (2012). In particular, the results of the linear regressions highlighted significant taste-nutrient relationships across 377 foods, including mono-disaccharides and sweet taste, sodium and salty and umami tastes, and protein and salty taste. These results were then used to model the taste intensity of a larger food set (3758 foods). However, contrary to what was expected, the results showed that the salt intensity was unrelated to the sodium content. In accordance with Van Dongen et al. (2012), it was suggested that, at least for complex mixed dishes and processed food products, other compositional and taste attributes (such as sugar/sweetness) may impede and alter the perception of saltiness. The findings of a recent study carried out by van Langeveld et al. (2017) reinforced those of Van Dongen et al. (2012) and Lease et al. (2016). It was demonstrated that for the 277 studied processed foods, the sweet taste intensity was associated with mono-disaccharides and the salty taste intensity was associated with energy and the sodium, protein, and fat contents. In their conclusion, van Langeveld et al. (2017) also suggested that if sweet and salty tastes can signal the presence of mono-disaccharides and sodium, respectively, these relationships may be weaker in complex foods with competing tastes. This aspect seems to be a very important factor for better understanding taste-nutrient relationships in commonly consumed foods, especially because taste mixture interactions have been clearly demonstrated in aqueous solutions (Green, Lim, Osterhoff, Blacher, & Nachtigal, 2010). Indeed, it is likely that at least part of these interactions in model solutions also occurred in more complex environments such as processed foods. The last study available about taste-nutrient relationships in foods was carried out by Teo et al. (2018) with 469 Dutch and 423 Malaysian commonly consumed foods. In line with the three studies mentioned above, the results of this work showed positive associations between sweetness and the mono-disaccharide content, umami and the protein content, saltiness and the sodium content, and fat sensation and the lipid content. Several other correlations corresponding to an indirect association were identified, including relationships between energy and salt and umami and fat sensation. When studying taste-nutrient relationships, it must be noted that the correlations observed can correspond to a direct or an indirect relationship. The relationship is direct only if a nutrient has taste properties (dose-response relationship). In the three studies mentioned above, the direct relationships include the relationships between salty taste and the sodium content, sweet taste and the mono-disaccharide content, and fatty mouthfeel and the fat content. Other correlations identified correspond to indirect associations. For example, fat or proteins are not known for their salty taste. However, many commonly consumed foods with a high protein and/or fat content also contain sodium

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(cheese, meat and fish, and cold cuts) and thus are perceived as salty. Therefore, the correlations observed between salty taste and the protein content and/or fat content are guided by the nature of the products. The fact remains that even through an indirect relationship, taste can provide valuable information about the nutrient content: "generally, when it is salty, it is rich in sodium, but also in protein and/or fat". Some essential nutrients or nutritional properties are tasteless or almost tasteless at the usual doses in commonly consumed foods, including water, proteins, vitamins, many minerals, and of course energy, which is an essential nutritional property. In the same way as it is possible to associate the flavor of some foods to their energy value, in theory, it is not absurd to think that some indirect strategies, based in particular on tastes or combinations of tastes, have been developed to indicate the presence of these tasteless essential nutrients in foods.

The present study therefore had three main goals: The first was to investigate correlations between the taste intensity and nutrient content in common foods. The five tastes and fat sensation were considered. Direct relationships (dose-response) were detailed, but indirect relationships were also studied. The taste-nutrient relationships identified in the four studies mentioned above were expected to be observed in the present study. The second objective was to explore the impact of the other perceived tastes, potentially competing, on each direct relationship identified. We hypothesized that the competing tastes occurring in common foods can confuse direct taste-nutrient relationships and that by taking into account competing tastes, it will be possible to improve the quality of the regressions. The last objective was to determine whether the content of certain nutrients could be inferred from a combination of the five tastes and fat sensation, considering these as explicative variables. This predictive approach strictly refers to the concept of nutrient sensing (tastes inform us about the nutrient content). In particular, the idea was to put together an overview of what can be learned from tastes about the nutrient content of today's foods. The degree of food processing was taken into account in the analyses related to the last objective.

2. Material and methods

The work described in this article was based on a food taste database (Martin, Visalli, Lange, Schlich, & Issanchou, 2014) and on the ANSES-Ciqual food composition table (ANSES/Ciqual, 2008). These two databases were used to obtain a new dataset containing sensory and nutritional information for approximately several hundred foods.

2.1. Food taste database

The food taste database provides the intensity of tastes and fat sensation perceived from 590 foods. For each of the 590 foods, the food taste database provides a mean intensity rating for sweetness, saltiness, sourness, bitterness, umami taste, and fat sensation. The number of data points used to calculate the mean intensity rating is specified for each food item. This database was obtained using an in-home profile method consisting of intensive training in the laboratory immediately followed by an 8-month in-home measurement phase, during which 12 trained panelists had to evaluate the five tastes and fat sensation of the foods they typically consumed. The food products to be assessed were not imposed. The subjects could freely choose among their everyday foods. The long duration of the measurement phase provided data about a wide variety of foods, including seasonal foods.

The rating scales were inspired by the scales used in the Spectrum™ method (Muñoz and Civille, 1992). This method is based on the extensive use of reference points positioned along each scale range. A reference sample (food product) or a sapid reference solution was assigned to each reference point. Specific scales were developed for fat sensation and umami taste. For fat sensation, the different levels of intensity were illustrated by seven commercial food references[1] (Martin et al., 2014). It can be noticed that fat sensation intensity was found to be higher in high-fat foods of various types (cheeses, cold cuts, pastries, etc.) or in food consumed with substances high in fat (mayonnaise, spreads, etc.). However, some non-fat ingredients, such as jam or honey, also increase the intensity of the "fat sensation", showing that fat sensation is a multidimensional sensation based largely on texture (Mattes, 2009).

2.2. ANSES-Ciqual food composition table

The ANSES-Ciqual food composition table presents the contents of different components (carbohydrates, proteins, fat and fatty acids, vitamins, minerals, etc.) and the energy values for several hundred food products. At the date of this work, the current version of the French food composition table was 2013 and contained average nutrient information for 51 components in more than 2000 food items. This list of nutrients was not exhaustive but contained the nutrients typically taken into account in order to evaluate the nutrient adequacy of the diet (e.g. Darmon, Darmon, Maillot, & Drewnowski, 2005; Arsenault, Fulgoni, Hersey, & Muth, 2012). All values are given as per 100 g of the edible part of the food. For each component (when available), the following information was used for this work: the average content value and the number of samples used to determine the average value. When the number of samples was not provided, we considered that the measure was obtained from only one sample.

2.3. Cross-referencing between databases

For each food item described in the food taste database, a match was searched in the ANSES-Ciqual food composition table. A similar approach was used in a previous work (Yuan et al., 2016) to predict the sweetness or fattiness intensity of some foods from their sugar and fat contents, respectively. In the case of an exact match, the values indicated in the composition table were used without alteration. Food items without a match were not retained in this study. In some cases (8.5% of the new dataset), the food names used in the composition table were more detailed than those in the food taste database, giving rise to multiple matches. For example, the composition table provided information about the nutrient contents of three types of apple juice (100% apple juice, apple juice from concentrate, and apple nectar), whereas a less detailed name (apple juice) was used in the food taste database. In this situation, an "average food" (apple juice) was created using the weighted average content of each nutrient in the three types of apple juice. The weighting was based on the average number of samples used to determine the nutrient content of each apple juice. This procedure allowed equalization of the levels of precision of both sets of data. The average number of samples was preferred over the sum to avoid overweighting the nutrient values of "average food" items. In some cases, the ANSES-Ciqual food composition table provides data for "theoretical" foods, whose denomination is deliberately vague ("Pizza", "Salad, vegetable, oil & vinegar dressing", and "Vegetables, cooked"). In this case, the authors surmise that this type of data can be very useful for nutritional epidemiologists, and the composition of such foods was estimated from a combination, weighted by levels of consumption if possible, of several individual food items. These theoretical data represent only 0.8% of the new dataset.

An exact match was made for 337 foods, representing approximately 57% of the food items described in the food taste database. This

[1] Food references for fat sensation (name and % scale): Single cream 15% fat Pâturages® (13.3%), Strasbourg sausage Knacki Herta®, (24.6%), Vache qui rit (Processed cheese) Bel® (34.3%), Camembert Lepetit® (45.6%), White chocolate Galak Nestlé® (60.0%), Mascarpone Fiorini® (72.0%), Unsalted butter Président® (90.0%).