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Flash Profile method, is it suitable for complex multi-layered products? Application to strawberry-filled biscuits: a “SWEET project”

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ABSTRACT

Composite foods are consumed daily, but understanding their sensory properties is a major challenge. This study aims to evaluate the efficiency of Flash Profile (FP) method to characterize strawberry-filled biscuits properties, in a context of sugar reduction. Investigations were carried out on fillings (with/without added sugar, with/without strawberry aroma), then biscuits (with sugar or maltitol or sorbitol, with/without vanilla aroma) and finally on the complex fruit-filled biscuits, corresponding to a progressive matrix complexification strategy.

FP allowed a discrimination of the products for the 3 matrices according to their formulation and flavouring. Fruit fillings and biscuits were described with both flavour and texture attributes, whereas fruit-filled biscuits were mainly described with texture attributes. This texture predominance could result from complex changes of texture perceived during chewing. Panellists may also have focused on the first perceived characteristics or on the product’s most distinguishing features to ease the task.

FP was efficient to discriminate samples in each set of samples according to formulation. The characteristics allowing differentiation between samples varied depending on the matrix. Flavour attributes were mainly used for fluid matrices while texture was dominant for solid matrices. In our study, all panellists evaluated the 3 sets of products in the same order which could have influence their evaluation of complex products during the last session. Further investigations about the evaluation of complex solid products with FP may determine if texture is always dominant, even with a lower number of products.

1. Introduction

Diet is largely identified as one of the main factors affecting the health status of the population (World Health Organization, 2003). The increase of non-communicable diseases such as obesity and diabetes has led public authorities to define recommendations on sugar consumption (World Health Organization, 2015). To meet these recommendations and improve the nutritional quality of products, different strategies have been developed to reduce the sugar content of food products without affecting their organoleptic quality.

Sugar-reduction strategies need to be adapted to the food matrix. Complete removal and partial reductions are efficient, but these strategies modify the ingredients ratios and may lead in some cases to higher energy values. Moreover, when sugar technological properties are essential to the product final qualities (such as jams, confectionery or biscuits), it is difficult to find alternatives. The substitution strategy can then help maintain technological functionality and consumer acceptance, especially regarding texture. The combination of a bulking agent and high-intensity sweeteners or the use of a sweet bulking agent enables sugar to be physically replaced in the formulation while maintaining a sweet taste (Sahin et al., 2019; Zhao et al., 2024). Other strategies can be used to enhance sweetness perception, such as

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inhomogeneous sugar distribution and modification of sugar granulometry to increase sweetness perception by a discontinue stimulation of the sweet taste receptors (Caporizzi et al., 2021; Dadalı & Elmacı, 2021; Zhao et al., 2024).

When eating, taste receptors are activated by non-volatile chemicals in the mouth while olfactory receptors are activated by volatile compounds in the olfactory epithelium (Zhang et al., 2023). The brain integrates all this information simultaneously, leading to sensory modification called interactions that can be used to increase the sweetness perception in sweet-reduced products. The efficiency of cross-modal interactions, such as aroma-taste interaction or aroma-texture-taste interactions are dependent on the matrix, the sugar concentration and the type of aroma but also the consumer's sensory history. Odour-induced sweetness is more efficient in solution with low or medium sugar concentration than in solution with high sugar concentration (Zhang et al., 2023). Moreover, the type of aroma has to be congruent with the taste to enhance it. In cereal sweet products such as muffins and cookies, vanilla and strawberry aromas were particularly efficient to increase the sweet taste (Zhang et al., 2023) and compensate for sweetness loss after sugar reduction. Aroma-taste interactions thus constitute a simple and easy way to slightly enhance sweetness of bakery products.

Texturally complex food represents a wide range of products including, chocolate bars with caramel and nuts, bread with grains, ice creams with crunchy biscuits, pizza and so on. Such products are highly appreciated by consumers as they provide various stimulation in texture and flavour during consumption (Patterson et al., 2023). Among all the food products, biscuits and cakes represent an important category of texturally complex foods. Fruit pieces, chocolate chunks, nuts, fillings and other inclusions are widely used to enhance the flavour and texture of biscuits and cakes. Texture and flavour variations perceived during mastication implies intra-oral discontinuities which may prevent weariness and enhance product palatability (Santagiuliana et al., 2019) as well as increase satiety, limiting the overall food intake (Patterson et al., 2023). Although texturally complex foods are widely present in our daily diet, most studies are conducted on model or simple matrices due to the complexity of such products.

The Flash Profile (FP) method combines the Free Choice Profiling (FCP) principles with a relative ranking of products for each attribute. Untrained subjects generate their own attributes to describe and evaluate a set of products simultaneously, and then rank the products for each attribute that they individually select. This method enables a quick and easy assessment of the most discriminating characteristics of the products (Dairou & Sieffermann, 2002). Flash Profile requires little to moderate training of the panel and offers freedom of sensory language, since each individual chooses his or her own terminology. Even for panellists with little training, Flash profile generally requires fewer panellists, as compared to other rapid descriptive methods like CATA, free sorting or napping (Varela & Ares, 2012). Moreover, when used with the same number of panellists, flash profile have been proven to give higher discriminating power than napping and free multiple sorting (Dehlholm et al., 2012). This makes Flash profile an interesting approach for R&D environment that usually have to deal with a lot of budget and time restrictions when developing food products.

FP has been shown to effectively differentiate sensory attributes in cookies, especially when comparing products made with different types of flours (De Castro et al., 2022). FP enabled clear discrimination of sensory differences such as aspect, texture and flavour among cookies. FP has been applied to the differentiation and characterization of various food matrices such as dairy products, baked goods, meats, and beverages, but, to our knowledge, never to composite food products.

Indeed, sensory analysis of complex food is a difficult task due to the various sensations perceived in the mouth during mastication. Several methods have already been applied to describe composite food. Rate-all-that apply (RATA) consists in selecting the attributes which are appropriate to describe a product and to rate their intensity on a scale (Ares et al., 2014). RATA has been successfully applied for the evaluation of cheeses with pepper bell pieces (Santagiuliana et al., 2019) and pectin-based gels with inserts (Patterson et al., 2023). RATA is a static, simple and rapid methodology that doesn't require panel training, as FP. Our study aims to explore three sets of products and intends to capture the spontaneous perceptions of panellists to describe them, particularly for complex food. As the RATA method imposes a limited list of attributes, if attributes are missing in the list, these perceptions will not be captured in the results, contrary to FP which allows panellists to generate their own descriptors, enabling the identification of unique or unexpected sensory attributes (Kim et al., 2023). As chewing is a dynamic process, temporal sensory methods have been used to explore sensory complexity. Among all, Temporal Dominance of Sensations (TDS) is one of the most used methods to evaluate products with complex textures. TDS describes the evolution of the dominant sensory perceptions during the consumption of a food product (Pineau et al., 2009). Another method based on an adaptation of the sequential profiling method was developed by Palczak et al. (2019) to study bi-layered desserts. In this method, trained panellists had to evaluate five sensory attributes for each spoonful just after swallowing. To mimic the total consumption of a real bi-layered fresh dairy dessert, ten spoonfuls were proposed to the panellists with an evolution of the amount of each layer in the spoonful all along the test. This method showed a link between perceived complexity of bi-layered dairy dessert and the richness of sensations perceived. Our study focuses on the discrimination of close samples. To reach this aim, FP seems better suited than dynamic methods. Moreover, considering the number of products to evaluate, dynamic methods may be too time-consuming. Analysing texturally complex product in order to understand the perception during food consumption is a great challenge. Static or dynamic sensory methods could be adapted to reach this aim, but the selection of the sensory method depends on various factors such as panellist training, time available, number of products and so on.

In this case study, Flash Profile was used to assess the impact of sugar reduction strategy on the sensory properties of strawberry-filled biscuits. This work was part of the SWEET project (Sweeteners and sweetness enhancers: Impact on health, obesity, safety and sustainability, www.sweetproject.eu) focused on the nutritional impact of sweeteners in medium-term human intervention trials (Gibbons et al., 2022, 2024).

To our knowledge, Flash Profile has not yet been applied to study complex solid food although it is simple, fast and does not require panel training. To evaluate its accuracy to analyse composite biscuits, it was used on separate components namely the strawberry fruit filling, the biscuit; and then on the sandwich biscuit. To determine if product complexification may impact sweetness or aroma of these products, three types of biscuits (with sugar, maltitol, or sorbitol) and two types of fruit-filling (with sugar, non-added sugar) were studied. Previous work have shown that maltitol and sorbitol can advantageously replace sugar in biscuits although they have a lower sweetening power which is perceived by consumers during hedonic evaluation (Roze et al., 2021). As the use of congruent flavours has been shown to enhance sweetness perceptions in several products (Zhang et al., 2023), the impact of odour-taste interactions was also studied with the addition of vanilla flavour in the biscuit and strawberry flavour in the fruit filling.

2. Materials and methods

2.1. Sample production

2.1.1. Fruit fillings

The fillings used in this study were developed with and without added sugars by Fruinov (Collonges-la-Rouge, France) according to the formulas presented in Table 1. They were prepared in a tank under partial vacuum to evaporate around 30 % water. The two fillings have comparable technological characteristics: 80 ± 2°B, pH = 3.50 ± 0.2 and $a_w = 0.50 \pm 0.03$.

Table 1
Strawberry fillings formulations with (STD) and without added sugars (NAS).

g/100 g	STD	NAS
Glucose-Fructose syrup	58	–
Fructo-oligosaccharides	–	59
Maltitol	–	20
Sucrose	20	–
Fruit filling mix: strawberry puree, glycerol, citric acid, pectins, natural colouring and natural flavouring	53	53
Evaporated water	−31	−32

Strawberry flavours were kindly provided by V. Mane Fils (Le Bar-sur-Loup, France). Propylene glycol was used as flavour carrier as it does not impact the sugar content of the products. The flavour was added to the cooled filling after manufacturing by manual mixing 4 days before each sensory analysis, according to a dosing plan (Table 2). In order to guarantee a precise concentration, the flavour was first mixed into 15 g of filling before being diluted with the remaining filling according to the quantity required for each sensory evaluation. An intermediate dosage of unflavoured propylene glycol (PG) was used for the control products to ensure a close composition of all the samples. Fruit fillings were stored at +4 °C prior to sensory evaluation.

The day before the sensory evaluation, the filling samples were packaged in clear plastic cups with lids at a dosage of 20 g per cup and kept at 20 °C protected from light.

2.1.2. Biscuits

The biscuits were produced using the formulations shown in Table 3. Butter (Président, Laval, France), baking powders (sodium acid pyrophosphate (Budenheim, Budenheim, Germany), sodium bicarbonate, (Brenntag, Saint-Herblain, France) and sweeteners, either sucrose (Beghin Say-Tereos, Nantes, France), maltitol or sorbitol (Louis Francois, France), were mixed with water in a VMI BV422 mixer (VMI, Montaigu, France) at 62 rpm for 1 min and then at 124 rpm for 2 min. The flour (Evelia-Terrena Meunerie, Andrezé, France) was added next and the mixture was mixed again at 62 rpm for 1 min, then at 124 rpm for 2 min. The dough was left to rest in a controlled chamber for 30 min before moulding (30 °C, 85 % RH). Using a Padovani R2 rotary machine (Padovani, Rovigo, Italy), the dough pieces were formed into round pieces with a diameter of 60 mm and a thickness of 4 mm. For each condition, 240 biscuits were baked in a Bongard Premio convection oven (Bongard, Holtzheim, France) for 9 min at 210 °C and then thermised in a Miwe Condo deck oven (MIWE, Sarreguemines, France) at 92 °C for 10 min to prevent any spontaneous cracking. The biscuits were then left to cool for 2 h and packed in sealed plastic bags (Penta 4200ts, Comezzano Cizzago, Italy).

The biscuits were flavoured with vanilla flavouring (V. Mane Fils, Le Bar-sur-Loup, France) at two different dosages except the control ones. As for fillings, unflavoured propylene glycol was used as flavouring carrier (Sigma-Aldrich Chimie, Saint-Quentin-Fallavier, France). It was added to the control biscuits in order to have similar compositions of the biscuits and avoid any bias due to its presence in the flavoured biscuits. In order to limit the number of formulations for the control products, an intermediate dosage between the two quantities of propylene glycol contained in the two dosages of vanilla flavouring was chosen. The propylene glycol or vanilla flavour was introduced at the end of the first mixing stage in the manufacturing process.

Biscuits were prepared 7 days before the sensory analysis and stored at 20 °C away from light. Each panellist had one biscuit of each recipe to perform the test.

Table 2
Formulations of strawberry fillings with (STD) and without added sugars (NAS) and unflavoured (PG basis) or strawberry-flavoured (moderate level S1, high level S2).

g/100 g	STD_PG	STD_S1	STD_S2	NAS_PG	NAS_S1	NAS_S2
STD filling	99.775	99.85	99.70	–	–	–
NAS filling	–	–	–	99.775	99.85	99.70
Propylene Glycol (PG)	0.225	–	–	0.225	–	–
Strawberry flavour	–	0.15	0.30	–	0.15	0.30

2.1.3. Fruit-filled biscuits

The day after the biscuits production day, the biscuits were assembled in pairs with the strawberry fillings acting as a binder to obtain the fruit-filled biscuits. Each fruit-filled biscuit contained 7 ± 0.1 g of filling, deposited by hand. Each panellist was provided with a half sandwich biscuit for each reference. To limit sensory fatigue and satiation for the panellists, only 10 of the 27 possible combinations were selected (Table 4). The set includes an unflavoured STD reference and an unflavoured maltitol-based alternative, as a baseline for highlighting the potential effects of flavourings on sweetness perception. Out of the two sugar substitutes used in the study, maltitol is the most commonly used by the food industry for this purpose, hence it was selected over sorbitol. Finally, the eight possible combinations including both biscuit and filling flavourings, were selected. Other combinations involving only one flavouring (either the biscuit or the filling) were not considered, as the results would likely have been redundant with the first two flash profiles.

2.2. Flash Profile sensory analysis

2.2.1. Experimental conditions

All sessions were conducted in a sensory analysis room equipped with individual booths with standardised temperature (23 °C) and lighting (6500 K) (NF EN ISO 8589, 2010). The products were systematically presented in balanced randomised order and anonymised by random 3-digit codes, with no link from one session to the next. The panellists were allowed to re-taste the products as many times as necessary. The panellists could request more samples if necessary during the session.

2.2.2. Panel, screening and training

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Inserm (IRB00003888, IORG0003254, FWA00005831) on July 7th, 2020.

The same panel evaluated the 3 different matrices over the course of the study which took place over a three-week period.

The panel selection included parameters such as exclusion criteria (pregnancy and breastfeeding, health concerns, food and non-food allergies or intolerances, minors), the ability to understand instructions and tasting abilities. To this end, each candidate was asked to taste in random order a series of solutions with varying sucrose concentrations (0, 5.76, 7.20, 12 and 24 g/L) and then to rank them in order of increasing intensity. The same method was applied to a serie of solutions with varying concentrations of strawberry flavour (0, 0.2, 0.4 and 1 g/L). As the study could be sensorially complex given the type of products, only panellists with a faultless score were selected to minimize the noise that could arise with panellists already underperforming at the outset.

The selected panellists were 10 men and 8 women of various age groups (21 % aged 18–25, 53 % aged 26–35, 0 % aged 35–55 and 26 % aged 56–65). All the panellists had already taken part in a sensory analysis panel at least once but not necessarily a Flash Profile one. Panellists were asked not to smoke, drink tea/coffee or eat in the hour before each session. Panellists were given a reward at each session in the form of a beverage or sweets.

2.2.3. Overall Flash Profile process

All panellists evaluated the 3 matrices in the same order: fruit filling, biscuits, fruit-filled biscuits. For each matrix, Flash Profile was

Table 3
Formulations of sucrose (STD), maltitol (MALT) and sorbitol (SORB) unflavoured (PG) and vanilla-flavoured (moderate level V1, high level V2) biscuits.

g/100 g	STD_PG	MALT_PG	MALT_V1	MALT_V2	SORB_PG	SORB_V1	SORB_V2
Wheat flour	63.18	63.18	63.24	63.13	63.18	63.24	63.13
Sucrose	16.27	–	–	–	–	–	–
Maltitol	–	16.27	16.29	16.26	–	–	–
Sorbitol	–	–	–	–	16.27	16.29	16.26
Butter	13.27	13.27	13.28	13.26	13.27	13.28	13.26
Water	6.08	6.08	6.1	6.08	6.08	6.1	6.08
Leavening agents	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Salt	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Vanilla flavouring	–	–	0.19	0.37	–	0.19	0.37
Propylene Glycol	0.28	0.28	–	–	0.28	–	–

Table 4
Formulations of the fruit-filled biscuits selected (X) for the Flash Profile (STD: sucrose; MALT: maltitol; SORB: sorbitol; PG: unflavoured; V1: moderate amount of vanilla flavour; V2: high amount of vanilla flavour; S1: moderate amount of strawberry flavour; S2: high amount of strawberry flavour).

		Biscuits					
		STD	MALT			SORB	
		PG	PG	V1	V2	V1	V2
Fruit-filling	**PG**	X	X	–	–	–	–
	S1	–	–	X	X	X	X
	S2	–	–	X	X	X	X

conducted in two sessions. In the first session, the experimenter explained the entire procedure to the panellists, including the product familiarization and attributes generation phase (session 1) and the product evaluation phase (session 2). The experimenter informed the panellists that the study did not concern the appearance of the products, but only the nasal and palate stimuli, *i.e.* odours, tastes, aromas and textures. Each panellist was provided with the complete set of products simultaneously but was asked to taste the products a first time in the order indicated on the form. In order to avoid carry-over effects between samples, panellists were asked to systematically rinse their mouth between two samples degustation with neutral water (Evian, France) at room temperature. Unsalted unflavoured crackers (Heudebert, LU, France) were also at their disposal if necessary. They could then re-taste the products as many times as necessary, in any order. In this session, each panellist issued a list of terms describing the products and enabling them to at least discriminate them.

As mentioned by Liu et al. (2016), the attribute generation step in FP plays an important role in the quality of the results obtained. In order to help panellists with their list, at the end of the generation phase, the panellists were gathered for a joint discussion led by the experimenters. Experimenters listed all the attributes generated by the panellists and adjusted the terminology of the terms used to limit duplicates. During this discussion, the panellists were invited to re-taste the products, if necessary, to adjust their personal list of attributes as they wished, like finding attributes they might have either neglected or named with difficulty. Hedonic attributes were not selected.

It has been suggested in various settings that modifying the original Flash profile approach was possible to improve the results: reducing the descriptor list size (Liu et al., 2018), providing descriptor definition (Moss et al., 2021) or providing defined descriptors lists (Delarue, 2015). An alternative approach has been proposed as a compromise to keep panellist freedom of choice and help results reliability and elucidation. Two attributes were imposed to all lists by the instructor: sweetness intensity and overall aromatic intensity. Those sensory attributes were selected regarding the product-space, they were most likely to have differences between the samples, have an impact on the overall perception and are congruent with the general purpose of the experiments.

The second session took place the following day or the day after the first one. The experimenter displayed the complete list of attributes generated by the group during the first session and recalled the objectives of the evaluation session. Each panellist was given their personal list of attributes and the complete set of products, but coded and ordered differently from the first session. The experimenter invited each panellist to start the evaluation with the attributes that were most discriminating in their opinion. Ranking was done on an unstructured scale for each attribute, and the panellist could rank several samples at the same level if the intensity was equivalent. If an attribute was not present in a sample, the panellist was asked to place it at the negative end of the scale. At the end of each evaluation session, the panellists were verbally debriefed to obtain their overall qualitative impressions of the method, the difficulty of the set, and the duration of the session.

2.2.4. *Data analysis*

Data were manually collected on spreadsheets at the end of the Flash Profiles. Each dataset was submitted to a Generalized Procrustes Analysis (GPA) (Gower, 1975) to obtain sensory maps with products and attributes. Only attributes cited by at least 2 panellists or which correlate satisfactorily with at least one of the first two principal components ($R > 0.7$) were considered for interpretation. GPA was performed using the Sensory data analysis module of XLStat (Addinsoft, Paris, France).

3. Results

3.1. *Flavoured fruit fillings*

The panellists individually generated between 4 and 9 attributes (on average 6.8 ± 1.8) in addition to the two criteria they were given (sweetness intensity and overall aromatic intensity). In total, the panel selected 34 different attributes. These are presented categorized in 4 modalities in Table 5: taste, odour, aroma, texture. The difference between odour and aroma perceptions had been explained to the panellists. Odour was evaluated when smelling the product (orthonasal perception) whereas aroma was perceived when eating the product (retronasal perception). The panel was explicitly asked not to consider aspect but only what they perceived while smelling and tasting, hence the absence of visual attributes.

Most of the attributes were shared by several panellists. The most recurrent attributes in the panel were acidity (cited by 83 % of the panellists), strawberry odour (61 %), stickiness (44 %), strawberry and red berries aroma (39 % each), chemical aroma (39 %) and chemical odour (33 %). The first axis on the product mapping in Fig. 1 exhibits a very clear distinction between products according to flavour concentration, ranging from S2-type products (high dosage of strawberry flavour) to PG-type products (no flavour). Analysis of the correlations circle of attributes along the first dimension shows the sub-space containing S2 products is associated with attributes of odours and tastes described as chemical, acidic, candy and artificial strawberry (Fig. 2). Although they differ semantically, these terms are grouped together in a small space and probably convey the same idea, however the panellists did not wish to group these different attributes under a common

Table 5
Compilation of attributes used by the 18 panellists for the Flash Profile evaluations of fruit fillings, biscuits and fruit-filled biscuits. Only attributes cited by at least 2 panellists or highly correlated (> 70 %) to one of the two main GPA components are presented. For each attribute, the citation frequency is indicated. The last row corresponds to the total number of attributes used for each matrix and each modality of evaluation. Attributes imposed on panellists are indicated with a *.

Attribute	Fruit filling				Biscuit				Fruit-filled biscuit			
	Odour	Aroma	Taste	Texture	Odour	Aroma	Taste	Texture	Odour	Aroma	Taste	Texture
Odour/Aroma												
Acidic	5	–	–	–	–	–	–	–	–	–	–	–
Aroma intensity*	–	18	–	–	–	18	–	–	–	18	–	–
Artificial_strawberry	1	2	–	–	–	–	–	–	–	–	–	–
Baked	–	–	–	–	3	3	–	–	2	–	–	–
Biscuit	–	–	–	–	3	4	–	–	4	2	–	–
Burnt	–	–	–	–	5	–	–	–	2	–	–	–
Butter	–	–	–	–	6	8	–	–	4	3	–	–
Candy	4	1	–	–	–	–	–	–	–	–	–	–
Caramel	–	–	–	–	4	–	–	–	–	–	–	–
Cereals	–	–	–	–	1	3	–	–	–	3	–	–
Chemical	6	7	–	–	–	–	–	–	–	5	–	–
Citric	1	–	–	–	–	–	–	–	–	–	–	–
Fats	–	–	–	–	–	–	–	–	–	–	–	–
Flour	–	–	–	–	–	6	–	–	–	–	–	–
Fruity	3	1	–	–	–	–	–	–	1	–	–	–
Grilled	–	–	–	–	2	4	–	–	–	5	–	–
Herbaceous	–	1	–	–	–	–	–	–	–	–	–	–
Jam	–	–	–	–	–	–	–	–	–	–	–	–
Lemon	–	1	–	–	–	–	–	–	–	–	–	–
Metal	–	–	–	–	–	–	–	–	–	–	–	–
Milk	–	–	–	–	1	1	–	–	–	–	–	–
Neutral	2	–	–	–	–	–	–	–	–	–	–	–
Odorless	1	–	–	–	3	–	–	–	–	–	–	–
Red_berries	1	7	–	–	–	–	–	–	–	–	–	–
Smoked	–	–	–	–	–	1	–	–	–	–	–	–
Strawberry	10	7	–	–	–	–	–	–	8	13	–	–
Sweet (“doux”)	–	1	–	–	–	–	–	–	–	–	–	–
Tasteless	–	1	–	–	–	2	–	–	–	–	–	–
Vanilla	–	1	–	–	8	8	–	–	7	3	–	–
Taste												
Acidic	–	–	15	–	–	–	–	–	–	–	7	–
Bitter	–	–	5	–	–	–	2	–	–	–	2	–
Bitter_aftertaste	–	1	–	–	–	–	–	–	–	–	–	–
Salty	–	–	–	–	–	–	5	–	–	–	2	–
Sweetness*	–	–	18	–	–	–	18	–	–	–	18	–
Texture												
Brittle	–	–	–	–	–	–	–	4	–	–	–	1
Compactness	–	–	–	2	–	–	–	–	–	–	–	–
Crispy	–	–	–	–	–	–	–	5	–	–	–	3
Crumbly	–	–	–	–	–	–	–	6	–	–	–	4
Crunchy	–	–	–	–	–	–	–	5	–	–	–	6
Dry	–	–	–	–	–	–	–	2	–	–	–	–
Firm	–	–	–	4	–	–	–	–	–	–	–	–
Gelatinous	–	–	–	1	–	–	–	–	–	–	–	–
Grainy	–	–	–	4	–	–	–	2	–	–	–	1
Hard	–	–	–	–	–	–	–	11	–	–	–	9
Mealy	–	–	–	–	–	–	–	3	–	–	–	2
Melting	–	–	–	5	–	–	–	1	–	–	–	–
Moist	–	–	–	–	–	–	–	–	–	–	–	2
Pasty	–	–	–	4	–	–	–	6	–	–	–	4
Powdery	–	–	–	–	–	–	–	2	–	–	–	2
Smooth_coating	–	–	–	–	–	–	–	–	–	–	–	–
Sticky	–	–	–	8	–	–	–	–	–	–	–	–
Viscous	–	–	–	3	–	–	–	–	–	–	–	–
Total of attributes	***10***	***13***	***3***	***8***	***10***	***11***	***3***	***11***	***7***	***8***	***4***	***10***

descriptor during the familiarization step. The ‘aromatic intensity’ attribute is also fairly frequently located in this part of the circle, although iterations can be found in other areas. At the opposite end of the cartography, the sub-area containing PG fillings is associated with a fairly neutral profile. One can assume the panel was more likely to describe flavoured products, since there was a higher concentration of attributes in this sub-space. The second axis also shows a sharp differentiation between products with added sugar (STD) and no added sugars products (NAS). This axis opposes attributes associated with acidity to those linked to sweetness. It seems several panellists also detected differences in texture between NAS and STD products on this axis. Standard products were therefore defined by their sweet and melting character, whereas NAS fillings were more associated with acidity and a pasty, firm and sticky texture.

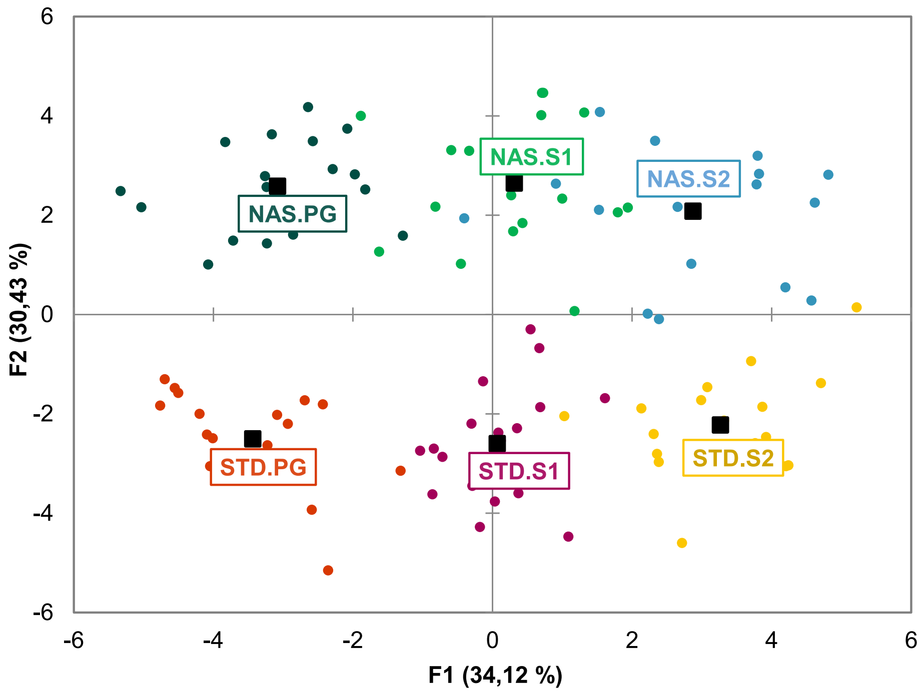

Fig. 1.. Factorial map of unflavoured (PG) and strawberry-flavoured (S1–S2) fillings sweetened with either sugars (STD) or sugar substitutes (NAS) strawberry fillings. Black squares symbols represent the barycentre position of each product.

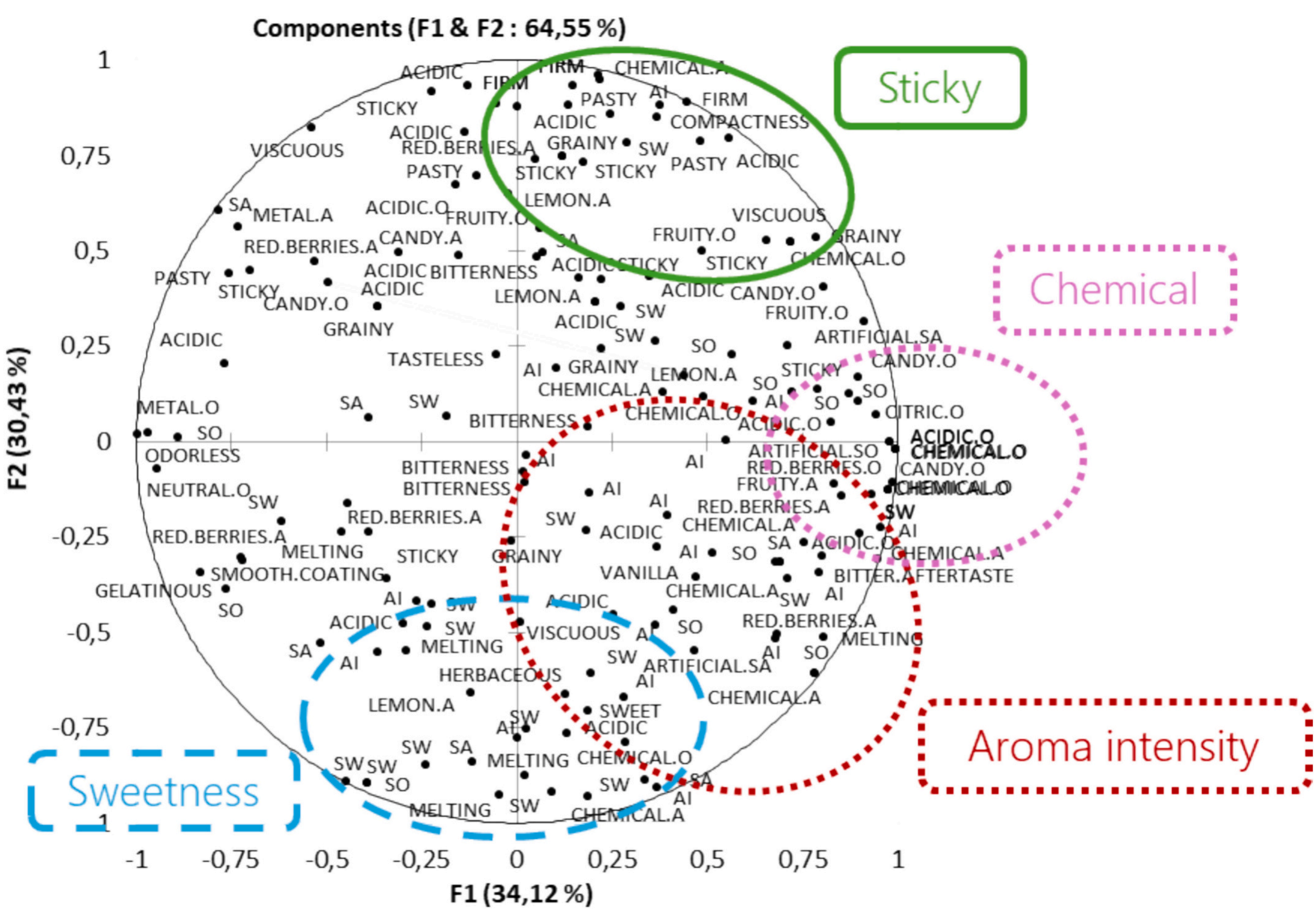

Fig. 2.. Correlation circle from General Procustes Analysis of strawberry fillings *(O: odour, A: aroma, AI: aroma intensity, SW: sweetness, SA: strawberry aroma, SO: strawberry odour).*

3.2. Flavoured biscuits

During the biscuits Flash Profile, the panellists selected between 4 and 13 attributes in addition to the two required (on average 7.7 ± 2). In total, 35 attributes were selected by the panel, of which the majority were shared by several panellists (Table 5). Several attributes were elicited by a single panellist but were correlated by over 70 % with one of the first two dimensions. The choice of attributes was balanced between texture, odour and aroma. The most widely shared attributes were: hard (cited by 61 % of the panellists), buttery aroma (44 %), vanilla aroma (44 %) and vanilla odour (44 %). The first dimension shows a clear discrimination between the sorbitol biscuits on the one hand and the maltitol and control biscuits on the other (Fig. 3). According to Fig. 4, sorbitol biscuits were described as pasty and mealy, lacking in flavour intensity, with a floury or cereal taste. In contrast, maltitol and control biscuits were associated with attributes such as aromatic intensity, hardness, buttery and sweet notes. Sorbitol biscuits seemed to be associated with fewer attributes compared to the other products. The second dimension is less structured, although a slight distinction between flavoured and unflavoured biscuits is exhibited. Flavoured biscuits were located towards attributes associated with vanilla (vanilla odour, vanilla aroma), caramel (caramel odour) and biscuit (biscuit aroma, cereals aroma, baked odour, grilled aroma).

3.3. Flavoured sandwich biscuits

The panellists individually generated between 4 and 10 attributes on this last Flash Profile in addition to the two imposed (on average 6.6 ± 1.8) (Table 5). A total of 29 attributes were chosen, 26 of which were shared by several panellists and 3 of which were elicited by a single panellist but well correlated with one of the two first dimensions. Once again, the attributes are fairly balanced between the different categories. The attributes most shared by the panel were: strawberry aroma (cited by 72 % of the panellists), hard (50 %), strawberry odour (44 %), vanilla odour (39 %), acidity (39 %) and crunchy (33 %). The first dimension of the product map discriminates between maltitol- and sugar-based filled biscuits *versus* sorbitol-based products (Fig. 5). This polarisation of the map by sorbitol products had already been observed in the biscuit Flash Profile on both aromatic and textural attributes. Here, the positioning of maltitol and sucrose biscuits was mostly associated with texture attributes such as hard, crisp, crunchy and brittle, which are positively correlated with this axis and mentioned by many panellists (Fig. 6).

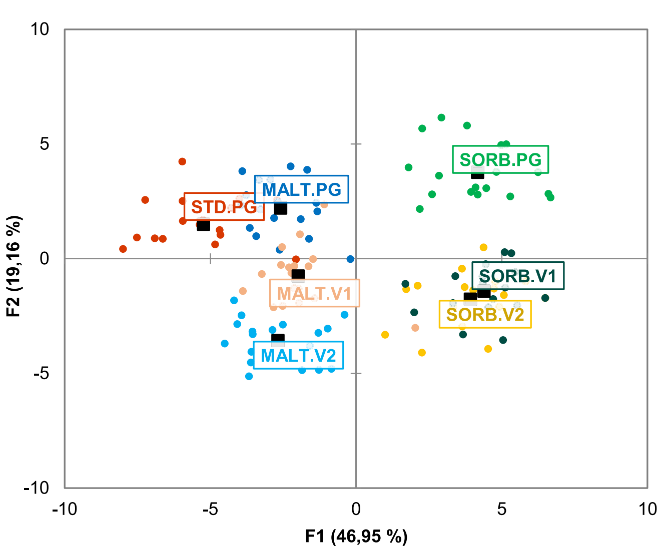

Fig. 3.. Factorial map of unflavoured (PG) and vanilla-flavoured (V1-V2) biscuits sweetened with either sugars (STD) or sugar substitutes (NAS). Black squares symbols represent the barycentre position of each product.

Again, the second dimension is more complex to interpret since no descriptor was categorically associated with this axis. However, aromatic intensity and sweetness intensity attributes were mostly clustered together on this axis. The products positioned in this sub-space were the control (STD_PG), Malt_V1S2, Sorb_V2S1 and Sorb_V2S2.

4. Discussion

The Flash Profile method allowed a discrimination of the products for the 3 types of matrix. In the first Flash Profile (fruit fillings), the panel seemed to be able to identify the differences between the products and find their own distinctions in terms of both formulation (standard *vs* non-added sugar) and flavour concentration (0 *vs* S1 *vs* S2). Biscuits as well were mainly discriminated according to formulation (standard and maltitol *vs* sorbitol) and presence of vanilla aroma (0 *vs* V1, V2). Fruit-filled biscuits were mainly distinguished according to formulation (standard and maltitol *vs* sorbitol). The effect of aromatisation on fruit-filled biscuits varied depending on the formulation. These results highlight the efficiency of the Flash Profile method to discriminate samples even with complex products.

Flavour intensity and sweetness perception were the main attributes responsible for the discrimination of fruit fillings. These two attributes were imposed on panellists in their assessment of products. For these two features, fruit fillings were ranked as expected: the fruit fillings with sugar were perceived sweeter than the non-added-sugars ones and fruit fillings with a high content of strawberry flavour (S2) were considered more aromatic than those with a lower aroma content (S1), which themselves were more aromatic than unflavoured ones. The positions of the different products on the map do not show *a priori* any effect of strawberry flavour on the perception of sweetness, whether for products with or without added sugar. The attributes associated with strawberry flavouring regularly referred to the notion of ‘chemical and artificial odour or flavour’. The chosen strawberry flavour was deliberately extremely simplified in its formulation to limit bias, and it is likely that at high doses (S2), off-notes emerged and were perceived by the panel. Interestingly, panellists also distinguished strawberry fillings by texture, with standard fillings described as melt-in-the-mouth while NAS fillings were described as pasty and sticky. This discrimination is probably the result of the formulation. Although the sugars were substituted in such a way as to achieve the same technological quality criteria (brix, pH, water activity), it is likely that differences persisted in the melting profile of the substitutes when tasted compared with the sugars, in particular on account of the fibres (FOS) which could confer a pasty, sticky consistency, resulting in differences in texture perceptible to the panellists.

Biscuits’ texture was the main characteristic that enabled the discrimination of products. Sorbitol biscuits were clearly separated from the rest of the set of products, described as pasty and floury, whereas standard and maltitol biscuits were hard, crispy and crunchy. These variations can be explained by the differing abilities of the substitutes to delay starch gelatinisation during baking (Roze et al., 2023). The reduced delay induced by sorbitol could promote the gelatinisation of some of the starch during baking, resulting in a more pasty and less crispy texture. Conversely, maltitol causes a delay in starch gelatinisation that is almost equivalent to sugar, resulting in a comparable texture. Flavour attributes were secondary, but still showed that the panel was sensitive to variations in biscuit flavour. Maltitol and standard biscuits were perceived as sweet and aromatic while sorbitol ones were tasteless and mealy. These findings are consistent with our previous work (Roze et al., 2021), which showed in a JAR (Just About Right) test that sorbitol biscuits were perceived as not aromatic or sweet enough. This can be linked to sorbitol’s lower sweetening power and its inability to undergo Maillard reactions that results in less aromatic biscuits. Indeed, the sweetening power of sorbitol is around 0.6, while that of maltitol is 0.85 and that of sucrose is 1. Furthermore, the absence of a reducing function in polyols prevents Maillard reactions from occurring, which usually

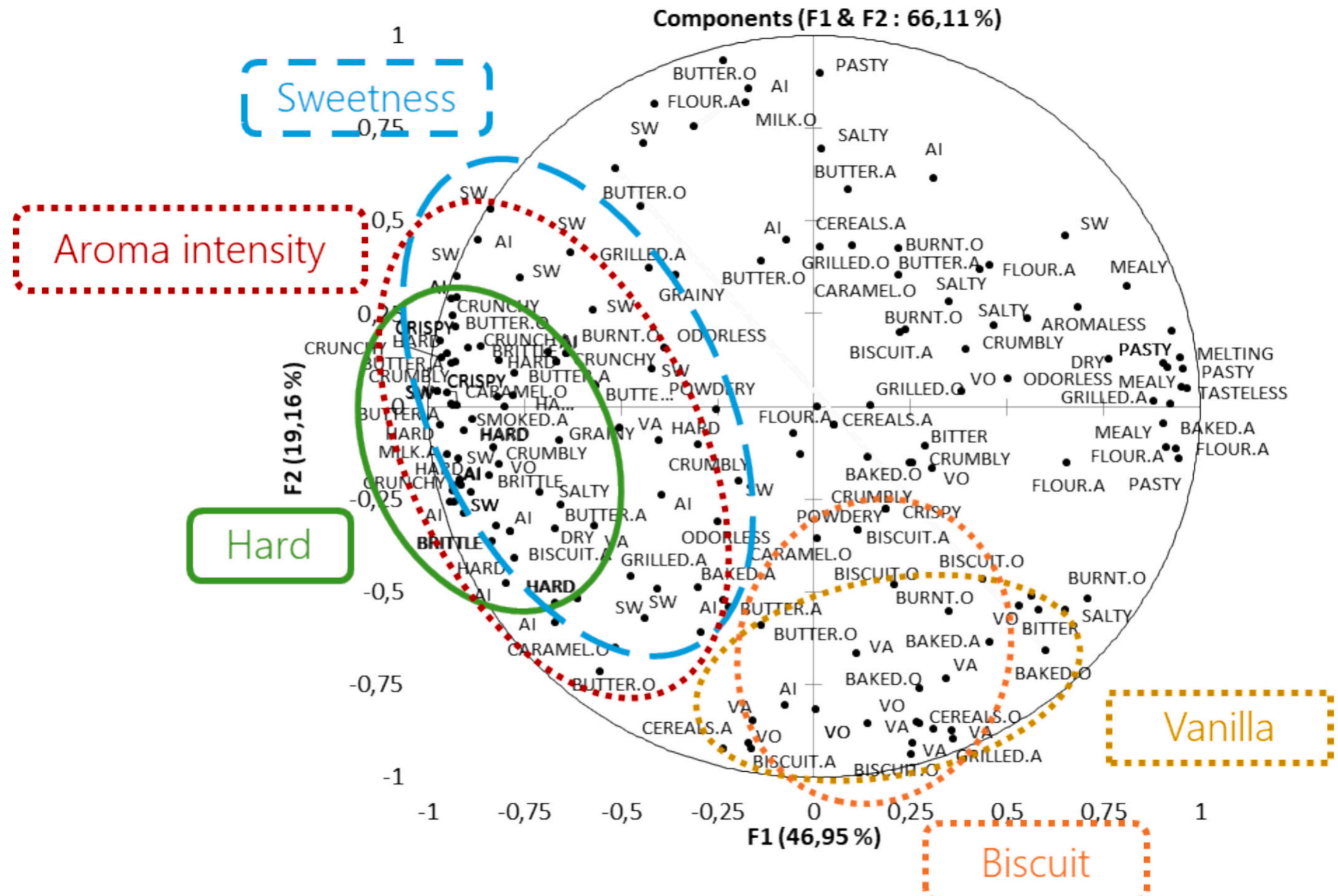

Fig. 4.. Correlation circle from General Procustes Analysis of biscuits *(O: odour, A: aroma, AI: aroma intensity, SW: sweetness, VA: vanilla aroma, VO: vanilla odour).*

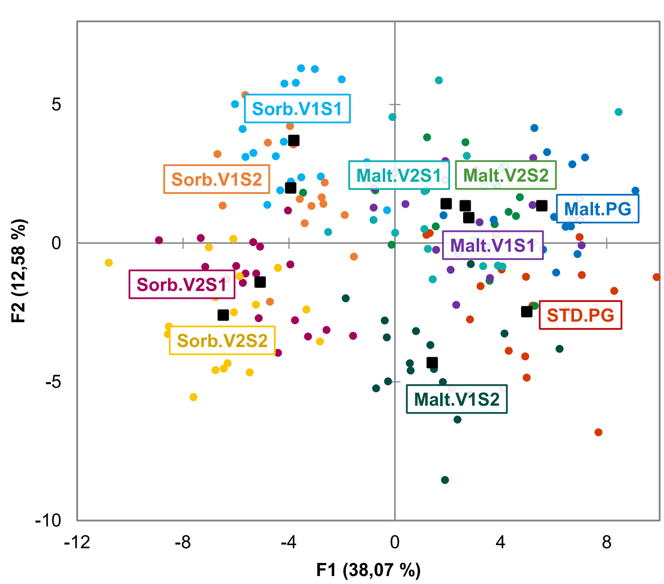

Fig. 5.. Factorial map of standard (STD) and no-added-sugars (NAS) strawberry-filled biscuits. The products were flavoured with different combinations and dosages of vanilla flavouring (V1–V2) in the biscuit and strawberry flavouring (S1–S2) in the filling, PG products were unflavoured. Black squares symbols represent the barycentre position of each product.

contribute significantly to the development of flavours in biscuits. A distinction was quite noticeable with the perception of vanilla flavour. Although less marked than in the Flash Profile on strawberry fillings, a distinction between moderately and strongly flavoured biscuits was made for both the maltitol and sorbitol formulations. However, the Flash Profile did not highlight the impact of vanilla flavour on the perception of sweetness in the biscuits.

The same results were observed for fruit-filled biscuits where texture was the main driver of discrimination. There was a strong consensus on these attributes. It is worth noting that despite the increased difficulty of the test linked to the growing complexity of the samples and their multiplicity, the panellists did not particularly reduce their workload by limiting the number of attributes. This may also result from the growing habituation of the panellists with the method. Odour, aroma and taste attributes seemed less discriminant for these products, despite a distinction along the first axis in the mapping between PG products (unflavoured standard and maltitol sandwich biscuits) and flavoured combinations (V1S1, V2S1, V1S2, V2S2) of maltitol and sorbitol sandwich biscuits.

The use of the own attributes of panellists allows to highlight the evolution of the criteria of description of the products depending on the complexity of the matrix. For fluid products, texture and flavour attributes were equally used whereas for solid products, consensus texture attributes were dominant. Several assumptions could be formulated to explain this phenomenon. As biscuits and sandwiched biscuits are solid products, their texture evolved during mastication with a breakdown of their structure explaining the use of various texture attributes. First, the biscuit is hard to crunch, then it breaks into small pieces leading to a grainy perception, then the mixture of grains with saliva gives a pasty

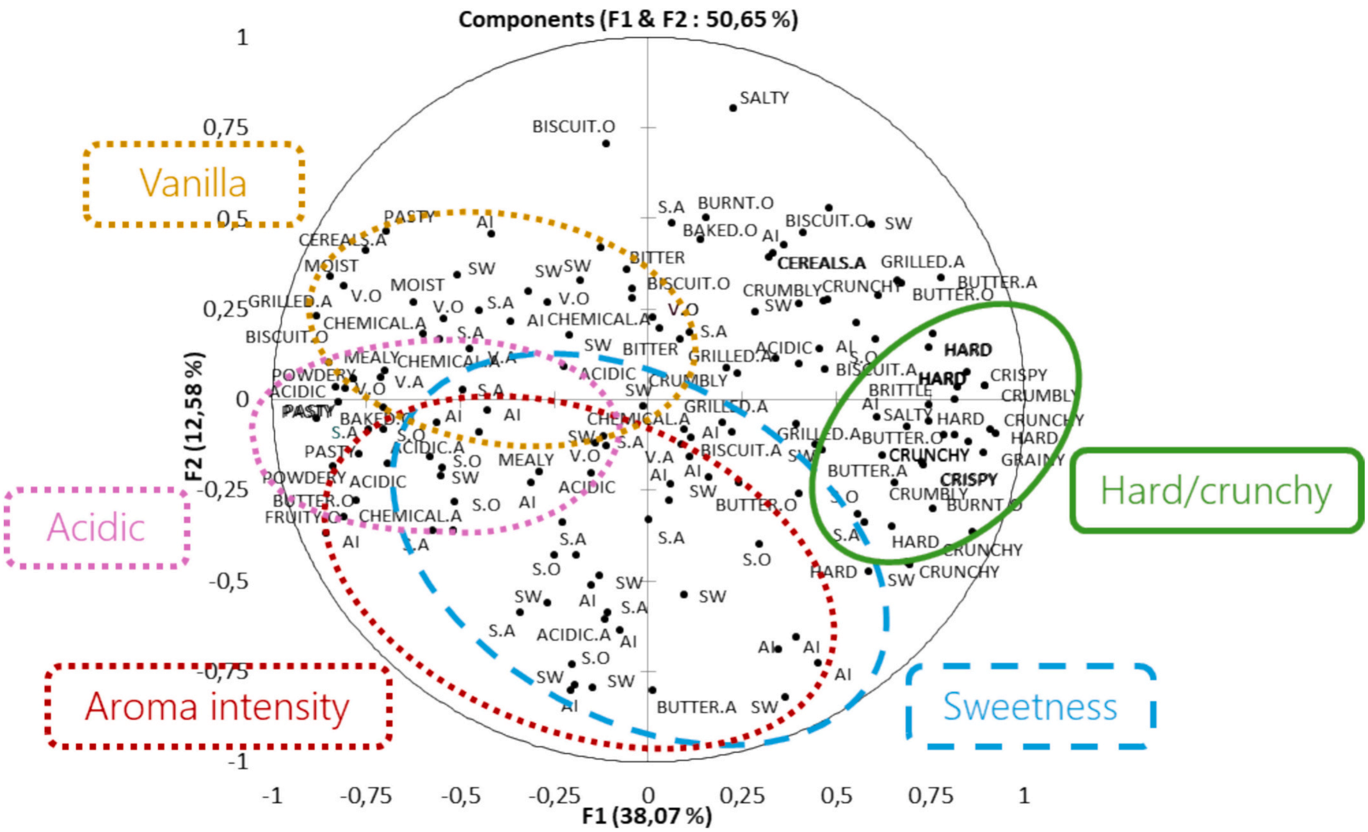

Fig. 6.. Correlation circle from General Procustes Analysis of sandwich biscuits *(O: odour, A: aroma, AI: aroma intensity, SW: sweetness, V: vanilla, S: strawberry)*.

texture to the bolus in order to be swallowed (Tarancón et al., 2013). These modifications are significant and could have more attracted the attention of the panellists than flavour or taste modifications. This phenomenon has already been observed on several matrixes (Tarancón et al., 2013). A second hypothesis of the different use of texture and flavour attributes depending on the matrix could be that the release of flavour compounds vary with the structure of the matrix (De Roos, 2003). As a fluid matrix, as soon as fruit filling is put in mouth, it is dissolved in saliva and flavour compounds could easily reach the taste buds and olfactory epithelium of panellists. Taste and aroma perceptions are thus important in this specific matrix contrary to biscuits where flavour compounds are relatively trapped in the structure and are mainly released during mastication. For fruit filled biscuits, the fruit filling is placed between two biscuits, it is thus not directly in contact with saliva, but mixed with biscuits during mastication preventing good flavour perception. Also, due to the experimental design proposed, the number of products was different for each Flash Profile, which could impact the evaluation of products by the panellists. One could easily assume that when the product is more complex, and/or when the number of products increases, consensus is reached on the most obvious and easiest element to qualify to facilitate the task during sensory analysis. Texture is also generally considered easier to describe than the aromatic profile (Delarue & Sieffermann, 2004). Indeed, texture is perceived through direct, physical sensations, while aroma perception is more complex, involving volatile compounds, individual physiology, and cognitive factors (Tournier et al., 2007). Another hypothesis is the proximity of the products, especially in the third set. Despite varying dosages, strawberry and vanilla flavours were present in almost all the products in the set, resulting in aromatic combinations that were ultimately very similar and therefore potentially less discriminating for the panellists. This effect was reported by Bredie et al. (2018) who observed a lower performance of the Flash Profile method when sensory differences in the product set were minimal. From a purely aromatic point of view, it is therefore possible that the latter set in our study suffers from this limitation, on top of the increase in the set size throughout the study.

The Flash Profile proved to be well adapted to highlight the major differences and dominant characteristics of fluid and solid products, even when complex matrices are analysed. Flash Profile is a static method, thus presenting advantages and disadvantages for the evaluation of complex products. As advantages, the ranking task was simple and allowed direct comparison of samples forcing the panellists to focus on the differences they perceive (Delarue, 2015). The method was rapid as only one session of training was needed before evaluating the samples contrary to classic profile methods such as quantitative descriptive analysis (QDA). The addition of a discussion at the end of the training session was useful to help assessors to build their final list of attributes in terms of number of attributes and definition. Moreover, as no repetition of evaluations was needed, experimenters and panellists saved a lot of time. FP is comfortable for the panellists as they can take the time they want to evaluate the samples and taste them as many times as they want. They can use their own vocabulary so they don't need to learn a list of imposed attributes contrary to other sensory methods such as RATA or QDA where a list of attributes is imposed to the panellists. Other advantage of FP is that panellists have adapted their list of attributes to the set of products to fully express all their perceptions. Indeed, our panel was able to characterize 3 different types of product in only 6 sessions. If one sample had a special characteristic, it could easily be expressed by the panellists, thus there was almost no risk of missing a characteristic of the product. Moreover, one can assume that the oral activity of panellists remains normal when they consume biscuits as the Flash Profile evaluation is performed after consumption, while it could be modified when a sensory task is performed during consumption like for dynamic methods for example (Rizo et al., 2019). From a practical point of view, there is no need for specific software to perform a Flash Profile.

As disadvantages, the temporality of texture and flavour perceptions all along the mastication process was not evaluated in contrary to methods such as TDS or RATA, which have also been successfully applied to complex foods (Santagiuliana et al., 2019; Watanabe et al., 2023). But, as concluded by Tang et al. (2017), both static and dynamic methods give interesting and complementary results for the analysis of complex food. In our study, all the panellists reported during the post-evaluation debriefings that the Flash Profile method was intuitive and easy, particularly for the first two sets of products (strawberry filling and biscuit), but that the task proved more difficult and uncomfortable for the third set, despite the limited number of products enabling us to remain within the order of magnitude of products' sets tested in previous studies (Dehlholm et al., 2012; Delarue, 2015; Lassoued et al., 2008; Liu et al., 2018). This qualitative feedback is a limitation that has been previously reported by Petit and Vanzeveren (2015) specifically on baked goods, pointing the satiating effect of this kind of products, and on intense-flavoured products inducing sensory saturation of the panellists. Thus, as the "sensory space" becomes more complex, whether it involves intense products or products that are sensorially close, one recommendation would be to further reduce the number of samples to 5 or 6 or switch to a method based on rating rather than ranking, such as FCP for example. This limited number of products may be a critical point if a large set of products needs to be characterized. It is also worth noting that although the panellists ranked the samples, they naturally used the free scale space to express distances between the samples, thus approximating this method. As FP is based on the ranking of products, the whole set of samples needs to be presented simultaneously to the panellists which could be a limitation for studies with technical constraints about product manufacturing. Finally, although FP could theoretically be performed with non-trained panellists, for complex products it should be recommended to perform the analysis with panellists familiar with sensory tasks.

5. Conclusion

Although the Flash Profile method has been mostly used to analyse simple homogeneous products, it presents many advantages for the evaluation of texturally complex food. Our study revealed that the Flash Profile method is suitable for discriminating products according to formulation and, eventually, aroma addition depending on the matrix. Attributes generated by the panel allowed a characterization of the products, highlighting the dominant perceptions for each matrix. Indeed, fluid matrices were equally characterized by flavour and texture attributes whereas solid matrices were mainly described with texture attributes. As FP uses panellists' own attributes, the results clearly reflected the characteristics that mostly attracted their attention. Although sensory characterization of complex food is known to be difficult, FP allowed discrimination and characterization of fruit-filled biscuits even with non-trained panellists. In our study, most of the panellists where familiar with sensory analysis which could have facilitated the sensory task for complex products evaluation. Further investigations may be conducted on these sets of products using a dynamic sensory test in order to have complementary information about the dominant sensation at each moment of product consumption. Direct evaluation of complex products using FP with non-trained panellists would also be interesting in order to determine whether the progressive matrix complexification used in this study could have "trained" the panellists to the complex product analysis task.

CRediT authorship contribution statement

Cécile Rannou: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mathilde Roze:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Doina Crucean:** Writing – review & editing, Investigation. **Guenaëlle Diler:** Writing – review & editing, Investigation. **Jason C.G. Halford:** Writing – review & editing, Project administration, Funding acquisition. **Joanne A. Harrold:** Writing – review & editing, Project administration, Funding acquisition. **Anne Raben:** Writing – review & editing, Project administration, Funding acquisition. **Carole Prost:** Writing – review & editing. **Alain Le-Bail:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Patricia Le-Bail:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Clément Catanéo:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Institutional review board statement

The sensory experiments of this study were conducted following the guidelines of the Declaration of Helsinki (WMA, 2013) and were approved by the institutional review board of the French Institute of Medical Research and Health (approval n°IRB00003888-IORG0003254-FWA00005831; 07/07/2020).

Ethical statement

The sensory experiments of this study were conducted following the guidelines of the Declaration of Helsinki (WMA, 2013) and were approved by the institutional review board of the French Institute of Medical Research and Health (approval n°IRB00003888-IORG0003254- FWA00005831; 07/07/2020).

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Anne Raben receives honoraria from Nestlé and Unilever. Anne Raben reports a relationship with International Sweeteners Association that includes: speaking and lecture fees and travel reimbursement. Anne Raben reports a relationship with Novo Nordisk A/S that includes: funding grants. Anne Rabenis currently employed by Novo Nordisk A/S. Jason C.G. Halford reports a relationship with American Beverage Association that includes: funding grants. Joanne A. Harrold reports a relationship with American Beverage Association that includes: funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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