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The Role of the Dynamic Sensory Perception in the Reformulation of Shakes: Use of TDS for Studying the Effect of Milk, Fiber, and Flavor Addition

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Abstract: Various factors need to be taken into account when reformulating a food or beverage. The food components, not only macronutrients but also minor ingredients such as flavoring agents, could affect the perception of the sensory sensations, importantly their dynamic aspects, as rising and duration, which are not normally considered. The novelty of this approach is the study of the effects of the addition of several ingredients (fiber, extra milk powder, and strawberry flavoring) on the dynamic perception of a food item (strawberry shakes) using the temporal dominance of sensations (TDS) technique. The occurrence and duration of the key sensory sensations (acid, natural strawberry flavor, thick, sweet, candy strawberry flavor, and milk flavor) extracted from the TDS curves were analyzed and linked to the composition factors and liking and expectations of satiety scores. For example, the addition of flavoring increased the liking scores (increments ranging from 0.3 to 1.1) that was linked to the attenuation of acid sensation; and the addition of extra milk powder increased the expectation of satiety scores (increments ranging from 0.5 to 0.7) that was linked to the perception of early thick sensation in the mouth. In general, the more complex sensory profiles the higher liking and expectations of satiety.

Keywords: beverages, Dynamic sensory evaluation, flavoring, sensory attributes

Practical Application: This work is a case study on how temporal sensory methods can contribute important information on the actual perception of food during consumption. Depending on the ingredients added these sensory properties appear at different times and with different dominance during evaluation affecting liking or fullness expectations. In consequence, the temporal sensory properties should be taken into account when designing or reformulating food.

Introduction

Reformulating existing foods might be one of the most effective ways to obtain healthier food products. Food reformulation might be defined as reformulating existing foods to remove, reduce, or add certain food components while maintaining sensory characteristics such as flavor and texture. It is simple to say but difficult to achieve, because most of these modifications could (and normally do) modify the sensory profile of the reformulated product, regarding both flavor and texture sensations.

In general, one of the goals of researchers is to avoid any reduction in the acceptability of the reformulated products (Ünal and Akalin 2013) compared to the regular item but (normally) changes in dynamic perceptions, that is, arising and duration of the different key sensory sensations are not analyzed; these changes can modify the food perception as a whole. To date very little research has been done on sensory interaction taking into account the temporal component (Charles and others 2017). Conventional descriptive sensory techniques require judges to make single-point evaluations; in many cases, this might imply some loss of vital information because the process of food consumption is not static (Di Monaco and others 2014). Different temporal methodologies have been developed over the last decades, such as time intensity and more recently, temporal dominance of sensations (TDS). TDS is a method that allows sensory perceptions to be followed during consumption of a food or beverage. It involves selection and continuous updating of the dominant sensation, and provides sequential data to characterize products (Castura and Li 2016) in a dynamic way.

In this study, strawberry milkshakes were reformulated by adding extra milk and fiber (a combination of inulin and oligofructose); in addition, a strawberry flavor was used to study its effect on the temporal sensory profile. TDS combined with acceptance tests can provide important information regarding the sensations that are key for products' quality as reported by Castura and Li (2016) for flavored fresh cheeses, and Bouteille and others (2013) on yoghurts. Bemfeito and others (2016), who studied different Minas cheese established that TDS analysis can provide important information on the peculiarities of each product.

A large body of research has shown that protein-enriched foods may enhance nutritional value and filling sensations (Bowen and others 2006; Chungchunlam and others 2017; Morell and Fiszman 2017). However, dietary fiber has outstanding health promotion functions; important constituents of dietary fiber are oligosaccharides (prebiotic effect) and bioactive compounds (antioxidant effect) which enhance its beneficial effects in the body (Viscione 2013; Macagnan and others 2016); particularly fiber enrichment of beverages has attracted more attention in recent years due to the appearance of new soluble fiber ingredients (Mudgil and Barak

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2016). Soluble fibers such as inulin and oligofructose are increasingly used in new food product development. Both inulin and oligofructose are ingredients which offer a useful combination that may significantly change the sensory characteristics (Franck 2002), and both have been shown to be effective prebiotics (Kolida and others 2002). Soluble fibers have been used in dairy foods for the development of functional products: Cruz and others (2013) added oligofructose into yogurt, Balthazar and others (2017) studied the effects of inulin and oligosaccharides addition to sheep milk ice cream, and Belsito and others (2017) evaluated the addition of galactooligosaccharides to processed cheese. These soluble fibers are added as functional food ingredients that have prebiotic effects but also have an important impact on the sweetness, texture, and mouthfeel of dairy products (Balthazar and others 2017).

A crucial challenge when developing beverages with enhanced nutritional value is the extent to which the physical product can actually live up to the anticipated enhancement of fullness feelings (van Kleef and others 2012). Reformulation should therefore pursue sensory characteristics, not only so that the new products will appeal more to consumers but also so that they will elicit higher expectations of satiety which may help people control their energy intake and weight. Food contributes satiating power by a number of mediating processes that can be classified as sensory, cognitive, postingestive, and postabsorptive. These processes that result from the effects of food on physiological, and biochemical mechanism have collectively been referred to as the Satiety Cascade. The Satiety Cascade shows that satiation and satiety are initially affected by sensory and cognitive factors, including expectations about what is to be consumed, the taste, texture, and smell of the food or drink and any associations with previous experience that arise (Fiszman and Tarrega 2017). These beliefs are important in appetite regulation, because some pieces of evidence have emerged which suggest that satiety expectations can influence the actual post-consumption experience of satiety (Cassady and others 2012; Wilkinson and others 2012).

In this study, the addition of a strawberry flavoring was also investigated. A number of studies investigated how changes in flavor can modulate the perception of other sensory sensations and liking; however, how these changes affect the elicitation of expectations of satiety has scarcely been studied. Consequently, the aims of this work were to study: (a) how enrichment with soluble fibers and protein affects the dynamic perception profiles of a strawberry-and-milk-based shake; and (b) how the addition of a strawberry flavoring agent further affects these profiles. The relationship between the changes in the formulation and the dynamic perception of sensations, consumer liking, and the expectation of satiety of the product was investigated.

Materials and Methods

Sample composition and preparation

Three batches of strawberry milkshake were prepared: a control formulation (sample compared to the control [CON]), a fiber-enriched formulation (sample FIB), and a protein-enriched formulation (sample PRO). Sample CON was made of 2 parts of natural strawberry purée provided by Fruselva (Barcelona, Spain) and 1 part of mineral water (Bezoya, Segovia, Spain, v/v), to which skimmed milk powder (6 g/100 mL, La Asturiana, Spain) and a commercial intense artificial sweetener (0.2 g/100 mL sodium cyclamate plus sodium saccharin, Hacendado, Spain) were added.

For sample FIB, 3 g of fiber were added per 100 mL of sample CON. The fiber was a 5:3 w/w mixture of inulin and oligofructose (Frutafit CLR and Frutalose OFP, respectively; Sensus, Roosendaal, The Netherlands). The proportion had been taking from a previous study (Cassani and others 2017). For sample PRO, the skimmed milk powder was increased to 18 g/100 mL to achieve 6 g of protein per 100 mL of milkshake.

All 3 strawberry milkshake batches (CON, FIB, and PRO) were divided into 2 parts and 0.5 mL/100 mL of artificial strawberry flavoring (10569A, Lucta, Barcelona, Spain) was added to one part, giving samples CON+Flav, FIB+Flav, and PRO+Flav, respectively. The samples were all prepared and kept under refrigeration on the day before testing.

Table 1–Description of the sensory sensations evaluated by temporal dominance of sensations.

Sensation	Description
Acid	Basic taste of acidity
Sweet	Basic taste of sweetness
Natural strawberry flavor	Flavor found in fresh strawberries
Candy strawberry flavor	Flavor as found in strawberry candies
Milk flavor	Flavor found in milk
Thick	Heavy consistency in the mouth

Temporal dominance of sensations

Sixteen participants (14 women and 2 men) who had previous experience in sensory descriptive evaluation and TDS technique were recruited from the IATA staff.

Three preliminary sessions were conducted. In the 1st session, the participants had to list all the in-mouth sensations they felt while tasting the 6 samples (CON, FIB, PRO, CON+Flav, FIB+Flav, and PRO+Flav). The sensations obtained were related to flavor and texture. Sixteen terms were generated. In the 2nd session, the most relevant sensations for characterizing the samples and the common vocabulary to describe them were reached by consensus among the participants (Table 1). The 6 sensations selected were sweet, acid, natural strawberry flavor, candy strawberry flavor, milk flavor, and thick. In the 3rd session, the participants were introduced to the concept of the dominance of a sensation at a given time during the consumption of a food product. They were able to understand the sequential appearance of sensations and dominant concepts, and performed simulated TDS runs with several strawberry milkshake samples in order to get used to the computer program and methodology.

Subsequently, TDS evaluation of the samples was performed in duplicate on different days. The participants were instructed to drink the sample (15 mL of milkshake served at 10 °C in a small plastic cup) in a single sip and simultaneously start the software by clicking on the "Start" button. Immediately, they selected which of the sensations displayed on the screen was dominant by clicking on it. Each time the participants felt a change in perception and that a new sensation appeared as the dominant one, they clicked the button corresponding to the new dominant sensation. Participants were told they did not have to use all the sensations in the list and were free to select any sensation several times. The evaluation continued until the participants had swallowed the sample completely and perceived no new sensations, at which point they clicked the "Stop" button. Each participant's individual evaluation time for each sample was calculated as the mean evaluation time for the 2 replicates. The 2 straight lines in the TDS graphs (Figure 1) show the "chance level" (the dominance rate that an sensation could have by chance) and the "significance level" (the minimum value for the dominance rate to be considered significant). Data

Figure 1–TDS curves obtained for the different strawberry milkshakes. (- - -) Acid; (...) natural strawberry flavor; (_) milk flavor; (_) thick; (_) candy strawberry flavor; and (_ _) sweet. Straight lines: (---) significance level; (– – –) chance level.

collection was performed using a computerized system: Fizz® (Biosystemes, Courtenon, France).

Assessments of liking and expected satiety

Liking and expected satiety were assessed by 99 consumers recruited form staff and students of IATA (69 women and 30 men, aged between 19 and 57 y). The 6 strawberry milkshake were coded with 3-digit numbers. After tasting 1 sip each sample, the consumers were asked to rate their liking of the samples on a 9-point hedonic scale ranging from 1 ("dislike extremely") to 9 ("like extremely"). Afterwards, they were asked to rate how satiating each milkshake was on a 7-point scale ranging from 1 ("It would fill me very little") to 7 ("It would fill me a lot"). They performed this task after being asked the following question: "Imagine drinking

a whole glass of this milkshake. Please taste it. How full do you think it would make you feel?" (a 200-mL capacity plastic glass was presented to the participants for size estimation purposes).

The evaluations were carried out in a standardized test room (ISO 2007). The samples (20 nL) were served in white small plastic cups (30 mL capacity) with random 3-digit codes, and were presented monadically following a balanced design. Mineral water was provided for the consumers to rinse their mouths between samples. Data acquisition was carried out with Compusense Cloud® software (Compusense Inc., Guelph, Ont., Canada)

All experiments were performed in compliance with the national legislation, and according to the institutional frame-work and practices established by the CSIC Ethics Committee. All participants received written information about the study before giving their informed consent.

Statistical analysis

To study the arousal and duration of each of the 6 sensations studied over the time of evaluation across the participants TDS curves were constructed for each sample. For this analysis, the dominant sensations chosen and the times when each of them began and finished were collected for each participant run. As the duration of the TDS evaluation (until swallowing was complete and no more sensations were perceived) was different from one participant to another, the data were normalized by adjusting them according to each participant's consumption time (left-right standardization). Finally, the TDS curves were computed according to the method described by Pineau and others (2009).

To study the effect of the addition of flavoring and composition on the overall liking and expected satiating capacity scores a mixed ANOVA was performed, taking into account the type of formulation (CON, FIB, and PRO), the addition (or not) of the flavoring (Flav), and their interaction, as fixed factors, and the consumers as the random factor. Tukey's HSD tests were used to analyze significant differences between the samples. XLStat version 2016 software (Addinsoft, France) was used for all the analyses.

Results and Discussion

Temporal dominance of sensations

The mean values of the time of evaluation ranged from 20.7 to 21.7 s that were not significantly different ($P < 0.05$) across samples. Figure 1 shows the TDS curves corresponding to the 6 milkshake samples.

Sample CON. Two major sensations dominated over the CON evaluation time. The TDS curve for this sample shows that *Acid* was a significantly dominant sensation both at the beginning and towards the end of the evaluation, and also exceeded the chance level throughout the evaluation time. Santos Gonçalves and others (2017) also found acid as the dominant sensation throughout the TDS evaluation of strawberry pulp subjected to pasteurization and different freezing methods, but in their case no sugar or intense sweetener were added to the samples. The other significant sensation in this sample was natural strawberry flavor, which also dominated during almost the entire evaluation time, alternating with acid, especially over the 1st half of the time. sweet, thick, and candy strawberry flavor made a timid (but over the chance limit) appearance at the beginning of the last 3rd of the consumption time.

FIB. In this sample, acid and natural strawberry flavor also dominated the evaluation time, although at lower dominance rate values than in sample CON. It seemed that the addition of soluble fiber had attenuated the perception of these 2 sensations. The dominance of the natural strawberry flavor in the 2nd half of the evaluation time appeared more significantly in this sample than in sample CON. The milk flavor dominance rate was over the chance level during almost all the evaluation time and thick also presented values over the chance level, especially during the 1st 3rd of the evaluation time. Villegas and others (2010) reported that different levels of inulin could vary the physicochemical and sensory properties of vanilla-flavored beverages, mainly as regards sweetness and thickness. In this case, it was obvious that the addition of soluble fiber modified the perceptual profiles: milk flavor increased its dominance rate, exceeding the chance level, probably due to the perception of a more dominant thick sensation. From this point of view, inulin has been shown to improve texture sensations considerably (creaminess, mouthfeel, and smoothness) when used to replace fat in low-fat yogurts (Kip and others 2006; Modzelewska-Kapitula and Klebukowska 2009). According to Alimi and others (2013), inulin addition levels of around 5 / 100 g contribute a creamy texture and create a mouthfeel that can be used to reinforce the mouthfeel lost as a consequence of sugar or fat reduction.

PRO. This sample presented a completely different temporal profile from those described for samples CON and FIB. The milk flavor sensation dominated significantly throughout the whole evaluation period, whereas thick dominated at the beginning and during the central evaluation time, and presented dominance rate values that were over the chance level for the entire period. The skimmed milk powder added for protein enrichment logically contributed to enhancing the thickness and, of course, the milk flavor, which dominated more than other flavor notes such as acid or natural strawberry flavor. A sweet sensation was the only sensation that also presented dominance rate values exceeding the chance level (although not at the significance level) over several periods during the evaluation. As in the case of soluble fiber addition (sample FIB), the addition of milk powder to sample PRO changed its temporal flavor profile. At this point it is important to remember that the TDS method is not a matter of intensity but of dominance of the sensations.

Control with flavoring (sample CON+Flav). Adding the strawberry flavoring agent to the CON sample formulation induced some changes in its sensory profile. natural strawberry flavor was no longer significantly dominant at any instant of the evaluation time, although its dominance rate value exceeded the chance level, as did candy strawberry flavor. This implies that consumers selected one strawberry flavor or the other interchangeably. With respect to acid, this sensation continued to be dominant, to a lesser extent, at the beginning of the evaluation time, but had a higher dominance rate at the end of the evaluation than in sample CON. Therefore, the addition of the flavoring had an important impact throughout the consumption period, allowing a lower dominance of the perception of acid notes at the beginning of the evaluation, and the occurrence of candy strawberry flavor dominance over natural strawberry flavor, resulting in a more complex profile. The occurrence of sweet, milk flavor, and thick sensation dominance did not change due to the addition of flavoring. Working with binary basic taste mixtures, Kawasaki and others (2015) found that the dominance rate and duration time of one basic taste modality are significantly affected by a coexisting taste modality, and its details depend on the combination of modalities. This may suggest sensory competition between 2 taste modalities based on several factors that occur during taste mixture consumption.

FBI with flavoring (FIB+Flav). The addition of flavoring to the FIB sample again attenuated the dominance of acid throughout the evaluation time, as in the case of the CON samples. Candy strawberry flavor presented higher dominance rate values, exceeding the chance level for almost the whole evaluation time, and even reaching a significant dominance around the 1st 3rd and 1st half of the consumption period. Sweet, thick, and milk flavor sensations also exceeded the chance level at several points in the evaluation time, with higher dominance rate values than those found for sample FIB, which again shows that the addition of flavoring can produce a much more complex dynamic profile of sensations. In this case, the addition of both soluble fiber and flavoring resulted in a complete dimming of the natural strawberry flavor, which remained below the chance level throughout the evaluation period.

PRO with flavoring (PRO+Flav). The addition of flavoring to sample PRO induced very interesting changes in the temporal sensory profile. As in sample PRO, PRO+Flav presented a dominance of thick at the beginning and during the central evaluation time, remaining over the chance limit through to 70% of the evaluation time, whereas milk flavor lost its salience and was significantly dominant only at the end of the evaluation time (from 80% onward). PRO+Flav was the only sample in which the sweet sensation was perceived as significantly dominant, appearing from 15% to 50% of the evaluation period and then again from 65% until the end. Acid remained below the chance level over the whole evaluation time (as in sample pro), and both natural strawberry flavor and candy strawberry flavor also had very low dominance rates.

Consumer liking assessment

Figure 2 shows the mean liking scores. ANOVA showed that formulation ($P < 0.001$), flavor (<0.001), and their interaction ($P = 0.037$) had significant effects on liking scores.

In the samples with no addition of flavoring, the order of the liking scores was as follows: FIB >CON> PRO. CON, the mean liking score for sample FIB was significantly higher, and that for sample PRO significantly lower. This trend indicated that consumers preferred an intermediate perception between the dominance of the acid/natural strawberry flavor and milk/thick pairs of sensations. Sample FIB showed lower dominance of the former pair and higher dominance of the latter, compared to CON. As commented above, the addition of soluble fiber seemed somewhat to increase the perception of milk flavor and thick (both sensations exceeded the chance level during some periods of time), and probably contributed a flavor profile without the sharp, salient sensation occurrence found in samples CON and PRO.

The same trend in liking scores was found for the samples with added flavoring: FIB+Flav>CON+Flav>PRO+Flav. In this case, only sample FIB+Flav showed a significantly higher liking value than sample PRO+Flav. The significant interaction found by the ANOVA indicated that the effect of the flavoring depended on the formulation. Although the liking scores for each individual sample increased with the addition of flavoring, the only one that increased its liking score significantly, compared with its counterpart without flavoring, was sample PRO+Flav.

Looking at the TDS curves (Figure 1), adding the flavoring to samples CON and PRO lowered the dominance of the above-mentioned pairs of highly dominant sensations (acid/natural strawberry and milk/thick, respectively), indicating that consumers preferred samples with more complex but flatter sensory profiles, where a number of flavor notes could be perceived without any salient dominance. It is worth noting that the addition of flavoring did not increase the dominance of any strawberry flavor but did decrease the dominance of other sensations, the only exception being the acid final taste in both CON samples.

The highest liking scores corresponded to the FIB and FIB+Flav samples, where the addition of soluble fiber, inulin, and oligofructose increased the liking scores compared to CON. In accordance with these findings, a review by Nair and others (2010) found that when inulin was added at low concentrations to plain unsweetened yogurt in a consumer study, the sample containing inulin was preferred over those without inulin, because of its slightly sweet flavor and creamier appearance. In addition, oligofrutosaccharides have been shown to mask the aftertaste of aspartame and acesulfame *K*, as well as providing a well-rounded flavor profile (Weidmann and Jager 1997).

It is very well known that conventional static sensory techniques (like quantitative descriptive analysis) provide very detailed, consistent, and reproducible results (Varela and Ares 2014); however, in this study, the temporal dimension of the sensory perception using the TDS dynamic technique contributed new insight that would be key to new product development. It has been shown that subtle changes in product formulation had an effect on the arousal and duration of the key product sensory sensations.

Evaluation of consumer expectations of satiety

Figure 2 shows the mean expected satiety scores. ANOVA showed that formulation ($P < 0.001$) and flavor ($P < 0.001$) both had significant effects on expected satiety values, although the effect of their interaction was not significant ($P = 0.56$).

To test if the expectation of satiety measures changed over the course of all 6 samples, the effect of the order of presentation of samples was analyzed and no significant effect was found. The type of formulation significantly affected the expected satiety scoring, in the following order: PRO>FIB>CON and PRO+Flav>FIB+Flav>CON+Flav (Figure 2). Both PRO samples (with and without flavoring) presented significantly higher expected satiety than the corresponding CON samples. Satiety expectations come mainly from previous eating experiences and the degree of satiety occurring after the ingestion of similar food items (Brunstrom and others 2008). In the literature it is widely reported that thickness increases expected satiety. For example, McCrickerd, Chambers, Brunstrom, and Yeomans (2014) demonstrated that varying the viscosity of drinks, using thickening agents, modified the expected satiation, and satiety ratings even when the perceived differences in thickness were relatively subtle. Thus, it is not surprising that both the PRO samples, which were perceived as dominantly thick (Figure 1), scored the highest expected satiety values, because the consumers would associate their perception of these samples with known metabolic consequences.

Incorporating the flavoring agent into each of the basic samples (CON+Flav, FIB+Flav, and PRO+Flav) increased the expected satiety compared to the corresponding basic formulation. The expected satiety of sample FIB was not significantly different from that of sample CON, but the addition of flavoring increased the expected satiety of sample FIB+Flav, which achieved a significantly higher value than sample CON (Figure 2).

The composition of sample PRO is nearer to that of commercial strawberry milkshakes, which are normally milk-based and artificially thickened. One possible explanation is that consumers found these beverages more familiar, which is also related to increases in expected satiety. Conversely, samples CON and FIB contained less milk and were perceived as thinner.

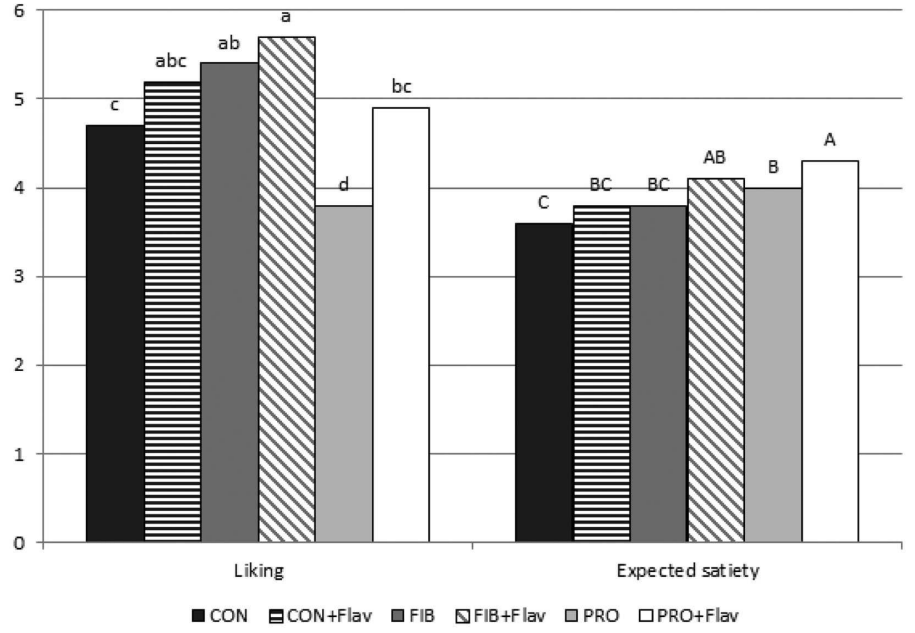

Figure 2–Mean values ($n = 99$) of liking and expected satiety scores for the different shake formulations. Different lowercase letters indicate significant differences in liking ($P < 0.05$) between samples; different bold letters indicate significant differences in expectation of satiety ($P < 0.05$) between samples. CON, control formulation; FIB, fiber-enriched formulation; PRO, protein-enriched formulation; Flav, Strawberry flavoring agent.

In the same way, Yeomans and Boakes (2016) found that odors that had been paired with a thick/creamy sensation in the mouth increased both expected satiety and expected satiation, and predicted that the presence of odors which generate an expectation that a product will be more filling could also act to enhance satiety. In this study, as commercial strawberry milkshakes normally contain an added artificial strawberry flavor, it could be well possible that the odor/ taste of the flavoring may have transferred higher expected satiety to all the flavored samples.

Combination of temporal techniques and hedonics suggests further future research on the preferences of the consumers regarding the order of arousal and dominance of certain sensory sensations over consumption time. In particular, these temporal studies could aid industry to develop functional food products with enhanced expectations of satiety; one important goal would be to construct "ideal" temporal curves for the key attributes linked to those expectations.

Conclusions

This study has highlighted that in the reformulation of beverages for enhanced nutritional and filling properties, not only changes in composition but also small additions of flavoring may have important consequences for the final product. Both the dynamics of the dominance of key sensory features and liking may be modified and this, in turn, may affect the perception of expectations of the food product satiety.

Specifically, this study has shown that additions of soluble fiber, protein, and flavoring brought about significant changes in the dynamic sensory profile of strawberry shakes. The addition of fiber attenuated the dominance of the acid/natural strawberry flavor pair in the control sample, whereas the addition of protein created a completely new dynamic sensory profile dominated by thick and milk flavor. The addition of flavoring produced more complex but flatter profiles in general in all the samples. From this point of view, TDS provided a holistic view of the sensory impact on consumption of the samples, which might influence the consumers' judgments.

Liking scores also proved to be dependent on composition, as they were higher for samples with soluble fiber. The addition of flavoring had a similar effect, creating more complex profiles without salient dominant sensations. As anticipated, expected satiety was strongly linked to perceived thickness in both of the samples that contained higher levels of milk protein.

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Authors' Contributions

A. Tarrega, S. Fiszman, and M.R. Moreira designed the study and interpreted the results. B. Tomadori collected test data and drafted the manuscript.

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