



From sensory toward instrumental characterization of texture. A case study on model dairy-based products.

Farnaz Hanaei

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**From sensory toward instrumental characterization of texture.
A case study on model dairy-based products.**

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General introduction

Texture is a major organoleptic property of food that determines its overall quality for consumers. Producing high quality products that meet the consumers' expectations is crucial for industries to remain competitive in the market. Hence, the developers need to understand the effect of formulation and/or process on perceptive characteristics for producing desirable products while anticipating the consumers' perceptions. That is why the industrial pressure to understand how consumers perceive and describe the product characteristics has increased (Faye et al., 2006).

The sensory properties of food texture are traditionally characterized through sensory descriptive methods. In these methods, a group of panelists are highly trained to work in union for using the same vocabulary and evaluation procedures to describe and assess the intensity of their sensations. To minimize panelist subjectivity, intensive focus is kept on panelist training and the use of references. The panelists are considered as "machines" and the evaluations as being "objective and analytical". Nevertheless, in order to respond to industrial need for anticipating consumers' perceptions, the panelists should be viewed as people, as consumers rather than "machines". In this context, an important question is how to involve consumers in a descriptive approach with a better balance between controlling the conditions while including more diversity?

Although sensory evaluation is the main method to determine texture perception, instrumental methods are also needed to understand why these differences in texture exist. Linking mechanical properties with sensory perception of texture would allow the formulator to define a rational design of texture to satisfy the perception.

In the past studies, the rheological measurements have been widely used in parallel to classical descriptive measurements to predict the sensory descriptors through physical factors. This dual approach allowed predicting some sensory properties of food texture mainly related to product firmness. However, the multidimensional perceptions related to both product texture and surface properties, such as stickiness, are less or poorly predicted through rheological methods. Hence, another question arises: Would sensory free descriptive approaches bring new information regarding the product evaluation that could possibly help orient and improve the choice of instrumental measurements and the parameters of these methods in order to better predict the complex perceptions such as stickiness?

To support this study, a defined range of model processed cheese with a large variety of texture is provided by the Supplier Company. The products cover the market diversity regarding texture for processed cheese varying from **spoonable to sliceable**. Moreover, the product space provides the advantage of studying the effect of several fabrication factors (ingredients and process) on final perception. It is therefore possible to investigate the sensory and instrumental data with regard to the formulation and processing. This will enhance the developer's knowledge of products through a reverse engineering approach.

In the framework of this study, we decide to firstly start with sensory evaluation. We apply a descriptive methodology that take the diversity in different aspects of perception, description and product handling into account. This goes along with the aim of developing methods without training panelists in order to gather sensory information directly from consumers. Secondly, we use the sensory results in terms of both description and evaluation procedure to inspire and improve the instrumental measurements especially for characterization of complex perceptions. Finally, we study the correlation between both approaches to eventually help the developers to master the texture

properties related to multidimensional perception. Therefore, the large part of this work is focused on the sensory characterization of the products. The study consists of 7 parts:

- The first part of this work is a bibliographical synthesis including three points. The first point is centered on the sensory analysis and its transition from reductionist to free methodologies. The second point regards the instrumental analysis for textural characterization. The third point represents the correlation studies (sensory-instrumental) on the texture characterization of the same type of products.
- The second part presents the objective and approaches of this work, which are triple: First of all, the goal is to describe in a fine way the possible differences of sensory characteristics by a method that includes the diversity in perception, description condition and evaluation. Then, the aim is to study to what extent it is possible to use sensorial results to inspire the instrumental approaches. Finally, we want to investigate the possibility of better predicting the sensory perceptions through instrumental measurements, with a focus on multidimensional perceptions. At the end the products range fabricated for our study, their preparation for various test and the reproducibility control is presented.
- The third part describes the whole sensory characterization of the products including the materials and methods, results and discussions for the two main descriptive studies that were carried out. The first study was a pre-study in order to verify the textural diversity of the fabricated products at the sensory level. The second study concerned the characterization of products through an individual descriptive method that provides a good balance between including diversity and controlling the assessment. This aimed at providing more information regarding the products' evaluations. Two types of panelists were used in this part: the consumers and the untrained experts with previous experiences in sensory and textural characterization of products.
- The forth part focuses on the transition from sensory to instrumental characterization. It represents how the sensorial results in terms of description and evaluation are taken into account for selecting a number of limited instrumental methods as well as optimizing testing conditions.
- In part five, the instrumental characterizations are presented along with the materials used and the two applied methods: rheological method and adhesion test. The results and discussions for each method are presented separately. The interest of combining the two methods is investigated.
- In part six, the possibility of correlating between both data sets and the possibility of predicting the sensory data by instrumental variables is discussed.
- In the last part, part seven, the general discussion, we compared our results with regard to the previous works. Finally, the general conclusion of this works addresses the proposed issues.

Part 1: Review of literature

Cheese is one of the oldest manufactured food products with large varieties and highly used as a ready food by consumers. Among the different types of cheeses, processed cheese was invented about 100 years ago to expand the shelf-life of natural cheese and has found a great acceptance by consumers. It is made from one or a combination of natural cheeses, small amounts of added dairy ingredients, flavoring and organic acid in the presence of emulsifying salts (usually sodium salts of citrates, phosphates or polyphosphates). The distinct structure and texture of different processed cheeses arise from ingredients, ingredient quantities and processing factors. The final product is in general homogeneous, stable and preserved perfectly in the time.

The physical properties of cheese are commonly identified in the terms “body” and “texture”. In the dairy industry, the term “body” refers to the consistency of the product (such as: firmness, softness, cohesiveness, rubberiness, elasticity, plasticity, pastiness, brittleness, curdiness, crumbliness), whereas “texture” refers to the relative number, type, and size of openings that can be observed visually (e.g., close, open, gassy, slit-openings, mechanical openness) or by the sense of touch (as in mealy/ grainy) to reveal internal particles (Lucey, Johnson, & Horne, 2003). Nevertheless, outside the dairy industry, all these terms are used to describe the textural, rheological, and fracture properties of foods (Bourne, 2002).

Food texture is one of the most important attributes in food assessment that can be perceived either by one sense (sight) or a combination of senses (sight, touch and sound) depending on the product (Lawless & Heymann, 1998). It is defined as “all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors” (Lawless & Heymann, 1998, Chapter 11). Therefore, it is one of the most important attributes in food assessment by consumers.

Cheese texture is a determinant of consumer acceptance (Adda, Gripon, & Vassal, 1982; Lee, Imoto, & Rha, 1978; Mcewan, Moore, & Colwill, 1989). According to Wendin et al. (2000) texture attributes are more important in describing differences between cream cheese samples than the taste and flavor attributes.

Cheese textures can be evaluated by sensory description to understand which aspects of texture differentiate the products (E A Foegeding & Drake, 2007), and by instrumental measurement to understand why these texture differences exist. Combining both approaches may increase the efficiency and accuracy of food texture measurement and enhance the knowledge of formulation and/or process effects on the textural properties through a reverse engineering approach.

An overview of each approach, sensory and instrumental, is presented in the section below, followed by a discussion on the correlation studies.

Texture assessment

1. Perceptual assessment

Perceptual assessment encompasses all methods to measure, analyze and interpret human responses to the properties of foods and materials as perceived by the five senses: taste, smell,

touch, sight and hearing (Chen & Opara, 2013 as cited by Civile & Ofteda, 2012; Pocztaruk et al., 2011). This measurement is known as “sensory perception” or “sensory evaluation”. Hence, the main objective of this evaluation is to use the human senses as measuring instruments to evaluate the different properties of products.

Among the stimulated senses while food consumption, the sense of touch occupies an important place in the texture perception. Bourne (2002) defines the textural properties as physical characteristics that are related to the product structure and can be perceived mainly by the sense of touch during the deformation, destruction or the flow of the food undergoing the force. He classified the sensory evaluation in ‘oral’ and ‘non-oral’ methods.

Similar to all the sensory perception, the perception of texture includes three successive stages:

- 1- Transduction: it consists of interaction between the stimulus and the sensory receptor that leads to nerve impulses towards the central nervous system.
- 2- Coding: It consists of transformation of the information to electric impulses that can go through nerve axons. The information is coded in terms of both intensity and quality.
- 3- Integration: it consists of the integration of the sensory impulses at central level, where memory and consciousness simultaneously come together. It consists therefore of various factors such as the degree of attention, emotional state, motivation and the level of learning (Meilgaard, Carr, & Civile, 1999). The sensory perception is thus an interpretation of the sensations on the basis of our experiences (MacLeod, Sauvageot, & Köster, 1998). In addition to the quality and the intensity of the sensory perception, the hedonic connotation comes in this stage of perception.

Sensory analysis includes various methods to analyze the sensory answers of the subjects to reach the information involved in the sensory perception. These methods can be categorized into 3 basic types of tests, (SSHA, 1998): the discriminative tests, descriptive tests and hedonic tests.

- Discriminative tests aim in detecting the existence of differences between two products, such as the triangular or the due-trio tests.
- Descriptive tests aim in quantifying and qualifying the perceived differences among the products. In classical sensory descriptive tests known as “classical profile” the relevant descriptive terms known as “descriptor” are quantified.
- Hedonic tests aim in measuring the pleasure or aversion of products by consumers during consumption. The hedonic answer depends on personal culture as well as personal experiences.

The sensory answer can vary not only between the subjects (inter variations) but also for the same subject (intra variations). The inter variations of the sensory answers are related to differences among the subjects in terms of their sensations due to their genetic, their past sensory experiences, their culture and religion. The intra variations of sensory answers are related to a number of physiological and psychological factors. Physiological factors such as: adaptation, interactions between synergy and stimuli. Psychological factors such as: the bias related to the products knowledge, habituation and temporal drift, logical associations of descriptors, halo effect, order of presentation of products, other panelists influences and the lack of motivation (Meilgaard et al., 1999).

To sum up, sensory science is a ‘tool’ for documenting and understanding human responses to external stimuli (E.A. Foegeding et al., 2011). The approach used in sensory analysis depends on the type of food and specific goals of the assessment.

Since in this study the sensory characterization of the products remained analytical, some of the various descriptive sensory techniques that could be applied are described below.

1.1.Sensory Descriptive Analysis

The following section describes the various descriptive methodologies that can be applied for product characterization. Two main categories of method are presented and their advantages and disadvantages are also discussed.

1.1.1. Classical descriptive analysis

The classical descriptive analyses are sensory methodologies that provide **qualitative and quantitative information** about products characteristics, based on the perceptions of a group of **qualified and trained panelists**. The evaluation can be total or can only focus on one sensory aspect such as texture (Stone & Sidel, 1993). Herein, the various classical methods are presented in chronological order.

Flavor Profile® Method

This method was the first descriptive method proposed by Cairncross and Sjostrom, 1950 at Arthur D. Little and Co. in 1948. This method presented the **consensus technique as an alternative to traditional expert’s evaluations** to obtain a detailed flavor description of the product in hand. The method aimed to minimize the subjective attitudes from having an impact on the product descriptions by following a **methodological procedure**.

The method is based on the selection of a very small number of subjects (4 – 6) according to their olfactory and taste capacities. The assessors had to undergo 2-3 weeks of training with definitions and reference standards. The aroma, flavor and mouthfeel, aftertaste and overall impression were evaluated on a 5-point absolute category scale.

Flavor profile is a consensus technique where both the vocabulary development and the rating sessions are carried out as group discussions. Individual assessments were followed by a discussion of results. The discussions were controlled by a moderator in order to reach a consensus score. In this way, the individual score applied by earlier sensory procedures were neglected and the final result was not based on statistical analysis.

A main disadvantage of this method was the influence of the panel leader on the panelist during debates for reaching the agreed-on list.

By 1988, Arthur D. Little, Inc. modified the method and named it Profile Attribute Analysis for including more sensory modalities as well as statistics of the measurements (Neilson, Ferguson, & Kendall, 1988).

Texture Profile® Method

The Texture profile was developed during the late 50s and introduced later by Brandt, Skinner, & Coleman in 1963 at General Food Corp. It built on earlier texture studies and the basic principles of the Flavor Profile but focused only on the description of textural attributes.

The Texture profile aimed towards giving a temporal profile from first bite of the product till residual mastication. It accounts for the temporal aspect of attributes by the use of reference product and precise evaluation methods. This method marks **the development of a descriptive terminology** that includes the terms definition, evaluation procedure and intensity scales with the reference products.

Six to nine panelists are selected and trained to evaluate quality, intensity and order of appearance of mechanical, geometrical, fat and moisture attributes, using varying scales. The training is extensive and references are used to anchor points on the standard rating scale. Like with the Flavor Profile, the consensus and concept alignment was ensured by the moderator. Originally, no statistical treatment was used to present the results (Szczesniak, 1975; Szczesniak, 1963). However, the method has been modified to include new definitions, scales and statistical measurements.

Quantitative Descriptive Analysis (QDA®)

The Quantitative Descriptive Analysis is more than a simple evolution of the previous methods that has overcome their weaknesses. The aim was to generalize the method to comprise relevant sensory modalities and to further stress the **importance of assessor training, the evaluation and data processing**.

The method was presented by Stone et al. in 1974, and is trademarked by Tragon Corporation which promotes the method under the name of QDA®. The QDA® has become the **reference method** in descriptive analysis, also named as “conventional profile”.

The main objective of the method is to describe all the product’s sensory properties. The method insists that no limitations should be established with regard to perceptions for a product. The method concerns the following innovative points:

1. Selection of 10 to 12 subjects based on their abilities to discriminate differences among samples of the specific product type.
2. The key point in this method is that the **panel leader acts as a facilitator** rather than an instructor and decision maker. Thus, the descriptors are resulted from a consensus among the panelists.
3. Assessments are given individually and can be continuously rated using unstructured line scales rather than the categories, with replications.
4. The result is not based on the consensus for intensity rates. The individual ratings are analyzed statistically and can be represented in the form of “spider web”.

Analysis of variance (ANOVA) and Principal Components Analysis (PCA) or similar approaches (Stone & Sidel, 1993) can be used for statistical analysis of the data.

Spectrum™ Method

The Spectrum method is designed by Gail Vance Civile in late 1970s at Sensory Spectrum Society. The main idea of this method is to have **a result which can be reproducible and repeatable at anytime and anywhere**.

The principal characteristic of the method is the extensive use of reference lists, specialized panel training and scaling procedures (Meilgaard et al., 1999).

This extensive training is necessary to enable the panel to be universal and evaluate all type of products. For this purpose, the method provides an array of standard attributes (for all aspects of product) named “lexicon”, with a set of standards defining the scale of intensity, usually from 0 to 15 (Meilgaard et al., 1999). Hence, **measurements are ‘absolute’** and the method is **a good way for comparing results from different studies** (Muñoz & Civile, 1992). The **panel leader has an active role** in directing the panel activities and the responses rather than facilitating. This method requires a training period much longer than conventional profiling. The panels choose attributes in consensus and assess at a 15-point absolute scale individually. The statistics were based at ANOVA (Meilgaard et al., 1999).

Free-Choice Profiling Method

Williams & Langron were the British sensory scientific who proposed this dramatically different approach in 1984. The Free-Choice Profiling method differs on at least two counts from the previously discussed method.

Firstly, the terms generation is done in a novel way. In this method each assessor produces **individual product’s profile based on his her own terms** without the need to explain the meaning of each term to other. Nevertheless, the individual must use the terms consistently during evaluation. Also, the panelists are allowed to evaluate the products in their own manner. Therefore, the training time is very short and just explains the instruction for evaluation. Then, each panelist evaluates the products using his or her unique list scoring them on a 6 point scale. The second feature of this method is the **statistical treatment** of the data by a procedure known as the Generalized Procrustes Analysis (Gower, 1975). This statistical method provides a consensus picture of the data from each panelist in two or three dimensional space.

The development of the idiosyncratic vocabulary was the method’s cardinal point that made up a substantial methodological difference compared to how the ‘conventional descriptive profile’ was and still is applied in laboratories. The development of this method opened the door to development of various new methodologies based on the individual characterization rather than consensus profiling.

Some of these new methodologies are further explained in the following section.

1.1.2. From classical descriptive methods to the emergence of free profiling methods

The development and emergence of individual-based descriptive approaches can be related to three main reasons or motivations: the first reason considers the **practical aspect** of consensus-based approaches. In fact, no matter how well potential experts could perform the task, if they are unable to attend all the several trainings or evaluation sessions they are of no value to the program. Nevertheless, this is not always the case in practice. Moreover, training an expert panel is a long process and can be very time consuming (up to 120h) for complex food characterization (Meilgaard et al., 1999). In addition, creating well-trained panel can be very expensive as the panelists are often paid for their participation. Therefore, the classical approaches could be expensive for small companies as well as for big companies with a wide range of products. Besides, establishing of consensus between the panelists in the way it is defined in the conventional profile can be questioned by the observation that very often, a disagreement remains between the panelists, even after intensive training (Bárcenas, Elortondo, & Albisu, 2003).

The second reason concerns the **fundamental theories**. The product description is the part of the evaluation procedure that prescribes how the panelist should approach the product. The classical

approaches are very analytical but reductionistic in terms of definitions of terms, evaluation procedure as well as description. This is in contrast to the individual-based approaches. Therefore, this reductionism and elimination of existing diversity can possibly influence the perception and/or description. Indeed, for certain authors the individual-based methods would be more representative of the sensory characteristics of products such as they are perceived by the consumers (Andani et al., 2001; Faye, 2004). Using classical methods involves working with trained panelists who are no longer typical consumers. Although characterizing the products with trained experts provides complete, consistent and reliable results, it could be different from consumer perceptions. This could be due to the fact that a trained panel characterizes products in different ways than naïve consumers. A study on beers has showed that training sharpens the panelist's conscious perception of flavors in terms of discrimination and reproducibility. On the other hand, the untrained panelist is likely to perceive the same flavor notes unconsciously (Clapperton & Piggott, 1979). The vocabulary of trained panelists may also be different from the terms used by consumers (ten Kleij & Musters, 2003). In addition to this, trained panelists may consider some differences that could possibly be irrelevant to consumers (Ares et al., 2010a; Bruzzone, Ares, & Giménez, 2012).

The third reason concerns the **industrial pressure** to understand how consumers describe the sensory characteristics of foods (Faye et al., 2006). This goes along with the aim of developing methods without training panelists in order to gather sensory information directly from consumers.

For all these reasons the transition of sensory descriptive analysis towards more rapid and flexible methods in terms of time and training requirements has been imperative. Over the last few years, several sensory mapping and profiling methods have been developed which can be used with semi-trained and even naïve consumers (Varela & Ares, 2012).

The question of whether one can use an untrained panel or consumers for a descriptive evaluation has always existed. Several authors have expressed that untrained assessors are suitable for descriptive analysis (Dehlholm et al., 2012; Moskowitz, 1996; Moskowitz, 1998) while some opposes (Hough, 1998). Nevertheless, many have applied untrained assessors to descriptive analyses (Husson, Dien, & Page, 2001; Lelièvre et al., 2008; Worch, Lê, & Punter, 2010). The hypothesis that consumers are able to accurately describe products is more and more accepted. According to Varela & Ares (2012) the line between sensory and consumer science is becoming blurred.

Valentin et al. (2012) have categorized the **new descriptive methodologies** into three groups: **verbal-based**, **similarity-based** and **reference-based**. Table 1 shows a brief listing of these methods, among which, three methods (sorting, Flash Profile and free comments) that were used in our study are more particularly discussed below.

Table 1: Summary of some of the new sensory methodologies, their theoretical aspects and their limitations (Adapted from Varela & Ares, 2012).

Method	Evaluation method	Vocabulary	Limitations
Sorting	Sorting samples based on their similarities and differences	Elicited by the assessors/ provided by the researcher	<ul style="list-style-type: none"> – Simultaneous samples presentation – Global characterization – No quantitative information on intensity of attribute
Flash Profile	Comparing and ranking samples on a set of key attributes important for product discrimination	Elicited by the assessors	<ul style="list-style-type: none"> – Simultaneous samples presentation
Napping or Projective mapping	Placing samples on a two-dimensional map based on their similarities and differences	Elicited by the assessors	<ul style="list-style-type: none"> – Simultaneous samples presentation – Practical limitation in terms of number of products
Check-all-that-apply (CATA) questions	Selecting the appropriate terms from a list to describe the samples	Provided by the researcher	<ul style="list-style-type: none"> – The attribute design could affect the responses – Not recommended for very similar samples – No quantitative information on intensity of attribute
Intensity scales	Rating the intensity of a set of attributes using scales	Provided by the researcher	<ul style="list-style-type: none"> – Lack of consensus in consumers' responses due to differences in using the scale
Free listing or Open-ended questions	Verbal description of the samples	Elicited by the assessors	<ul style="list-style-type: none"> – Complexity of analyzing verbal descriptions – No quantitative information on intensity of attribute
Preferred attribute elicitation	Ranking attributes based on their importance and rating products using structured scales	Elicited by the assessors	<ul style="list-style-type: none"> – Simultaneous samples presentation – Around-table discussion is necessary
Polarized sensory positioning (PSP)	Comparing the differences between samples and a set of fixed references	Not gathered in the original method	<ul style="list-style-type: none"> – The choice of the reference product could strongly affect the results
Paired comparison	Paired comparisons between samples for a set of provided attributes	Provided by the researcher	<ul style="list-style-type: none"> – Complicated experimental design
Pivot profile	free descriptions of the differences between samples and a single reference product	Elicited by the assessors	<ul style="list-style-type: none"> – The choice of the reference product could strongly affect the results

Sorting Method

Sorting is a **similarity-based method** that has been introduced in the sensory field since the nineties (Lawless, Sheng, & Knoops, 1995; Faye, 2004), however, it has been used routinely in psychology since the late 1960s. Among other methodologies, the sorting task has gained ground as being holistic and simple.

In sensory science, the main aim of the free sorting is to **provide the global degree of perceived similarity** between samples by sorting them into groups. The assessors are presented with a set of samples and instructed to sort them into groups based on the similarities/ differences they perceive. That is to say that the samples that are similar are placed in the same group while the different ones go to separate groups. They can make as many groups as they want as long as they do not make one group of whole set or a single group for each product. This limitation is usually applied to avoid the trivial answers (Varela & Ares, 2012).

The sorting task is relying firstly on a global perceptual step during which the products are evaluated based on their global similarities. The **verbalization** of the differences, if any, only **comes as a second step**. Therefore, once the task is completed the assessors can be also asked to provide descriptive terms for the groups they made in order to obtain the characteristics responsible for similarities and differences. The verbalization can be done by asking the assessors to describe the groups in their own terms or by providing them a predefined list of terms from which they can choose the descriptive terms.

Among the new approaches, sorting has become popular for being natural, simple and quick. It is not based on strongly analytical perception and the ability of translation of the sensation to terms. According to Cartier et al., (2006), one of the main advantages of the method is that it does not need any quantitative system such as intensity scale. This method is suitable with a large number of samples. However, the characterization stays global, and the interpretation of the terms remains difficult as same terms can be applied to different groups. In addition, it involves the simultaneous presentation of samples in a single session.

The common approach for analyzing the data is Multidimensional Scaling (Lawless et al., 1995). However, some other method such as DISTATIS can be carried out (Abdi, et al., 2007).

This method has been successfully used to describe various food products such as cheese (Lawless et al., 1995), drinking waters (Teillet et al., 2010), fruit jellies (Blancher et al., 2011), beers (Abdi et al., 2007; Chollet et al., 2011; Lelièvre et al., 2008), wine (Green et al., 2011; Sáenz-Navajas et al., 2012), yoghurts (Saint-Eve, Paçi Kora, & Martin, 2004), cucumbers and tomatoes (Deegan et al., 2010).

Flash Profile Method

Flash Profile is a **verbal-based method** that was initially developed by Sieffermann, (2000). It is a **synthetic** method which combines Free-Choice Profiling and ranking method. The theory is based on the noted fact that comparing the products is more natural and easier than evaluate them on an absolute scale. It has three basic elements: **identifying the key notions** for product discrimination, **comparing the products** and finally **ranking the product** for each attribute.

The method is based on simultaneous presentation of the whole product set (Dairou & Sieffermann, 2002). Assessors use their own terms during evaluation to describe the key different characteristics of the products. Afterward, they rank all products according to the perceptible intensity for their own generated attributes from “low” to “high”. Assessors can generate as many descriptive terms as they

want and they can take the time they needed. For examining the performance of assessors usually a repeated control is included within the sample set. The method can be used with assessors having different level of expertise (trained or semi-trained) as well as consumers. It is recommended to anticipate a half day per participant, however the test can last more or less according to the ability of the assessor.

The common approach for analyzing the data is Generalized Procrustean Analysis (GPA, Gower, 1975). However, some other method such as Multiple Factor Analysis (MFA) or any multi-block analysis such as DISTATIS (Abdi et al., 2007) can be also used. GPA provides a product and an attribute biplot. For the attribute plot, consensus is based on the usage of the same/similar attributes by different assessors in the same way. Additionally, Hierarchical Cluster Analysis (HCA) can be applied to find the clusters of the correlated attributes.

Even if Flash Profile is an easy and quick method to perform, it remains analytical in terms of both perception and describing the sensation. While the simultaneously presentation of the product makes the evaluation easier, it can have some limitations in terms of the number of sample evaluated. However, Tarea, Cuvelier, & Sieffermann, (2007) applied this method successfully for evaluation of 49 apple and pear puree with 6 trained, motivated assessors.

This method has been successfully applied in different studies to describe various types of food such as red fruit jams (Dairou & Sieffermann, 2002), fruit dairy products (Delarue & Sieffermann, 2004), chewing gum (Delarue & Loescher, 2004), fruit jelly (Blancher et al., 2007), bread texture (Lassoued et al., 2008), fruit purees (Tarea et al., 2007), lemon ice tea (Veinand et al., 2011), cloudy apple juices (Jaros et al., 2009) and for complex and hot food such as fish nuggets (Albert et al., 2011)

Free Comment Method

Free comment also referred as free listing or open-ended questions is a verbal-based methodology that has been recently introduced to the sensory domain for obtaining product characteristics. In this method assessors are merely asked to describe and write down a number of attributes that describe a given product and the characterization is established on **word counting** (Hough & Ferraris, 2010).

This method has been used in some studied as a complementary step to preference mapping (Lawrence et al., 2013; Symoneaux, Galmarini, & Mehinagic, 2012). It has been applied together with hedonic test to understand the main characteristics that **determine the drivers of liking of the consumers** and their perception of the products in their own words (Ares et al., 2010a; Lawrence et al., 2013; Symoneaux et al., 2012; ten Kleij & Musters, 2003). In these studies the authors aimed at understanding the consumers' perceptions through direct collecting of their words.

In some studies consumers were asked to describe the products characteristics in their own words in a non-mandatory way while in other studies the description step was a mandatory task. For example ten Kleij & Musters, (2003) asked consumers to provide them descriptive terms if they want. Nevertheless, Ares et al. (2010a) asked consumers to describe the samples after their overall liking evaluation by a maximum of four words. Recently, Symoneaux, Galmarini, & Mehinagic, (2012) gave consumers the option to freely state what they liked and/or disliked in products. In all these studies free comment method was applied in combination with hedonic test. However, they explained that further research is necessary to evaluate if the use of this type of question could affect overall liking scores.

Apart from identifying the consumers' drivers of liking through their own terminology, this method can most likely provide information about the **relevant characteristics** of the products and **their importance** for consumers (Ares et al., 2010a). This also makes it possible to build a **consumer-derived sensory profile** for each product (Lahne, Trubek, & Pelchat, 2014).

The data processing can consist of a preprocessing (Symoneaux et al., 2012; ten Kleij & Musters, 2003) or can be carried out on the raw data (Kostov, Bécue-Bertaut, & Husson, 2014). It is based on counting the number of participants that used a similar term to describe each product and establishing a frequency table. Correspondence analysis (CA) is the reference method to identify a consensus between the subjects and to represent the relative positioning of products. However, Kostov et al., (2014) have recently proposed "Multiple factor analysis for contingency methodology" to treat the frequency-based data in order to investigate if consumers used the same terms consensually or not.

This method has been regularly used in anthropological studies (Hough & Ferraris, 2010), however, it has been only used in limited number of food products studies such as: mayonnaise (ten Kleij & Musters, 2003), milk desserts (Ares et al., 2010a), appels (Symoneaux et al., 2012) and cheese (Lahne et al., 2014).

1.1.3. Comparison between methods

The methodologies based on individual characterization of panelists have been compared to conventional profiles and to each other in several studies for wide range of the products (Albert et al., 2011; Barcenas, Elortondo, & Albisu, 2004; Bruzzone et al., 2012; Cadena et al., 2014; Campo et al., 2008; Cartier et al., 2006; Dairou & Sieffermann, 2002; Dehlholm et al., 2012; dos Santos Navarro et al., 2012). The comparison of these methodologies to conventional profiles concerns the aspects regarding the methods' practical differences, their configuration output, their semantic output and their reliability.

In terms of **practical differences**, the new methods can be carried out with trained, untrained and consumers based on the objective of the study. As these methods do not include training and consensus establishing phases, they have all the advantage of being faster and easier than conventional methods to carry out. For example, new methods provide products characteristics for specific target market without the need of training. Furthermore, the new methodologies are of interest and advantageous when the product range is very heterogeneous and reaching consensus is very difficult (Varela & Ares, 2012). On the other hand, classical profiling provides more accurate and robust information and identifies smaller differences between the samples which are more actionable for developers. Nevertheless, requiring the consensus for reference concept, descriptors and their definitions as well as evaluation procedures can lead to information loss for that minority of assessors whose perception is different from the majority (Albert et al., 2011). The extensive trainings can also lead to a risk of losing part of the information related to specificities of product handling and description. This can lead to modify the specificity of sensory response that concerns studying **the interaction between human and product**. Hence, a question can be raised regarding the level of adequacy of formalized classic sensory approaches to anticipate the sensory perceptions of consumers, which is the main goal of the industry.

In 1996, Moskowitz refuted the term that consumers are incapable of validly rating sensory aspects with the characterization of 37 sauce products by experts and consumers. In addition, several studies comparing the results from conventional methods carried out by trained panel and new

methods carried out by untrained or consumer panel have showed similar sensory spaces for products with different complexity via different criteria such as R_V coefficients (gives the degree of similarity between two matrices and varies between 0 and 1. The more it is close to 1, the more both matrices are similar) or sensory maps similarities and dimensionality. The comparison of both types of approaches (classical versus new alternative methods) showed that the **sensory spaces for products remains similar** and comparable (Albert et al., 2011; Ares et al., 2010a; Ares et al., 2010b; Ares, Giménez, & Bruzzone, 2011; Bruzzone et al., 2012; Cartier et al., 2006; Chollet et al., 2011; Dairou & Sieffermann, 2002; Delarue & Sieffermann, 2004; Dooley, Lee, & Meullenet, 2010; Moussaoui & Varela, 2010; Symoneaux et al., 2012; Teillet et al., 2010). However, the comparison of the semantic universe of terms showed that **consumers' terms are richer but more spontaneous and varied despite of the trained experts** who describe the product with **fewer but more precise terms** (Albert et al., 2011). Dairou & Sieffermann (2002) also explained that gathering information from panelists without having consensual terminology allows for a diversity of point of view and richer information.

With insight of the extensive training of assessors in classical profiling, the assessors' analysis are more appropriate for comparing and therefore leads to a more robust and precise results (Moussaoui & Varela, 2010). Even though the semantic results from classical methods are more actionable for developers, we should keep in mind that the vocabulary of trained panelists may be different from the terms used by consumers (ten Kleij & Musters, 2003). Therefore, having insights on the terminology of the consumers is of interest to design communication strategies (Ares et al., 2010b; Symoneaux et al., 2012).

The **reliability** of new methods is evaluated in various ways and as Guillaume Blancher et al., (2011) have noted, there is still no unified tool. It can be verified by putting a blind control and carrying a HCA on products to verify the product in duplicate (Varela & Ares, 2012). Some authors have compared the confidence ellipses around the products for duplicate product, whereas others have compared sensory maps resulted from several panels according to product positioning or R_V coefficients (Chollet et al., 2011; Lelièvre et al., 2008).

Choosing of the right descriptive method is insight in the questions that need to be answered. For example, the various new technics are different in the way of gathering the sensory characteristics and they lead to different information. Therefore, the application they are recommended for is different (Blancher et al., 2007). The methodologies such as sorting and napping, known as holistic methods, provide a global perception of assessors and the main characteristics for describing the perceived differences. However, the methods based on specific attribute evaluations, such as Free-Choice Profiling and Flash Profile, are more synthetic as the assessor is focused on a specific feature (Valentin et al., 2012; Varela & Ares, 2012). Therefore, they give a more detailed characterization of products than similarity-based method.

1.1.4. Sensorial characterization of processed cheese

There are an important number of studies on sensory description of various types of cheeses. Herein, we present mainly the studies more specifically on processed cheese. Several studies have been carried out on sensory characterization of processed cheese in relation to processing factors and chemical composition to investigate the effect of these factors on structure, texture and rheological properties. A summary of the studies on sensory characterization of processed cheese is presented in Table 2. These studies are compared according to **sensory methodology, product**

presentations, product range diversity, the evaluation procedure, the number of descriptors and the number of sensory dimensions.

The comparison of these studies showed that the **classical profiles** were always used by a group of experienced/ trained/ qualified panelists to evaluate the product characteristics (Adhikari et al., 2009; Černíková et al., 2010; Drake et al., 1999c; Everard et al., 2007; Fagan et al., 2007; Pereira et al., 2002; Piska & Štětina, 2004)

The product ranges are different between the studies in terms of **number and their compositions, process and natures**. The **form, quantity** and the **temperature** of the sample serving were different. Most of the served sample were sliced in the form of block and cube shapes or in slices (Drake et al., 1999c; Everard et al., 2007; Pereira et al., 2002; Saint-Eve et al., 2009). Piska & Štětina, (2004) served the sample in the form of foiled-wrap individual portions and Strohmaier et al., (1992) in plastic mugs and Fagan et al. (2007) presented the cube in the 110 ml polystyrene cups. The served quantity varied from 5 gr (Fagan et al., 2007) to 100 gr (Černíková et al., 2010). The serving temperature also varies between different studies. Mainly, the products were presented at room-temperature varying from 20 °C to 24 °C (Černíková et al., 2010; Drake et al., 1999c; Everard et al., 2007; Fagan et al., 2007; Piska & Štětina, 2004; Saint-Eve et al., 2009). Muir et al., (1997) presented the product at lower temperature (10.0 ± 0.5 °C). Pereira et al., (2002) presented the samples on trays lying on ice bags to keep the temperature close to the refrigerator and recorded the serving temperatures.

Sensory descriptors have been obtained either through consensus or were predefined. The **number of descriptors** varies between 2 (Černíková et al., 2010; Strohmaier et al., 1992) and 18 (Adhikari et al., 2009). The number of descriptors is varied based on evaluated sensory modality, the influence of animator and the variety of product set. The descriptors included the sensory characteristics related to all modality (oral and/or non-oral texture, taste and flavor) or just texture. The influence of the animator seems to be important in the number of descriptors finally used for characterization. For example in the case of Černíková et al. (2010) and Strohmaier et al., (1992), descriptors were most probably predefined by the authors and therefore are in limited number. Another factor that can affect the number of sensory descriptors generated by the panel is the diversity in the product range. Table 3 shows the texture descriptors used for evaluation of the processed cheese and their importance.

A number of sensory descriptors of the texture were presented in more studies such as the terms related to adhesiveness and firmness of products. However, certain descriptors have been used by one or two studies. Certain descriptors have been used with similar or identical definitions or evaluation procedure such as firmness, while others descriptors were evaluated more differently like adhesiveness and spreadability.

Different **types of scales** were used in order to evaluate the descriptors. In some studies the structured intensity scales have been used such as 7 point scale (Černíková et al., 2010), however some others have used 10 cm unstructured scales (Everard et al., 2007; Fagan et al., 2007).

In the majority of the studies, the analysis of variance was used for data analysis. In most of the studies, the number of **sensory dimensions** does not exceed two. The two first dimensions represent more than 70% of the information.

In view of the form of product presentation in different studies (cut mainly into cubes or sliced) we can notice that the products were enough structured in all studies to sample the products in

particular shape. On the other hand, sensory characterization was always applied using the classical methods and, to our knowledge, there has been no work on the description of processed cheeses using less formalized descriptive methodologies.

Table 2: Comparison of the descriptive sensory studies on the processed cheeses. (1) PCA values are calculated from raw standardized data .

Reference	Type & number of product	Methodology	Number of panelist	Number of descriptor	Data analysis	PCA components % of Variance
Muir et al., (1997)	16 processed cheese spread	Conventional Profile	13	13 (5 texture, 6 flavor, 2 after taste)	ANOVA, PCA	PC1 (27.5%), PC2 (22.4%), PC3 (19.1%), PC4 (9.9%)
Tamime et al., (1999)	8 processed cheese analogue and gel base samples	Conventional profile	13	5 texture & mouth feel	ANOVA, PCA (1)	PC1 (72%), PC2 (16%)
Drake, Truong, & Daubert (1999c)	10 processed cheeses (lecithin type & concentration)	Descriptive analysis of texture	11	7 texture	ANOVA, PCA (1)	PC1 (73%), PC2 (11%)
Pereira et al., (2002)	12 Model processed cheese analogous	Predefined terms	7-9	7 texture	ANOVA, PCA (1)	PC1 (73%), PC2 (18%)
Piska & Štětina (2004)	5 processed cheese composition + cooling	ISO standards (ISO, 1994)	12-16	5 (1 flavor, 4 texture)	Averaged data (not specified), PCA (1)	PC1 (69%), PC2 (22%)
Everard et al. (2007)	15 processed cheese	Descriptive analysis of texture	10	9 texture	ANOVA, PCA	PC1 (54%), PC2 (27%)
Fagan et al., (2007)	17 processed cheeses (cheese, butter, water, emulsifying salt)	Descriptive analysis of texture	10	9 texture	Range of values, PLS regression	
Saint-Eve et al., (2009)	5 flavored model cheeses (Dry matter, fat, salt)	Quantitative descriptive analysis	10	17 (4 aroma, 2 taste, 8 texture, 3 persistence)	Averaged intensity (histograms), ANOVA	
Adhikari et al., (2009)	8 processed cheeses (extrusion temp, moisture, emulsifying salt)	Descriptive analysis	8	18 (8 texture, 8 flavor, 2 after taste)	ANOVA, PCA(1)	PC1 (82%), PC2 (14%)
Černíková et al. (2010)	20 model processed cheeses	Descriptive test (ISO 8586-2)	5	2 texture terms	Median values reported	
Hladká et al. (2014)	2 model processed cheese	Descriptive test (ISO 8586-1)	20	3 preselected terms (2 texture)	Kruskal-Wallis & Wilcoxon (median values)	

Table 3: Texture related descriptors evaluated in sensory characterization of processed cheese and their frequencies.

	Studies												
	Adhikari et al., (2009)	Kealy (2006)	Strohmaier et al., (1992)	Muir et al., (1997)	(Fagan et al., 2007)	Piska & Štětina (2004)	Pereira et al., (2002)	Everard et al. (2007)	Tamime et al., (1999)	Saint-Eve et al., (2009)	Drake, Truong, & Daubert (1999c)	Hladká et al. (2014)	Total number
Adhesiveness/stickiness	X	X		X		X	X		X	X	X X		9
Firm (H/M)			X		X		X	X		X	X		6
Elasticity/rubberiness					X		X	X			X		4
Fatty/greasy/oily				X	X			X	X				4
Spreadability (H/M)			X	X		X			X				4
Mouth coating				X	X			X	X				4
Cohesiveness	X	X									X		3
Fragmentable					X			X		X			3
Graininess (H/M)				X			X		X				3
Melting				X				X	X				3
Fracturability						X	X						2
Rigidity						X						X	2
Springiness (H/M)	X									X			2
Hardness	X	X											2
Smoothness/roughness of mass	X										X		2
Mass formation					X			X					2
Creamy					X			X					2
Moist	X									X			2
Curdiness							X						1
Crumbly										X			1
Gumminess	X												1
Slipperiness of mass											X		1
Homogeneity												X	1
Chewy								X					1
Shiny										X			1

(X): presence of "x" means that at least a descriptor of this type was used in the corresponding study.

1.2. Conclusion

The bibliographical synthesis on sensory evaluation of products shows that:

- The conventional profiles are on one hand the most sophisticated sensory approach and the reference method for descriptive evaluation of product. The evaluations are detailed, robust and actionable for developer. On the other hand, they are reductionist due to the extensively training of assessors and requiring the consensus. In conventional methods, the environment, the evaluation procedure and even the language are controlled. This can lead to information loss for that minority of assessors whose perception is different from majority (Albert et al., 2011). In addition, the defined descriptors of experts may differ from the consumers terminology (ten Kleij & Musters, 2003). Hence, it has been raised several questions concerning the level of the adequacy of the evaluation of an expert panel for anticipation the consumers' perception.
- The new rapid approaches, from a sensory point of view, that are being expanded and tested by consumers are less controlled. They have rendered to similar product spaces; however, the interpretation of consumers' vocabulary can be difficult due to the lack of definitions and evaluation procedures information about specific sensory attributes (Varela & Ares, 2012). When it comes to verbalization the consumers would use more diverse attributes.

The product elicitation is the part of the evaluation procedure that prescribes how the assessor should approach the product. This includes the conditions of the test, the methodology applied and the evaluation procedure. Several questions in this regard have not yet been investigated:

As explained by Meiselman (2013), there should be a trade-off between adequate control and real world to get the results relevant to the real world. The new methodologies are less controlled in terms of description and evaluation. But, the question is: How can we improve them to include a better compromise between control and more freedom. Moreover, there is no study investigating consumers' behavior while product evaluation to obtain more information and possibly more insight for interpretation of results. How to provide more information about the evaluation procedure of consumers?

Several studies have been conducted to compare the new methods with the more conventional approaches in order to see whether they lead to the same sensory results or not. However, to our knowledge, there has been less consideration to combine different approaches for the interest of the different information they can provide. Therefore, it would be of interest to apply or combine the different methodologies according to objective to obtain more and complete information.

Last but not least, it would be of interest to investigate more this questions in context of processed cheese for which, to our knowledge, there is no studies, directly through consumers.

2. Instrumental assessment

Instrumental characterization of the texture includes various approaches. To measure the physical properties of materials, rheological methods are widely employed (Adhikari et al., 2009; Berg et al., 2008; Brighenti et al., 2008; Brown et al., 2003; Gliguem et al., 2009; Lee et al., 1996; Lee & Klostermeyer, 2001; Loret et al., 2011; Marshall, 1990; Pereira et al., 2011; Pereira et al., 2001).

Rheology is the study of the deformation and flow of materials (Steffe, 1996). Food rheology investigates the relationships among stress and strain of a material including the timescale effect. It can be used to understand the processing effect on food products, probe the system structure as well as reveal the critical aspect of food (Foegeding et al., 2003). The aim of quantifying the functional relationships between these parameters is to characterize the resulting rheological properties such as viscosity, elasticity, or viscoelasticity of the material (Fischer & Windhab, 2011).

The rheological measurements can be done in the large deformation (non-linear domain) to characterize the flow properties of materials, or in small deformation (linear domain) to characterize their properties at-rest. There are two categories of rheological methods: fundamental tests and empirical and imitative tests. Fundamental tests give information as to the elemental properties of a material while empirical and imitative tests place the food in conditions closer to sensory evaluation ones.

As presented in the sensory section, the adhesiveness was the sensory characteristic frequently evaluated by classical sensory methods in different studies for processed cheese. Whereas this characteristic could be influenced by the rheological properties of the product, surface properties should be also considered for the evaluation.

From a physical aspect, adhesion is defined as the sticking together of two materials involving liquid-solid or solid-solid interface, with or without an intermediate layer (Kilcast & Roberts, 1998). According to Keijbets et al., (2009) stickiness is “the force of adhesion that results when two surfaces are contacted with each other”. Moreover, in most food systems, the adhesion force is a combination of adhesion and cohesion forces. A food material is perceived as being sticky when the adhesive force is stronger than the cohesive force (Fizman et al., 1999). The energy that is required to separate the two materials is referred as adhesiveness. With respect to the sensory evaluation of food products, the terms stickiness, adhesiveness and adhesion are often used interchangeably (Keijbets et al., 2009).

Potentially stickiness is a characteristic that can be considered negative or positive, depending on type of food and consumers’ expectation. For example, adherence of food to packaging presents problems (Adhikari et al., 2001). However, in some foods such as cheeses or sweets a certain degree of *stickiness* can be a welcome sensory attribute and is what consumers expect of them (Fizman & Damasio, 2000a). Specific methods may therefore be developed to evaluate such a property.

2.1. Rheological properties and measurements

2.1.1. Fundamental methods

The fundamental methods are more sophisticated and measure properties that are well-defined. The types of methods are distinguished according to the magnitude of the deformation the sample undergoes. They include some dynamic rheological testing, viscosimetry and transient rheological testing.

Oscillatory method – small strain methods

The small strain rheological methods known as oscillatory or dynamic tests are the most common method to characterize materials at-rest. In oscillatory tests, materials are subjected to either stress or strain in a sinusoidal movement and their responses are recorded as a function of the time. The

phase lag between stress and strain is a function of frequency and describes viscoelastic behavior of material. The magnitude of the stress and strain and phase lag δ between them allows finding the two components: Shear storage modulus (G') – the “elastic part” of the product behavior – and Shear loss modulus (G'') – the “viscous part” of the product behavior with $\tan \delta$:

$$\tan \delta = \frac{G''(\omega)}{G'(\omega)}$$

The value of phase lag varies from 0 to infinity ($0 \leq \delta \leq \pi/2$). The phase lag approaches the minimum value for the purely elastic material and to its maximum for the purely Newtonian fluid.

Oscillatory methods are designed to be non-destructive. They are performed at very low reversible domain of strain, within the linear viscoelastic region of the material in which the elastic and loss moduli (G', G'') are independent of the strain or stress magnitude applied.

A variation of the amplitude of strain/stress permits to determine the limits of the domain of linearity beyond which the product structure starts to get disrupted. This critical stress and strain (referred to the point that the modulus values start to decrease constantly, Rogers et al. (2009)), or a “yield stress value” (referred to the point that the elastic and loss modulus cross over, Guggisberg et al., (2009)) are sometimes used as a characteristic of the weakness of the material (Tunick, 2000).

Oscillatory methods reveal important information on network structure and molecular arrangement of natural and processed cheeses (Drake et al., 1999b). These methods have been used to compare the cheese regarding their technological parameters (Pereira et al., 2001) as well as the effect of formulation. Černíková et al. (2010) compared viscoelastic properties of processed cheese to examine the effect of different hydrocolloids. Subramanian & Gunasekaran (1997) investigated changes in the linear viscoelastic region of Mozzarella cheese due to changes in storage time and temperature. They found that the strain limit decreased with increasing temperature and age which would result in decreased viscosity and elasticity of the material.

The viscoelastic behaviors of cheeses with different textures have been in general analyzed using plate-plate geometry (Brown et al., 2003; Drake et al., 1999b; Pereira et al., 2011; Rogers et al., 2009). However, the small amplitude oscillation using vane geometry has been carried out to characterize other products such as yoghurts (Guggisberg et al., 2009), it has not been applied for cheese characterization until recently. Lately, the structure of four cheddar-based melted cheeses was characterized using two geometries (plate-plate and vane geometry) to identify the relative advantages of each technique. The authors reported that plate-plate geometry and vane geometry (with four blades) produced comparable results. However, using vane geometry was more efficient in terms of adherence condition and normal loading force. In fact, in plate-plate rheometer sample loading is an important aspect. On one hand applying an appropriate normal loading is required to guarantee the adherence and minimize the wall slip. Since, increasing the given load brings more elements into contact and interact, the value of G' and G'' increase in proportion to force. Therefore, the vane geometry is recommended for oscillatory tests to characterize cheese. It provides greater control of the measurements, especially with respect to the set-up (Patarin et al., 2014).

Creep recovery tests – transient methods

In transient tests the material undergoes an instantaneous and a constant stress or strain while its responding behavior is recorded with lapsing time. These tests are generally carried out in transient between linear regime and non-linear regime.

In creep test an instantaneous and constant stress is applied on the material and the strain or the compliance (J , ratio of strain over stress) is measured as a function of time. After a given time, the constant stress is removed and the recovery is observed by the evolution of the strain over time, which reflects the more or less elastic properties of the material.

Factors such as the instant compliance (J_0), the maximum compliance (J_{mx}), retardation time (λ_{ret}) and the percent creep recovery (crp) can be extracted or calculated through this test. This method was used for differentiation of various natural and processed cheeses (Brown et al., 2003; Drake et al., 1999c; Melito et al., 2013).

Viscosimetry methods – large strain methods

Food properties can be studied by imposing large strains that force the material to flow. The parameter that is defined through this measurement is the viscosity (η), so called apparent viscosity (η_{app}) either as a function of shear rate ($\dot{\gamma}$) to obtain flow curves or as a function of time at a constant shear rate for product. The range of shear rate often used to characterize the flow behavior in view of correlation with sensory analysis is between 10-100 s⁻¹ (Shama & Sherman, 1973). The viscosity measurement at shear rate of 50 s⁻¹ is often admitted today for obtaining a good correlation with "thickness" perception.

The apparent viscosity of processed cheese in relation to its composition has been studied by Dimitreli & Thomareis (2004). They reported that the product behaves as a shear thinning (or pseudoplastic) fluid, the apparent viscosity decreases when the shear rate is increased, which is the case of many concentrated food products. For some products like yogurt and soft white cheese, apparent viscosity (η_{app}) was investigated as a function of time at a fix shear rate since their structure disrupt strongly and their behavior depend on the time as much as the rate of deformation.

2.1.2. Empirical methods

The imitative tests are a subtype of empirical methods. They try to imitate the forces and deformations associated with a specific process of food in-mouth or while handling. The disadvantage of these methods is that the physical properties they measure are not evident. Empirical tests supply basic, single-point information, and the parameters for such tests are usually guided by previous experience. However, the procedure stays arbitrary and does not determine the strictly defined fundamental rheological properties. Among the empirical methods some types of tests are presented regarding the type of strain the product undergoes.

Penetrometry test

This test is one of the simplest and most widely used methods. The test consists of measuring the required force for pushing a probe or a punch into a defined depth of the food with constant speed. The penetration cause irreversible crushing or flowing of the food (Bourne, 2002).

The firmness of modified processed cheeses in which young Cheddar cheese solids were replaced by whey protein concentrates was evaluated by penetrometry test (Gupta & Reuter, 1993).

To predict cheese texture as observed by a trained panel, Breuil & Meullenet (2001) has applied this method in accompany with other large strain rheological methods, uniaxial compression and puncture test. Sensory hardness, springiness and cohesiveness were best predicted by cone penetration test. Other attributes such as roughness of mass and toothpick were predicted using either a uniaxial compression or puncture tests. They concluded that it is often necessary to run several tests in order to predict all the sensory descriptor of texture.

However, the lack of the precision regarding the used material prevents the possibility of generalizing the results between different studies with different protocols.

Extrusion and back extrusion

During capillary extrusion the food is compressed by a piston until its structure disrupts and it extrudes through a hole. The force is measured as a function of time (Bourne, 2002). Maurer & Hardy (1995) used this method to characterize the viscous and pasty food products. The fractal dimension of the curves was determined and correlated to the “smooth” sensory perception. According to Sanchez et al. (1994), the extrusion shear stress could be an estimation of the firmness for double cream cheese products fabricated with various curd homogenization pressures.

In back extrusion a force is applied by a cylindrical piston that goes inside another cylinder with larger diameter that contains the product. The process of extrusion continues until the point where product is force to flow between the cylindrical piston and the inside wall of the product container. This is actually a flow in an annular space. The force required for extrusion is recorded as a function of time or distance.

The force required for extrusion was denoted as hardness in characterization of gel type products with different formulations by Autio et al., (2002). Type of this technic has been used by Brighenti et al. (2008) to evaluate spreadability of cheese. They defined the maximum force as spreadability hardness.

Vane test

The vane method is another large strain test used to determine the yield point or failure stress of various materials. In this method, a vane, having four to eight blades of specified diameter and length, is lowered into the sample and rotated at a defined speed. The maximum stress in stress-strain curve represents the stress at which the product breaks. The vane method is advantageous due to its simplicity in sample preparation, its applicability to a wide range of food consistencies, and its ability to minimize sample destruction. However, it is questionable whether this method provides purely fundamental information for viscoelastic solids.

The vane method has been used to define spreadability in soft textured foods (Daubert, Tkachuk, & Truong, 1998). Additionally, yield stress and apparent yield strain were determined using the vane method to create texture maps describing cream cheese (Breidinger & Steffe, 2001).

The ability of the vane method (using 4-bladed vane) and torsion method (using plan-plan discs) to characterize different cheeses has been compared (Truong & Daubert, 2001). This group concluded that the vane method would be appropriate to compare the textures of the products, given that the diameter of the vane fracture surface was approximately equal to the diameter of the vane.

Compression test

During a compression test a cylindrical sample is squeezed in one direction between two plates: one a fixed plate and a mobile one that measure the applied force for a given deformation. This test is widely used for the solid food.

There are two categories of uniaxial compression tests: nondestructive test in which the compression force is small and does not lead to product fracture and destructive test in which the compression force increases to a level that product fractures and deforms irreversibly.

The simple compression has been used in several studies on mixed gels (Çakır et al., 2012; van den Berg et al., 2008) and cheese (Benedito et al., 2003).

The double compression test known as Texture Profile Analysis (TPA) was developed by Szczesniak on the imitation of mastication or chewing process (Szczesniak, 1963). In this method the instrumental parameters that are quantified from recorded force-time /displacement curves (height and area of the peaks) are named after sensory characteristic (Bourne, 2002), Figure 1.

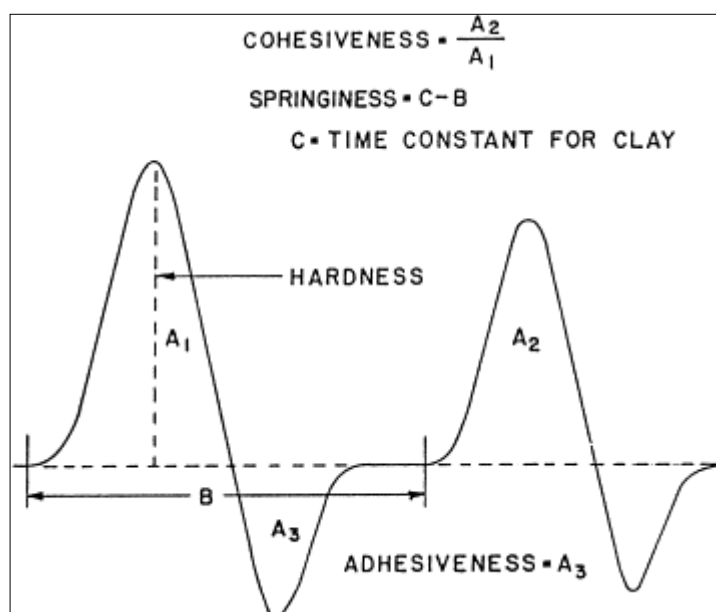


Figure 1: Generalized instrumental texture profile curve (Szczesniak, 2002).

The TPA method has been used for texture assessment of different products as well as hard and semi-hard cheeses (Adhikari et al., 2009; Adhikari, Heymann, & Huff, 2003; Drake et al., 1999b; Drake et al., 1999c; Kealy, 2006). However, the method is only applicable for products sufficiently structured. The sensibility of the test does not allow to discriminate different types of stirred skim milk products since the products were far from a well-structured product (Domínguez-Soberanes et al., 2001).

Even though the TPA presents the advantage of generating various parameters through a single test, the parameters of the TPA were widely went under question, notably with regard to their power of prediction of the corresponding sensory descriptors in their nominations (Fiszman & Damasio, 2000a; Fiszman & Damásio, 2000b; Fiszman, Pons, & Damásio, 1998; Pons & Fiszman, 1996). For instance,

the instrumental determination of adhesiveness through TPA methods, used widely in solid and semi-solid foods, has been criticized due to several experimental problems. One of these problem concerns the sample adherence to probe and its detachment from the platform while the decompression phase. This difficulty could possibly prevented by gluing the specimen to the main platform. Another deficiency of TPA for determination of adhesiveness is due to the high instantaneous recovery of some products. Fiszman & Damásio, (2000b) in a study of adhesiveness on model gels discarded the measured values. They explained that in TPA test the probe returns to “trigger” position (the point at which the probe came into contact with sample) at the end of the first bite, so the products remained in contact with the probe due to their high instantaneous recovery. Therefore, as the tensile force cannot be extracted unless the complete probe-product separation occurs, the measured values have no relationship with adhesiveness and should be discarded.

2.2. Adhesion properties and tack measurement

Food adhesion or stickiness manifests in different ways such as adhesion to process equipment, packaging, fingers or part of mouth. Among these the last three points are perceivable by consumers during the consumption of food. It can be perceived either in terms of oral sensation through mastication between the palate, teeth and tongue or in terms of non-oral surfaces such as fingers, cutlery and packaging surfaces.

Even though this textural feature is easily perceivable, its characterization and quantification is more difficult through instrumental measurements and various methods have therefore been developed to do so. According to Kilcast & Roberts (1997), the **perception** of stickiness can occur through **a combinations of adhesive and cohesive forces**. Hoskeney & Smewing (1999) explains that when the adhesive force is high and the cohesive force is low that material is perceived as being sticky. They explained that since the cohesive properties can be measured by rheological techniques, it is imperative to have a clean separation at the probe-material interact to measure adhesive properties.

Depending on product type, various methods have been developed to measure stickiness. Methods that are applied in food industry to measure the stickiness include adhering weight, probe tests, Texture Profile Analysis and back extrusion (Kilcast & Roberts, 1998). Among these methods, the most important ones are Probe tests and Peel tests with Probe tests more frequently used in food domain (Fiszman & Damasio, 2000a). Even though there is a great diversity of methods for adhesiveness measurements, TPA has been almost exclusively applied for cheese or dough adhesiveness characterization (Fiszman & Damasio, 2000a).

The probe tack approach is used for stickiness characterization of different systems such as sugar-rich foods (Adhikari & Howes, 2003), dough (Ghorbel, Launay, & Heyd, 2003; Hoskeney & Smewing, 1999), chocolate (Keijbets et al., 2009). The intention in this measurement is to mimic the aspect of stickiness that is of interest for example mimicking the human finger touches a sticky surface. In a probe tack test, a probe is firstly brought into contact with a material with a light contact pressure and for a short time and then is pulled off at a fixed speed, during which the force-time or force-distance curve is recorded. The adhesiveness has been related to the force of separation and/or the required energy (area under the curve) to separate the probe from the material. It is qualified by the **work of adhesion** or the **strength of adhesion** (Michalski, Desobry, & Hardy, 1997).

There is not a clear consensus among authors concerning the factors and forces that are involved in stickiness (Adhikari et al., 2001). However, in general, the physical aspect of stickiness includes surface energies, sample rheology and failure mechanisms.

During probe withdrawing, different failure mechanisms may occur between the probe and the food. They can be classified to three major (Adhikari & Howes, 2003): **“Adhesive failure”** occurs when the complete separation takes place at the material–probe interface and result in a clean separation of probe. **“Cohesive failure”** occurs when the breakage takes place within the material and the probe surface remains completely covered with the residue material. This mode of failure takes place when the adhesive (bonding) strength between the material and the probe surface is stronger than the cohesive strength of the material. **“Cohesive–adhesive failure”** occurs where the cohesive and adhesive modes exist together. It could be further classified into three subclasses: “Cohesive–adhesive failure with cohesive dominance”, “Cohesive–adhesive failure with equal dominance” and “Cohesive–adhesive failure with adhesive dominance”.

For solid and semi-solid materials (such as gels, chewing gums, dough, etc.), where the interfacial bonding balances against the internal mechanical strength of the material, both failure mechanisms are possible, but for many viscous (or viscoelastic) fluid foods, cohesive failure is most likely the dominant mechanism (Chen et al., 2007).

The factors such as contact force, contact time, the downstroke and upstroke rates, probe material and dimension, the temperature, the sample dimension can influence the probe test (Adhikari et al., 2001; Kilcast & Roberts, 1997). On the other hand the food compositional factors and rheology can also contribute to the degree of stickiness. In fact, the material compositions affect not only the surface properties but also the rheological characteristics. Compositional effect on the material rheology is important because it derives in more or less energy dissipation while debonding two surfaces for a complete separation.

In an attempt to find the rheological test that better related to sensory breakdown terms such as chewdown cohesiveness and adhesiveness, adhesion testing was conducted in parallel to rheological one on cheddar cheeses with different fat content (Rogers et al., 2009). The authors explained that, the low-fat cheese with higher J_{max} (lower G') in creep-recovery test had the highest adhesion area in the adhering test.

Childs et al.,(2007) used adhesion method along with rheological methods in order to measure shred quality of Mozzarella, Monterey Jack, and process cheese. They reported that the combination of high tack energy and low retardation time cause an increase in the amount of cheese that adhere to the blade during shredding. However, the rheological properties were the best indicators of adhesion.

3. Correlation of perceptual and instrumental texture assessments

Different types of cheese or model cheese products have often been taken as support of correlations studies between sensory and instrumental measurements. Table 4 presents a synthesis of some of the main concerned articles. The studies are on products with texture close to those we used in our

study. In this part, more emphasis will be put on studying the correlation between sensory and instrumental factors related to tactile and adhesive properties of product while handling and consumption.

In all these studies, **classic profiles** were used for product characterization by experts and, to our knowledge, there has been no work on the description of processed cheeses directly through consumers' terms.

The **products texture** between these studies varies from soft to hard. These studies show big variety in terms of product range and texture diversities of commercial or model products such as natural, processed and cream cheese. The number of studied products varies from 3 to 29. The texture variety constituting the product space also varies in terms of compositions and product types. Some studies restricted their result on product with hard texture, some on softer products while others include both. Nevertheless, it can be noted that in all these studies, all the products were sufficiently structured to be sampled in the same shape and form (sliced, cut in cube or cylindrical form). The studies presenting the largest variety of products is this of Breuil & Meullenet (2001) in which a range of 29 type cheeses were evaluated.

Different strategies were used concerning the choice of the instrumental measurements. In some studies, various types of methods were applied in order to cover the linear to nonlinear domain while others used only one type of measurements.

Fundamental methods such as frequency sweep or creep-recovery test have been widely used in parallel to classical sensory methods in several studies. Good correlation have been reported for sensory perception related to products firmness or hardness and fundamental parameters (Brighenti et al., 2008; Brown et al., 2003; Drake et al., 1999b; Drake et al., 1999c; Pereira et al., 2011). Moreover, González-Tomás & Costell (2006) have investigated the relationship between consumers' perception of the texture of dairy dessert and fundamental instrumental characterization. They reported a high reverse correlation between the consumers' perception of *soft* and *fluid* and fundamental parameters of G' and η^* ($r > -0.85$).

In most of the studies, the **fundamental methods have been used along with empirical methods**. In fact, to obtain better relations between the sensory and instrumental data it is necessary to do the measures at large deformations and beyond the break threshold.

Uniaxial compression test have been used most frequently to describe cheese texture. Sometimes, the properties of products were studied by means of a test of specific compression (Benedito et al., 2000; Berg et al., 2008; Goh et al., 2003; Viñas et al., 2007) or by means of double compressions of TPA.

Using specific compression tests, Viñas et al. (2007) reported the best predicting model for sensory *hardness* versus poorest model for sensory *adhesiveness* for manchego cheese. In a compression/penetration test on yogurt the sensory *stickiness* was also poorly predicted. While Çakır et al. (2012) applying a compression-decompression test reported a very good correlation between the sensory *adhesiveness* and *cohesiveness* perceptions and percent recoverable energy (recoverable energy to total energy) for gel type products.

Many studies have used the TPA method in combination with sensory analysis to characterize various types of cheeses (Adhikari et al., 2009, 2003; Drake et al., 1999b; Drake et al., 1999c; Everard et al., 2007; Kealy, 2006; Truong et al., 2002). Other authors used a test of double compression similar to

the TPA (Breuil & Meullenet, 2001) or a test consisting in twice penetration into the products (Strohmaier et al., 1992) or three times for yogurt characterization (Carson, Meullenet, & Reische, 2002).

Drake et al. (1999b) applied both fundamental and TPA methods for characterization of 13 natural and processed cheeses. They reported that fundamental methods revealed important information on products structure. However, the TPA-hardness predicted better the sensory firmness than fundamental methods. Regarding the sensory *adhesion* (hand and mouth) and *cohesion* perceptions, fundamental methods rendered poor correlation. No correlation was found between these perceptions and corresponding TPA parameters. Analyzing separately the processed cheeses, the authors reported that empirical methods allow predicting of all sensory texture properties as well as or even better than fundamental methods. In a study for investigating the effect of fat reduction on texture perception of cheese, no correlation was found for the sensory perception of "*Cohesiveness, teeth coating, toothpull, smoothness*" and instrumental factors neither through fundamental methods nor through TPA (Drake et al., 1999c).

Drake et al. (1999b) and Truong et al. (2002) did not find simple relation between the TPA adhesiveness and/or cohesiveness parameters and their sensory descriptors. In correlation studies on peanut butter texture, the "*first compression of stickiness*" and "*adhesiveness to teeth after swallowing*" were not significantly correlated with TPA parameters (Lee & Resurreccion, 2002).

In contrary to these studies, Adhikari et al. (2003) have found that the sensory perception of "*sticky, first-bite-sticky*" and "*mouth coating*" were positively correlated to TPA-adhesiveness and negatively to TPA-hardness. On the other hand, the sensory *adhesiveness* of processed cheese was reversely correlated to its corresponding TPA-factor (Adhikari et al., 2009). The authors explained that the panel probably perceived the higher moisture cheeses to be more adhesive while the TPA adhesiveness values for the higher-moisture cheeses were lower.

Even though the TPA method is largely applied, the method has been criticized concerning the parameters and their nominations of the sensorial perception that they are supposed to model. The method has been questioned for its accuracy for adhesion measurement (Fizman & Damasio, 2000a; Fizman & Damásio, 2000b; Pons & Fizman, 1996; Truong et al., 2002). According to Patarin et al. (2014) the method presents some limits and difficulties concerning the interface conditions of perfect slip or perfect adherence which leads to uncertain results. In addition, Drake et al., (1999b) explained that sensory *cohesiveness* being defined as the degree of compression required before rupture is more closely related to deformation (distance) than the definition of TPA cohesiveness: ratio of the work energy of two compression cycles.

Among the TPA parameters, good relations were mostly obtained for sensory *hardness* and TPA-hardness. However, the results for correlating the instrumental data for adhesion and cohesion to the corresponding sensory perceptions are more contradictory and inconsistent (Adhikari et al., 2009, 2003; Drake, Gerard, & Civille, 1999a; Drake et al., 1999b; Everard et al., 2007).

Cheese constitutes a group of foods in which adhesive property is important and has been received considerable attention. Even though there is a great diversity of measurement methods, the adhesiveness in cheeses is evaluated almost exclusively by means of TPA. This is probably due to the fact that, in general, it is relatively simple to obtain samples with a regular size and shape (Fizman & Damasio, 2000a). Tack or Adhesion test is a method to measure the adhesiveness widely used for characterization of other food product especially bakery and cereal-derived products. This method has been used by Childs et al. (2007) to investigate the shred quality of cheese. However, they did not run a sensory-instrumental correlation study. Rogers et al. (2009) used the Tack test to evaluate

the adhesiveness property in cheddar cheese. They reported a very high reverse correlation ($r \geq -0.95$) between the sensory *adhesion* and *cohesion* perceptions and work of adhesion, Table 4. The authors suggest two theories to explain the unexpected negative correlation. One possible reason is the differences between the instrumental condition and sensory evaluation that involves the effect of temperature and saliva. Another explanation is the difference between the unchewed adhesion (probe and product) versus sensory breakdown adhesion (chewed products).

The method has been very recently applied to measure the cheddar, mozzarella and American cheeses stickiness. However, no result is reported concerning the correlation between the resulted instrumental factors and corresponding sensory perceptions (Melito et al., 2013).

Apart from compression test that have been used to determine the fracture properties of material, torsional tests have been also applied along with conventional sensory evaluation. The stress and strain at fracture determined either by normal or torsional deformation has been shown to be correlated to sensory *firmness*, *elasticity* and *springiness* (Brown et al., 2003; Rogers et al., 2009; van den Berg et al., 2008), Table 4.

Another empirical method applied for correlation studies was (back) extrusion test. Brighenti et al. (2008) had applied the spreadability test (back extrusion type) along with penetration and oscillatory methods. They reported that the sensory *spreadability* was similarly correlated to instrumental factors resulted from different tests. In a study on processed cheese and gel type products, an extrusion test was applied along with TPA. The authors reported that these instrumental methods result in a good prediction for sensory *stickiness*, however, the prediction is less consistence for sensory *spreadability* (Tamime et al., 1999).

The **sensory descriptors of texture which seems to be best predicted** within the framework of these studies are related to firmness of the products. Nevertheless, finding correlation between instrumental parameters stemming from diverse methods and certain types of descriptors remain either less documented, or even not predictable. Comparing the sensory definitions and evaluation attributes related to *hardness* or *firmness* versus more complex perception such as *adhesiveness*, *cohesiveness*, *creaminess*, etc using the conventional method used in different studies showed that:

- The sensory definition and evaluation of attributes related to hardness or firmness by the conventional method in different studies are fairly similar and less complexes. Firmness is related to mechanical properties and is explained as required force to compress, bite (compression) or fracture (compression to fracture) the products.
- More variation in terms of definition and evaluation protocol is noted for example for adhesion/stickiness perception. Adhesiveness results from surface and rheological properties of foods. In some studies the amount of product that sticks is taken as indicator (Adhikari et al., 2009; Brighenti et al., 2008), in others the force needed to remove the product and in some both. On the other hand, variation can be seen in stickiness evaluation to different contact surfaces: hands, oral cavity, palate, lips, between teeth and/or to the teeth. In some studies the stickiness to a combination of these contact surfaces have been evaluate while in other only an overall sensation was evaluated. This shows that the stickiness is easy to perceive from the first contact to the whole consumption. Hence, its evaluation procedure involves more differences between the studies.

Table 5 shows a summary of definition and evaluation of some descriptors (related to hardness, adhesiveness, cohesiveness, spreadability and creaminess) in different studied.

Table 4: Comparison of the studies concerning the correlations between sensory and instrumental measurements of the texture for different cheese products (sensory descriptors in italic)

Reference	Type of product	Applied instrumental methods	Principal correlation results between sensory and instrumental results
Drake et al. (1999b)	13 natural & processed cheeses	<u>A. TPA</u> : cube shape sample (15mm), compression= 80% at 0.4 mm/s, time pause: 5s. Room tem. TA-25 probe. TAXT2, 25 kN load cell Measured parameters: Hardness, springiness, cohesiveness, gumminess, adhesiveness <u>B. Oscillatory test</u> : disk shape sample (h=3.5 mm, ϕ =35 mm), Frq= 0.01-15 Hz, strain= 0.004% OR stress=10-200 Pa. 23°C. 3.2 gap, 20 mm parallel plate. Stress Tech / Bohlin VOR rheometer Measured parameters: G' , G'' at 1Hz <u>C. Creep/recovery</u> : Stress= 10-200 Pa Measured parameters: J_0 , Crp	<u>Sensory descriptors well correlated by instrumental parameters ($r \geq 0.70$):</u> <ul style="list-style-type: none"> ● <i>S-firmness</i> (hand & mouth) \leftrightarrow hardness ($r = 0.88$), springiness_A ($r = 0.82$), G', G''_B ($r = 0.78$), J_0_C ($r = -0.75$) ● <i>S-Elasticity</i> (mouth) \leftrightarrow springiness_A ($r = 0.74$) ● <i>S-cohesiveness</i> \leftrightarrow G', G''_B ($r = 0.72$) ● <i>S-stickiness to teeth</i> \leftrightarrow G', G''_B ($r = 0.77$) ● <i>S-Slipperiness</i> \leftrightarrow J_0_C <u>Sensory descriptor best predicted</u> : <i>S-firmness</i> (hand & mouth) No correlation between <i>S-Adhesiveness to teeth</i> , <i>stickiness</i> to hand and <i>S-Cohesion</i> with corresponding TPA
c)	10 full-fat & reduced fat processed cheeses	<u>A. TPA 1 bite</u> : cube shape sample (15 mm), compression= 80% at 0.4mm/s, time pause: 5s. TA-25 probe, TAXT2, 25 kN load cell. Measured parameters: Firmness, cohesiveness, adhesiveness, springiness, gumminess <u>B. Creep-recovery test</u> : disk-shape (h=3.5, ϕ =3.5), Stress= 200 Pa. 23°C. 3.2 mm gap, parallel plate, StressTech rheometer. Measured parameters: Crp	<ul style="list-style-type: none"> ● <i>S-firmness</i> \leftrightarrow <i>firmness_A</i> ($r=0.86$), <i>Crp_B</i> ($r=0.72$) ● <i>S-slipperiness</i> \leftrightarrow <i>Crp_B</i> ($r=-0.84$) ● <i>S-elasticity</i> \leftrightarrow <i>springiness_A</i> ($r=0.82$) <u>Sensory descriptors for which no correlation is reported</u> : <ul style="list-style-type: none"> ● <i>S-Cohesiveness</i>, <i>teeth coating</i>, <i>toothpull</i>, <i>smoothness of the mass</i>
Breuil & Meullenet (2001)	29 varied cheeses	<u>A. Uniaxial compression double compression</u> : compression= 70% at 1mm/s. 50 mm parallel plate. 14 measured parameters from force-distance curve. <u>B. Cone penetration test</u> : distance= 10 mm at 1 mm/s. 30° stainless steel cone. 11 measured parameters from force-distance curve. <u>C. Needle puncture tests</u> : distance= 10 mm at 1 mm/s. 2 mm aluminum needle probe. 9 measured parameters from force-distance curve. All test at 7 °C, with trigger force at 8 g. TAXT2, 25 kN load cell.	<u>Sensory descriptors well predicted by instrumental parameters ($r \geq 0.80$):</u> <ul style="list-style-type: none"> ● <i>S-springiness</i>, <i>S-hardness</i>, <i>S-cohesiveness</i>, <i>S-cohesive of mass</i>, <i>S-roughness of mass</i>, <i>S-toothpack</i> <u>Sensory descriptor least predicted</u> : <i>S-toothpull</i> <u>Sensory descriptors not predicted</u> : <i>S-moisture absorption</i> , <i>residual film</i> , <i>loose particle</i>
Adhikari, Heymann, & Huff (2003)	9 commercial hard cheeses	<u>A. TPA double compression</u> : cube shape (20 mm ³), compression= 50% at 1mm/s. TAXT2, 25 kN load cell. Measured parameters: Hardness, springiness, cohesiveness, gumminess, adhesiveness, chewiness	<ul style="list-style-type: none"> ● <i>S-rubbery</i> \leftrightarrow <i>cohesiveness_A</i> (<i>PLS regression coeff</i> > 2.30) ● <i>S-grainy</i>, <i>hardness</i>, <i>dry</i>, <i>crumbly</i>, <i>mealy</i> \leftrightarrow <i>hardness</i>, <i>cohesiveness_A</i> ● (<i>PLS regression coeff</i> > 1.00) ● <i>S-fist-bite-sticky</i>, <i>sticky</i>, <i>creamy</i>, <i>mouth coating</i>, <i>viscous</i> \leftrightarrow <i>negatively to hardness_A</i> & <i>positively to adhesiveness_A</i> (<i>PLS regression coeff</i> ~ 0.7)
Brown et al. (2003)	Mozzarella, Monterey Jack, process cheese	<u>A. Strain sweep</u> : sliced shape sample (2mm). Strain= 0,00015 – 0.1.5, Frq = 0.001, 0.01, 0.1, 1.0 Hz <u>B. Frequency sweeps</u> : Frq= 0.001-20 Hz, return to 0.001 Hz, 25°C , 2 mm gap, serrated parallel plates (ϕ =30 mm), Bohlin VOR rheometer. Measured parameters: G^* , G' , G'' , $\tan \delta$ at 0.1 Hz <u>C. Creep –recovery</u> : sliced shape sample (2mm), stress= 71.9 Pa for 600 s, recovery time= 1200 s. 25°C. 20 mm parallel plates, Stress Tech rheometer. Measured parameters: λ_{ret} , J , J_{max} , J_0 , Crp <u>D. Torsional methods</u> : cylindrical sample (h=28.7). Speed = 0.045, 0.45, 4.5 rpm. Haak 550 viscotester	<ul style="list-style-type: none"> ● <i>Correlation anomaly for instrumental chewiness and springiness</i> <u>Sensory descriptors well correlated by instrumental parameters ($r \geq 0.70$):</u> <ul style="list-style-type: none"> ● <i>S-firmness (hand)</i> \leftrightarrow <i>negatively to max compliance&crp_C</i>, $\tan \delta_B$ ● <i>S-firmness (mouth)</i> \leftrightarrow <i>negatively to max compliance_C</i> ● <i>S-springiness (hand)</i> \leftrightarrow <i>negatively to shear fracture modulus_D</i> <u>Sensory descriptors least correlated to rheological parameters</u> : <i>S-chewdown</i> (<i>adhesiveness</i> , <i>cohesiveness</i> , <i>smoothness</i>)

Measured parameters: True shear stress, true shear strain, shear fracture modulus			
Everard et al. (2007)	15 Processed chesses	<p><u>A. TPA double compression:</u> cubes shape sample (25mm), compression=30% at 1mm/s. 75 mm plate, TA-Hdi Texture analyzer, 100kg load cell. .</p> <p>Measured parameters: Fracture strain, fracture stress, firmness, springiness, cohesiveness, adhesiveness, chewiness</p>	<p><u>Sensory terms best predicted ($r \geq 0.89$):</u></p> <ul style="list-style-type: none"> ● <i>S-chewy, creamy, melting, firmness, rubbery, fragmentable</i> <p><u>Sensory descriptors least correlated:</u> <i>S-Mouthcoating, mass formation, greasy</i></p>
Berg et al. (2008)	13 Whey protein/polysaccharide mixed gels (semi-solid)	<p><u>A. Uniaxial compression:</u> compression rate= 10% at 0.8 s^{-1}.</p> <p>Measured parameters: Fracture strain, fracture stress, energy to fracture</p> <p><u>B. Uniaxial compression:</u> compression rate= 50% at 0.1 s^{-1}</p> <p>Measured parameters: serum volume fraction.</p> <p><u>C. Compression-decompression:</u> 60% at 20 mm/s.</p> <p>Measured parameters: recoverable energy.</p> <p><u>D. Wedge test:</u> 10% deformation</p> <p>Measured parameters: Critical speed for fracture. For all test Instron 543</p>	<ul style="list-style-type: none"> ● <i>S-firmness ↔ stress_A, energy to fracture_A</i> ● <i>S-spongy ↔ strain-A</i> ● <i>S-Crumblly (mouth) ↔ recoverable energy_B ($r = 0.70$)</i> <p><u>Sensory descriptors not correlated:</u> <i>S- Spreadable, roughness, stickiness, resilient, thickening, melting, airy, thin, mealy, oily, fatty, creamy, fibrous</i></p>
Brighenti et al. (2008)	18 Cream cheeses	<p><u>A. Oscillatory test:</u> cylindrical sample (h=2-3 mm, ϕ =25 mm), Frq= 0.1 Hz, strain= 0.05%, heating cycle (5°C to 80°C), immediate cooling (80° to 5°C) , 30 min at 5°C. Rate=1°C/min. 25 mm serrated parallel plate. Controlled-stress rheometer.</p> <p>Measured parameters: G', G'', $\tan \delta$</p> <p><u>B. Penetration:</u> brick-like sample, distance = 15 mm at 1 mm/s. 45° conical stainless steel probe. TA.XT2, 5-kg load cel</p> <p>Measured parameters: Fmax=Penetration (hardness)</p> <p><u>C. Spreadability tests:</u> distance= 2mm above female cone, 1 mm/s (no specification for rate). 5°C. Male and female 45° Perspex cones, TA.XT2: 20-kg load cell</p> <p>Measured parameters: Fmax= (hardness), areas</p>	<p><u>Sensory descriptors well predicted by instrumental parameters ($r \geq 0.75$):</u></p> <ul style="list-style-type: none"> ● <i>S-firmness, cohesiveness of mass, difficulty to dissolve, difficulty to spread ↔ G'_A, hardness_B&C ($r \geq 0.75$)</i> ● <i>S-Stickiness ↔ G'_A, hardness_B&C ($r = -0.85$ & $r = -0.83$)</i> <p><u>Sensory descriptor not predicted:</u></p> <ul style="list-style-type: none"> ● <i>S-Gumminess ↔ hardness_B&C</i> ● <i>S-Particle size</i> <p><u>Sensory descriptors well predicted:</u></p> <ul style="list-style-type: none"> ● <i>S-Hardness, S-chewiness ↔ TPA-corresponding parameters ($r \geq 0.79$).</i> ● <i>S-Adhesiveness ↔ Adhesiveness ($r = -0.81$).</i> <p><u>Sensory descriptors for which no correlation is found/reported:</u> springiness, cohesiveness, gumminess.</p> <p><u>Sensory descriptors well correlated by instrumental parameters ($r \geq 0.95$):</u></p>
Adhikari et al. (2009)	8 Processed cheese	<p><u>A. TPA double compression:</u> cube sample (20 mm^3), compression= 50% at 1mm/s, 23 ± 1 °C. TAXT2, 25 kN load cell.</p> <p>Measured parameters: Hardness, springiness, cohesiveness, gumminess, adhesiveness, chewiness</p>	
Rogers et al. (2009)	5 Cheddar cheeses	<p><u>A. Stress sweep:</u> Stress= 1-1,000 Pa, Frq =10Hz, sliced (4 mm).</p> <p>Measured parameters: critical stress, critical strain</p> <p><u>B. Creep/Recovery:</u> Stress=100 and 150 Pa for 200 s, recovery time= 200 s.25°C, 20-mm smooth parallel plate, Stress Tech rheometer</p> <p>Measured parameters: Jmax, J_0, λ_{ret}, Crp</p> <p><u>C. Adhesion test:</u> cube shape sample, downward & upward rate= 0.1 mm/s, force load= 1,96 N for 5 s. Brookfield LFRA texture analyzer</p> <p>Measured parameters: Area under the curve</p> <p><u>D. Torsion Analysis:</u> 3 strain rates= 0.040, 0.40, 4.0 s^{-1}. Haake VT-550 rotational viscometer</p> <p>Measured parameters: fracture stress, fracture strain, fracture modulus (initial slop)</p>	<ul style="list-style-type: none"> ● <i>S_Adhesiveness, cohesiveness, smoothness ↔ negative correlation with area_C, critical stress & strain_A</i> ● <i>S-firmness terms ↔ positive correlation with area_C, critical stress & strain_A AND negatively correlation to fracture modulus_D (at 0.04 s^{-1})</i>

(Continuation of Table 4)

Table 5: Some of the texture terminology applied for sensory evaluation for various type of cheeses.

Attribute	Definition → Evaluation	Reference
Spreadability (Non-oral)	(1) Initial stage force (time and effort) needed → Cover 1/4 of flat knife surface with sample and spread it to a thin even layer on a cocktail bread (2) No definition → spreading on a biscuit	¹ (Brighenti et al., 2008), ² (Muir et al., 1997)
Hardness/ Firmness	(1) The force required to bite /the force required to compress → 5 Press completely through the sample using the thumb and first two fingers → Completely bite through the sample using the molars/ 7 Place sample on tongue, compress it against the palate once at a steady rate (2) The extent of initial resistance offered by the cheese (3) The maximum force required to deform the food → 10 bite down between the molar teeth, (4) Amount of resistance to compression/Force required to cut through with knife → pushed between the thumb and index finger/guillotine-like movement	¹ (Drake et al., 1999b), ¹ (Drake et al., 1999c), ¹ (Adhikari et al., 2003), ¹ (Breuil & Meullenet, 2001), ¹ (Brown et al., 2003), ² (Everard et al., 2007), ¹ (van den Berg et al., 2008), ¹ (Brighenti et al., 2008), ¹ (Adhikari et al., 2009), ¹ (Rogers et al., 2009), ² (Fagan et al., 2007), ³ (Kealy, 2006)
Adhesiveness/ Stickiness	(1) The degree of sticks to the fingers / the molars/ palate/force required to pull your teeth or jaws apart (2) Overall sensation of stickiness during mastication/ Sticky sensation experienced during the first bite (3) The degree to which the chewed mass sticks to mouth surfaces → Chew the sample 5 times and evaluate the chewed (4) Amount of sample that adheres to palate → Place sample on tongue, lift it up softly against palate without squeezing the sample (5) Force to subsequently move the sample with the tongue → pressing each sample to the palate with the tongue. (6) The force required to remove materials that adhere on oral mucosa and teeth (7) Sample sticks in the oral cavity, as with gingerbread (8) No definition	¹ (Drake et al., 1999b), ¹ (Drake et al., 1999c), ¹ (Pereira et al., 2002), ² (Adhikari et al., 2003), ³ (Brown et al., 2003), ³ (Rogers et al., 2009), ⁴ (Brighenti et al., 2008), ⁴ (Adhikari et al., 2009), ⁵ (Kealy, 2006) ⁶ (Saint-Eve et al., 2009), ⁷ (van den Berg et al., 2008), ⁸ (Tamime et al., 1999)
Toothpull	(1) A significant force to pull your teeth apart after biting into it/ the force required to separate the jaws during mastication	¹ (Drake et al., 1999b,c)
Toothpack	(1) The amount of products pack into the crowns of teeth after mastication	¹ (Breuil & Meullenet, 2001)
Cohesiveness of mass/ Mass-forming	(1) The amount sample deform rather than splits apart, cracks or breaks/ the amount chewed sample hold together → Chew the sample 5 times and evaluate the chewed mass/Place sample in mouth; compress it with tongue against palate at least 5 times/9 Chew the sample 5 times and evaluate the chewed mass/10 → placing a sample between the molar teeth and estimating (2) Resistance to breakdown of the sample in the mouth during mastication (3) Using molars, during first one to three chews, evaluate the degree to which the sample deforms (cohesive) rather than shatters or fractures (4) Degree to which sample holds together in a mass	¹ (Breuil & Meullenet, 2001), ¹ (Brown et al., 2003), ¹ (Rogers et al., 2009), ² (Adhikari et al., 2009), ³ (Drake et al., 1999b), ³ (Drake et al., 1999c), ⁴ (Brighenti et al., 2008),
Creaminess	(1) The feeling associated with heavy whipping cream (2) The texture associated with cream that has been whipped	¹ (Adhikari et al., 2003), ² (Everard et al., 2007)
Mouthcoating	(1) The degree of coating on the tongue and palate during mastication (2) The extent to which the cheese clings to the inside of the mouth (roof, teeth, tongue, gums, etc.) (3) No definition	¹ (Adhikari et al., 2003), ² (Everard et al., 2007), ³ (Muir et al., 1997)

4. Overview and conclusion

Food texture is a cognitive property we assign to food on the basis of how our senses **interact** with the product in extra-oral manipulation (spreading and touching) and during consumption.

The correlation studies on cheese have commonly been performed by a trained sensory panel via descriptive analysis. Classical sensory evaluation has been used in parallel to rheological characterization for predicting the sensory descriptors through instrumental variables. In general, this approach has permitted to predict the sensory perception related to firmness of the products. However, the adhesiveness as an important characteristic in cheese products remained weakly or not predicted. The Tack test was a method rarely used in correlation studies; the measured tack energy shows the highest correlation with sensory adhesiveness perception. However, this correlation was negative likely due to the differences of product state in sensory and instrumental (chewed product, saliva and temperature effect). Hence, applying the tack method along with taking the product state into account seems to be a good way to improve evaluation by an instrumental approach.

The product elicitation is the part of the evaluation procedure that prescribes how the assessor should approach the product. This includes the conditions of the test, the methodology applied and the evaluation procedure.

To our knowledge, sensory characterization of processed cheese has always been done through classical methods. Comparing the different studies shows that the definition and evaluation are more different for multidimensional sensations like adhesiveness. The lack of a commonly accepted lexicon shows the more variations involved in these perceptions. Putting panelist in agreement for evaluation of a perception can possibly lead to some information loss. The more variation is involved in a perception, the more difficult is to reach a consensus and the more the result could differ from consumers perception. This can bring the question of adequacy of the classical methods for evaluating the consumer perception especially for perceptions that involves more variations.

Numerous questions remain to investigate how it is possible to ameliorate this existing approach in both sensory and instrumental senses.

Part 2: Main issue, objectives, approaches

1. Problematic

An aim of industries/developer is to anticipate consumers' perception by relating specific ingredient and/or process variables to specific changes in sensory perception to manufacture products with desirable characteristics.

Classical sensory analyses have been commonly used in parallel to rheological analyses to predict the sensory descriptors through physical factors. This existing approach has shown a good correlation for sensory perception related to firmness of the products, whereas the more complex perceptions related to texture, product breakdown, rheology, and surface properties, like adhesiveness, are harder to be predicted. Therefore, mastery of the fabrication with anticipating the complex perceptions still remains difficult for developer. The question is: How can we improve this existing approach to enhance the knowledge for better predicting the multidimensional sensations?

The first point that takes the attention in this approach is using the trained panel to predict the consumers' perception. The trained panel provides detailed product profile actionable for formulator. However, the perception and description of trained assessors could differ from consumers. This is possibly due to extremely controlled and reductionist nature of the method. Extensive training could possibly lead to losing a part of information related to product specificities or the different perception of the minority of the assessors. Hence, a question can be raised about the level of adequacy of formalized methods to anticipate the consumers' perception. This could be especially more important for the perceptions that involves more variations like *stickiness*.

Descriptive sensory approaches by consumers showed to be comparable to trained panelists for product discrimination. However, the semantic universe is more varied and less precise. The lack of information regarding the definition and evaluation procedure in less controlled approaches makes the interpretation more difficult. On the other hand, as mentioned by Meiselman (2013), sensory science deals with human measurements, therefore panelists should be viewed as people, as consumers rather than "machines". Therefore, the question is how we can involve the consumers in a descriptive approach while providing a better trade of between the controlled condition and the including diversity? How to obtain more information by including more diversity and at the same time maintain an adequate control? How to make consumers terms more explicit for developers?

The last question concerns the efficiency of the rheological approaches commonly used for characterization of the complex sensation: Which other method can be applied and how can we improve the instrumental method/conditions to get closer to consumers evaluation condition?

2. Objectives and procedures

Three main objectives have guided our study:

1. **Describe a set of model processed cheese using an individual approach that takes the diversity** in terms of perception, manipulation and description **into account**.
2. **Establish the instrumental assessments on the basis of sensory results**. This is with the aim of using the sensory step for obtaining more information about evaluation procedures in order to better determine the efficient instrumental methodologies and conditions to characterize the identified perceptions.
3. Study the possibility of **predicting the sensory perception** of the texture of processed cheese, in particular the multidimensional ones, **by instrumental factors**.

These objectives were with the aim of **helping the formulator/developer** for mastering the product fabrication along with anticipating the consumer perceptions for complex perceptions. Therefore, a set of model processed cheese with varied textures were fabricated according to an experimental design and provided by the Supplier Company as a support for this study. **The strategies** to reach our objectives are divided into 5 main steps:

1. Firstly, validate the broad texture variation of fabricated product at a sensory level. In this step, the aim was to quickly verify the global textural characteristics of the supplied products and their variations at sensory level. Therefore, a similarity-based method was carried out to obtain a quick and global knowledge of the product set. Moreover, as the supplied model products were fabricated to provide broad texture variations regardless of taste, we wanted to investigate the eventual possibility to simplify the texture evaluation of model products for future evaluations. Therefore, a sorting method in three steps (visual, In-hand and In-mouth) was applied to study the texture variations at sensory level.
2. Evaluate the products through sensory analysis by **an individual approach that includes diversity**.

In order to reach the spontaneous and various perceptions of products, the products were evaluated by consumers.

In fact, how the assessors approach the products, the test condition and evaluation procedure prescribe the perception and description. Hence, a combined method was applied: firstly, a free comment method to investigate “One panelist – One product” interaction. It allows providing the common terminology of consumers, and a very detailed consumer-derived sensory profile of each product. Then, a Flash Profile was conducted. Flash Profile permitted to involve the consumers in a more synthetic descriptive approach and to study “One panelist – Set of product” interactions. The products could be discriminated based on the key characteristic important to assessors.

To improve the methodology for taking more diversity of evaluation into account, panelists were provided with various means (bread and cutlery). Hence, in addition to evaluation procedure, the evaluation conditions differs based on individual choice. The data was collected for each panelist and each product to have an adequate control.

The panelists were also observed while evaluating some products to obtain extra information concerning the way of description and evaluation of the products.

Finally, to investigate the effect of prior expertise on product characterization, a group of expert had also evaluated the products under the same conditions.

3. Establish the **instrumental assessments on the basis of sensory results** (descriptions and observations).

This step was a **transition step** from sensory assessment toward the selection of instrumental methodologies and conditions. Instead of carrying out sensory and instrumental assessments in parallel, it was decided **to start from the sensory evaluation**. For using the sensory evaluations to select/improve the instrumental assessments, the simple description of products is not sufficient, especially for the sensations that are multidimensional and related to various factors. Therefore, supplementary information concerning the test conditions and evaluation procedures were collected in the sensory step to inspire instrumental characterization. Both sensory results (terms and observation) were used to establish a logical strategy for instrumental characterization.

- From the sensory evaluation, free descriptive terms were collected and classified in categories representing different physical properties related to textural behaviors. Then, various instrumental methods appropriate for the characterization of identified categories were selected. The methods should be applicable for the whole set to characterize all categories/ the categories of interest.
 - Observations and/or videotaping of the evaluation procedures of products allow to advise some instrumental testing conditions.
4. Characterize the products through **efficient instrumental methods**.

Once the appropriate methods and conditions were identified, the products were assessed using selected instrumental approaches, with a focus on categories that could contribute to the evaluation of complex perception like “stickiness”. The rheological measurements and the tack methodology were carried out for texture assessment of products.
 5. **Correlate** the sensory and instrumental studies.

Finally, the correlation between the both sensory and instrumental data set is studied to possibly predict the sensory perceptions of assessors by instrumental parameters. This aim goes along with helping the formulator for product fabrication.

3. Product range

To study the correlation between the sensory and instrumental characterization and their link to product formulation, we wanted to work on a range of products representative of texture diversity for processed cheese in the market. Hence, a range of model processed cheeses developed in the Supplier Company was used in support of this study. The product set provides a rich textural diversity representing the texture diversity available in the processed cheese market.

The model products were chosen due to the advantages they offer, such as: providing a simplified system while staying close to the texture of real food, the possibility of developing various product textures by mastering the ingredients and/or processes of fabrication, treating a large number of variables and studying the effect of formulation underlying texture perception. In the framework of

this study, a set of 20 model products (fat-free) were produced on the basis of a 3-factor experimental design:

- 4 types of texturing agents presented as TA-1 to TA-4. A control product with no texturing agent (Ctrl) was also included.
- 2 Concentrations: Diluted products with the lowest level of concentration and Non-Diluted products with slightly higher concentration.
- 2 Processes of fabrication: an additional processing step was used with half part of the products (Processed products).

Code	Symbol used in figures	Texturing agent	Dilution factor	Additional processing
P1	●	Ctrl	-	-
P2	◆		-	+
P3	■		+	-
P4	▲		+	+
P5	●	TA-1	-	-
P6	◆		-	+
P7	■		+	-
P8	▲		+	+
P9	●	TA-2	-	-
P10	◆		-	+
P11	■		+	-
P12	▲		+	+
P13	●	TA-3	-	-
P14	◆		-	+
P15	■		+	-
P16	▲		+	+
P17	●	TA-4	-	-
P18	◆		-	+
P19	■		+	-
P20	▲		+	+

Table 6: List of the products. codes and symbolizations that are used in the figures. Each color presents a group based on texturing agent (TA) and Control (Ctrl). Symbols: (o) not-diluted-not-processed, (◊) processed, (◻) diluted, (Δ) diluted-processed

The products are referred as P1, P2, ..., P20 in the study. Table 6 summarizes the different production factors. Different colors represent the different texturing agents. Different symbols represent the dilution and processing factors.

The experimental design made it possible to develop a range of textures in close proximity one to another while representing a large texture variation **from spoonable to sliceable**. The products provided by the Supplier Company were fabricated to provide a rich **texture variety for processed cheese regardless the taste**. Figure 2 shows some example of typical textures fabricated.



Figure 2 : Typical textures of product range

The mixture of ingredients consisted of: Natural cheeses, milk powder, salts, melting salts, water and texturing agent except the control product with no texturing agent. The products were prepared at pilot scale using a laboratory mixer cooker (Universal Machine UM/SK5, Stephan Machinery France) equipped with direct and indirect steam injection.

Manufacturing process involves, firstly, mixing the products shear continuously at high temperature for sanitation purpose. Then, reducing the temperature around 85°C and either fill the cup directly or maintaining the products for 5 minutes more under shearing before filling step. Finally, sealing the product and holding them at least for three days at -4 °C for stabilization.

The fact that there is no objective criterion of measuring the viscosity in the cutter in addition to the other inevitable variations between two fabrications, such as the quality of vapor/water, results in some differences between two fabrications.

In order to evaluate the reproducibility and validate a fabrication, quality control was carried out in three ways: firstly by subjective controlling of the chief formulator. Once, all the products were produced, he compared and evaluated them by his knowledge and experience. In case of unexpected characteristics of any products, it would be directly reproduced. Then, after at least three days (the necessary time for product stabilization), penetrometry and dry matter measurements were carried out. These methods are the reference tests to validate the production and its reproducibility in the Supplier Company.

To support this study, three separate productions were carried out: Two separate productions for the sensory assessments and one for instrumental assessments. Figure 4 shows the penetrometry and dry matter tests results for quality control of the fabrications for sensory and instrumental evaluations.

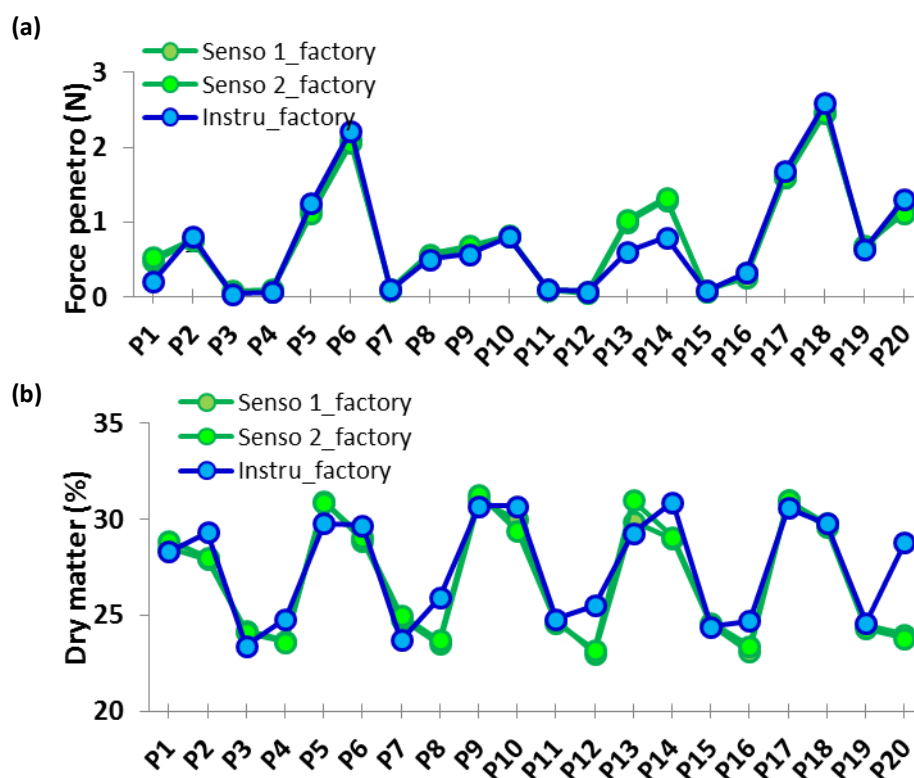


Figure 3: Penetrometry force of products measured at 0.2 mm/s at room temperature 25±2 °C (a). Dry matter results measured at 102 °C for 100 g of product (b).

The manufactured products for sensory assessments were further analyzed by microbiological tests in order to control the hygiene quality of the products for tasting.

The products were sampled in different type of containers in each production based on the type of analysis:

For the first sensory assessment, approximately 150 g of each product were sampled and sealed in brick-like containers (dimensions: 120 × 35 × 80 mm).

For the second sensory assessment, approximately 20 g of each product were sampled and sealed in small rectangular plastic containers (dimensions: 55 × 15 × 45 mm). Conditioning in the form of individual portions was applied in order to provide the same form of product presentation for all types of texture.

For instrumental assessment, the products were conditioned in three different types of containers suitable to specific product assessments: big round containers ($\phi = 90$, $h = 30$ mm), cylindrical polypropylene containers ($\phi = 33$, $h = 70$ mm) and cylindrical containers that were modified by piercing a small hole ($\phi = 3.9$ mm) in the center of their base. Then, the base of the container was covered with a piece of aluminum foil scotch resistant to water, heat and moisture. The products were sampled at high temperature, taped on the table to even the surface and remove the air bubbles and sealed quickly afterward.

Once the production was validated, the products were transported to the university laboratory by refrigerated truck. As the products were stabilized by high thermal treatment, they presented a long shelf life and could be conserved for 3-4 months in a refrigerator.

Part 3: Sensory assessment

We **start** our experimental work from the sensory assessment of the products. The sensory characterization of products remained analytical. Our objective was to obtain descriptive data on model products using an approach that takes inter-individual differences into account.

The free sorting method was used for a preliminary study for validation of texture variations. A combined method (Free comment followed by Flash Profile) was then applied for a more detailed characterization of each product and a synthetic comparison of the entire range based on the important characteristics for each assessor. Finally, statistical analyses were applied to interpret and represent the data.

I. Validation of texture variations at the sensory level

1. Objectives

The main objective of the preliminary study was to verify the texture variations of the fabricated model products at the sensory level. The goal was to obtain a global vision of the perceived similarities in order to investigate if the texture distribution is homogenous and eliminate any atypical products in the range, if any.

The model products were formulated to provide a rich variety of textures regardless of taste. Because the fat had been eliminated, the products' tastes were not as fine as commercial products. To eliminate any taste bias in the texture evaluation, we wanted to investigate the possibility of eventual texture evaluation without oral processing. According to Drake, Gerard, & Civille, (1999a) In-hand and In-mouth evaluations of texture characterization of cheese are related and either of them can be used to discriminate cheese texture.

As our final aim was to use the consumers for final characterization of products, another point to take into consideration was the feasibility of the evaluation of a large number of products

2. Materials and Methods

To achieve our objectives, a three-step sorting method was applied to obtain a quick and global knowledge of the product range and investigate the possibility of simplifying the texture evaluation by eliminating tasting phase.

2.1. Products and conditions

The firm cheeses were cut into 1×2 cm rectangular shape. The softer cheeses were spooned out in approximately equal volume (15g). One product was served in duplicate. The products were served coming out of the refrigerator in sealed plastic pots identified by random 3-digits numbers. The evaluation was conducted in an air-conditioned room (25±2°C) and under the white light in separate sensory booth. The In-hand evaluation was approximately 20 min after the products were taken out of the refrigerator. Plastic spoon were provided for manipulation and tasting. Water and unsalted crackers were available as palate cleanser between samples tasting.

2.2.Assessors

Seventy one untrained panelists (cheese consumers) were recruited from the staff and students of AgroParisTech according to their motivation and availability, in order to gather a diversity of perceptions. The panel consisted of 45 females and 26 males, ages between 18 and 69 years.

Even though the panelists were not trained to evaluate this type of model products or to perform a sorting task, they were familiar with sensory evaluation and/or texture evaluation.

2.3.Procedure

The sorting method is simple and therefore easily applicable with untrained panelists. It allows quickly obtaining knowledge about existing similarities and differences among products. In this method, the products are presented simultaneously to each panelist and they are instructed to sort out the products according to their similarities in the same group (Faye, 2004).

Cheeses texture can be assessed visually, by proprioceptive sensation while handling as well as by tactile sensation in the mouth. Therefore, Three-step sorting method was applied to evaluate the product textures firstly visually, then by In-hand evaluation and finally by tasting.

The 71 untrained panelists were presented with a tray of 20 different samples with one product in duplicate. Due to the limitation of model product quantity, the same tray was used in the three steps. However, between each step the product tray as well as the response sheet was recollected. Meanwhile, the panelist had a break of 5 to 10 minutes, the groups of samples made by the panelist were disarranged in the tray, the samples were cleaned and arranged if necessary (especially after In-hand evaluation) for the next step. This was done in order to reduce the bias of re-using the same tray in all the steps.

Instructions and a picture example of free sorting task were given to the panelists upon their arrival.

In the initial step, assessors were asked to evaluate the products and sort them into the groups based on visual textural similarities. In the second step, assessors were asked to evaluate and sort the products by manipulating them using a plastic spoon. In the third step, the assessors were asked to sort the products based on the texture perception In-mouth without taking into account the taste of the products. The panelists were free to choose the number of groups from 2 to 20.

In addition, once panelists had finished each step they were asked to describe their groups by using one or several descriptive terms. The test was completed in one session and the quality of evaluation was checked through the duplicate product.

2.4.Data analysis

For each panelist, an individual matrix showing which samples belonged to the same group was built. Individual matrices were then summed. The aggregated matrix is a matrix of similarity. Each cell corresponds to the number of times the two samples were placed in the same group. This matrix was transformed into a dissimilarity matrix that was then analyzed by nonmetric Multidimensional Scaling, known as MDS (Faye, 2004). A hierarchical cluster analysis (HCA), using Ward's method was carried out on the 10 resulting components of MDS. This was done for every sorting step. Data analysis was run using the MATLAB™ program.

Hierarchical Cluster Analysis (HCA) seeks to build a typology of various observations present in a table of data. The objective of HCA is to aggregate similar individual to build groups following two criteria: the inter-group homogeneity and the intra-group heterogeneity.

This classification is then presented in the form of a dendrogram that we cut according to the number of desired classes. This choice is most often based on a compromise between a restricted number of clusters and a good homogeneity of each cluster. Data analysis was run using the MATLAB™ program.

3. Results

All the panelists could complete the task successfully. The test took about 1h–1h30 for complete the three steps (respectively 10 min, pause, 20 min, pause, 20-30 min).

The quality of evaluation was checked by duplicate evaluation. Hence, the evaluations of 11 panelists were eliminated as they did not sort the duplicates in the same group in at least one of the steps. The following results are based on the evaluation of 59 panelists (42 females and 18 males).

3.1.Product clusters

The number of groups formed in each step and the number of products per group were compared in order to study inter individual differences, Figure 4.

The results showed that 96% of the panelists made 3 to 10 groups in all three steps. It can be noted that the number of groups used by the highest number of panelist increased from 5 to 6 between Visual and In-hand evaluations and from 6 to 7 between In-hand and In-mouth evaluations. A higher number of groups were made in In-hand and In-mouth evaluations than in Visual sorting, Figure 4. In the Visual step; 61% of panelists made a maximum of 5 groups. In the In-hand and the In-mouth evaluations, 64% made 6 to 10 groups.

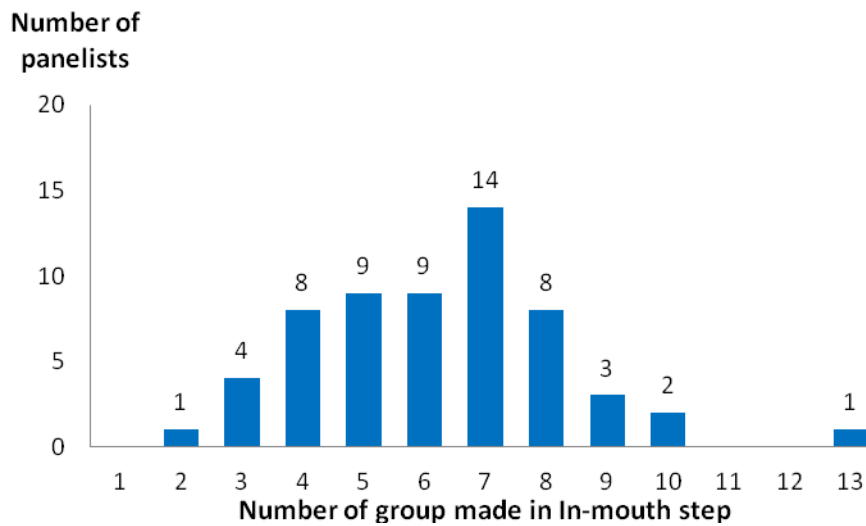
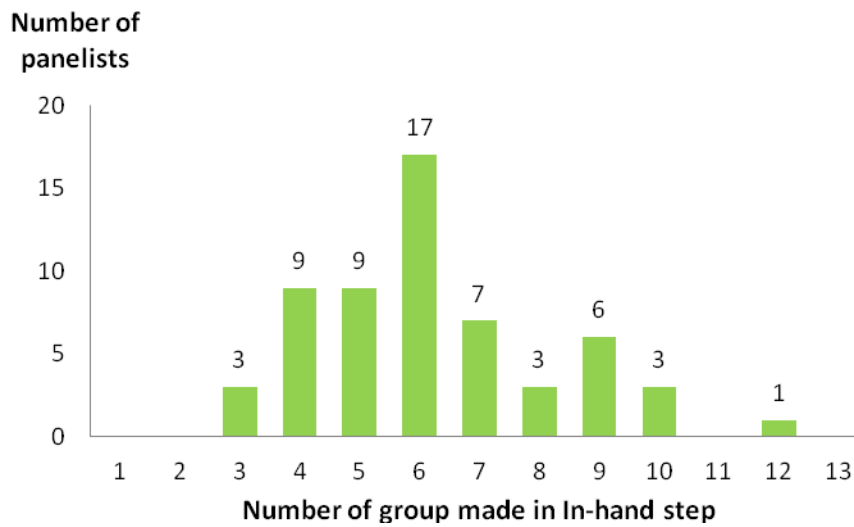
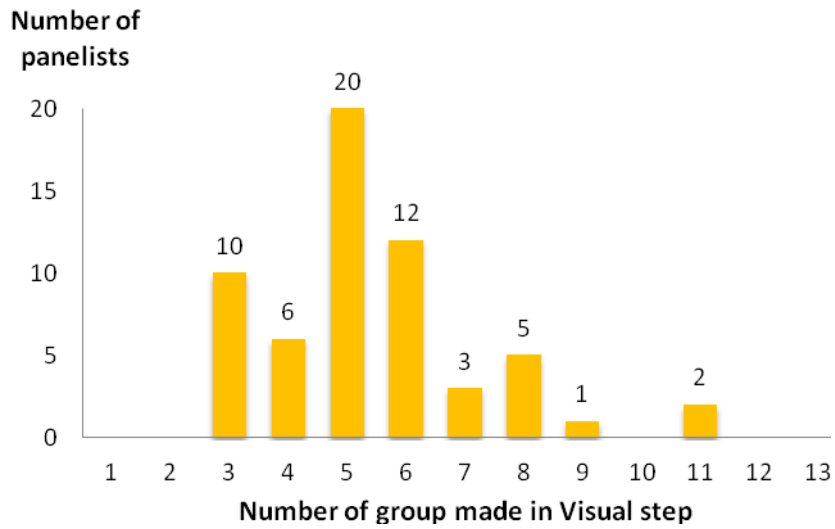


Figure 4: The number of group made by assessors in each step of sorting task

Investigating the number of product per groups showed that the panelists have made more groups with one or two products in tactile evaluations in compared to visual evaluation, Figure 5. Assessors made more groups with a lower number of products in tactile evaluations. However, differences can also be seen between the In-hand and In-mouth evaluations. In general, they are less different in

comparison with visual evaluation. This could be explained by two reasons: either more differences were perceived among products in mouth, or the task was more difficult for the panelist and therefore they made more groups with only one product.

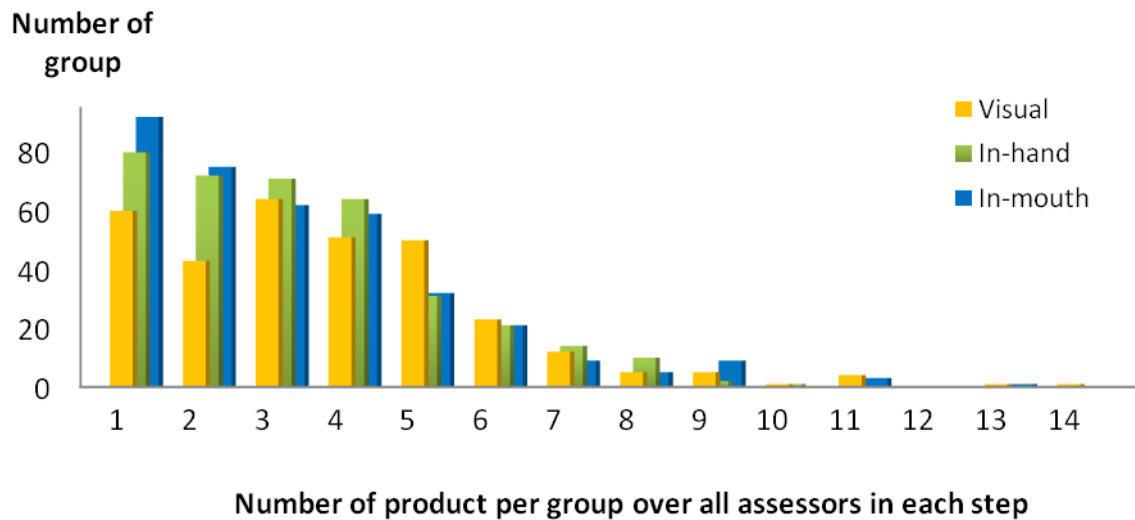


Figure 5: Distribution of products per group in each step

The nonmetric MDS analysis was conducted to treat the data at the aggregated level. Then, the MDS configuration of each step was input into HCA with Ward criterion. Figure 6 demonstrates the result for each step.

The HCA analysis resulted in 3 main clusters consisting of 5 sub-groups in all three steps. No single product has resulted in one cluster. Comparing the results demonstrated that In-hand and In-mouth evaluations resulted not only in the same groups of product but also in same group proximities. However, the resulting clusters for visual evaluation were different in terms of products as well as group proximities. Figure 6 depicts that cluster 1 (CL1) of visual evaluation contains a group of 5 products and is more discriminated from the two other clusters. However, in tactile evaluations, cluster 3 (CL3) is more discriminated and consists of two groups of products (Group 3 and Group 5).

Moreover, the groups' proximities are also different in the visual step in comparison to the tactile ones. Groups 4 and 5 are closer visually. However, they show more textural differences while handling or tasting. The same result can be seen concerning Groups 3 and 4 of visual evaluation. Finally, product P4 showed more texture differences in tactile evaluations compared to the visual one.

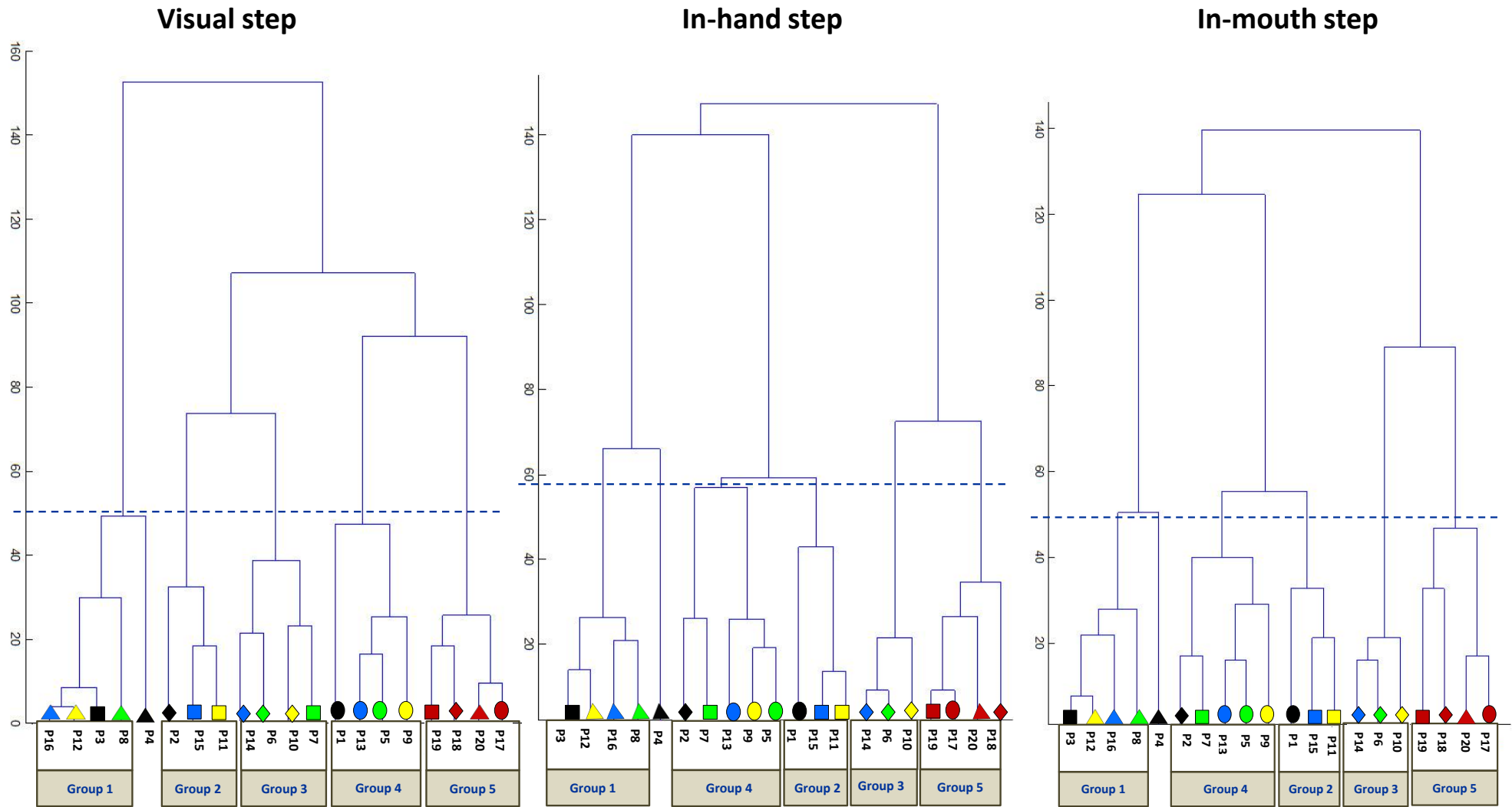


Figure 6: Classification of products on 10 dimensions of Multidimensional Scaling for each step of sorting resulted in three main cluster (CL1 to CL3) and 5 sub-groups (Group 1 to 5).

Our results are consistent with the literature. In a study on texture characterization of 13 different types of natural and processed full fat and reduced fat cheeses by trained panelists, Drake, Gerard, & Civile (1999a) have reported that hand and mouth evaluations differentiated the cheeses in a similar manner. Karagul-Yuceer, Isleten, & Uysal-Pala (2007) have also found a high correlation between hand and mouth evaluations of texture of soft and semi-hard cheeses. In another study on texture characterization of a range of model processed cheese analogues, Pereira et al., (2002) reported that the in-hand evaluation, despite being unconventional, could be used for textural assessment and cheese discrimination with relatively narrow textural ranges. The oral and mental fatigue in the sensory evaluation of natural and processed cheeses is an issue and is likely to affect textural assessment so that In-hand evaluation could be efficient (Pereira et al., 2002). The correlation between In-hand and In-mouth evaluations has also been reported in studies on different type of products. For instance, in a texture study of apple purees a strong correlation between the attributes used to evaluate the texture using a spoon and in mouth was reported by Espinosa-Muñoz et al. (2012). However, they explained that in some cases the evaluation in mouth is more sensitive than with a spoon.

The results show that the product clusters were related to formulation variables. In general, the Group 1 was related to dilution factor and Group 3 to additional processing step. In Group 1, for all three steps and in Group 4, for tactile evaluations, the products which were additionally processed but had no texturing agent (P2 and P3) were grouped with products containing texturing agent that were not processed. Figure 6 shows that Group 1 regroups P2 with P5, P9, P13 and Group 4 regroups P3 with P8, P12 and P16. This reveals that the additional processing step had an important effect on product texture. It compensated the effect of the addition of texturing agent for the control. Furthermore, it can be noted that among the 4 different texturing agents, the products containing TA4 (Group 5) were perceived distinctively from other products in all the steps. This shows the distinctive effect of TA4 compared to the other texturing agents on product texture. Indeed, the results showed that the resulting groups were mainly related to processing and concentration factors rather than to the polysaccharides' family with one exception.

To sum up, the experimental design used for formulation made it possible to obtain a range of model products with diverse textural properties at the sensory level. Moreover, none of the texture extremities conditioned the clusters of product. The relation between resulting clusters and experimental design show the relationship between product description and formulation factors. This also confirms the reliability and consistency of the sorting method.

3.2.Product descriptions

Right after the assessors made their groups in each step, they were offered the possibility to describe those using descriptive terms. Terms cited by at least 10% of panelists per product per sorting step were studied in order to have a general idea of each cluster's characteristics.

In all three steps, a total of 1789 terms were cited (538, 622 and 629 terms respectively for the first second and third evaluation steps) with 124 different terms (77, 74 and 84 different terms respectively for the first second and third evaluation steps). The majority of panelists described their groups using 1 to 3 terms (75%), whereas others used up to 5 terms to describe a group in one or all the three steps, [Figure 7](#).

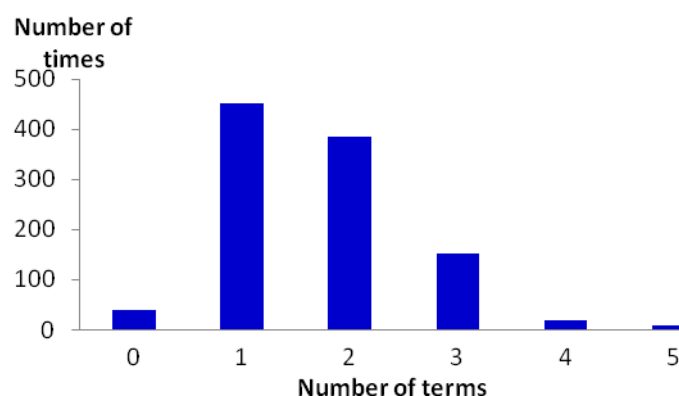


Figure 7: Number of terms cited to describe a product over the three steps

Quantifying the frequency of citation of terms made it possible to describe each HCA cluster in each step. The most cited terms to differentiate groups of products were related to consistency and to adhesion/cohesion properties: “Collant (Sticky), Liquide (Liquid), Ferme (Firm), Mou (Soft), Dur (Hard), Fondant (Melting)” and “Pâteux (Pasty)”. Table 7 shows the terms applied by at least 10% of the consumers to describe each cluster per step.

Table 7: Terms cited for each HCA group by at least 10% of assessors. English translation in *italic*.

	Visual	In-hand	In-mouth
G1	Ferme (<i>firm</i>), Dur (<i>hard</i>), Mou (<i>soft</i>), Solide (<i>solid</i>), Sec (<i>dry</i>)	Dur (<i>hard</i>), Ferme (<i>firm</i>), Collant (<i>sticky</i>), Compact (<i>compact</i>), Solide (<i>solid</i>)	Collant (<i>sticky</i>), Pâteux (<i>pasty</i>), Dur (<i>hard</i>), Ferme (<i>firm</i>), Fondant (<i>melting</i>)
G2	Brillant (<i>shiny</i>), Ferme (<i>firm</i>), Mou (<i>soft</i>), Compact (<i>compact</i>), Dur (<i>hard</i>), Fondant (<i>melting</i>), Solide (<i>solid</i>)	Collant (<i>sticky</i>), Mou (<i>soft</i>), Moelleux (<i>smooth</i>), Elastique (<i>elastic</i>), Crémeux (<i>creamy</i>)	Collant (<i>sticky</i>), Fondant (<i>melting</i>), Pâteux (<i>pasty</i>), Crémeux (<i>creamy</i>), Mou (<i>soft</i>)
G3	Compact (<i>compact</i>), dur (<i>hard</i>), ferme (<i>firm</i>), solide (<i>solid</i>), blanc (<i>white</i>), brillant (<i>shiny</i>), sec (<i>dry</i>)	Dur (<i>hard</i>), Ferme (<i>firm</i>), Cassant (<i>brittle</i>), Solide (<i>solid</i>), Compact (<i>compact</i>), Tranchable (<i>sliceable</i>), Mou (<i>soft</i>)	Granuleux (<i>grainy</i>), Ferme (<i>firm</i>), Dur (<i>hard</i>), Cassant (<i>brittle</i>), Pâteux (<i>pasty</i>), Friable (<i>crumbly</i>), Collant (<i>sticky</i>)
G4	Coulant (<i>runny</i>), Liquide (<i>liquid</i>), Fondante (<i>melting</i>), Visqueux (<i>viscous</i>)	Liquide (<i>liquid</i>), Collant (<i>sticky</i>), Crémeux (<i>creamy</i>), Mou (<i>soft</i>), Tartinable (<i>spreadable</i>), Pâteux (<i>pasty</i>), Visqueux (<i>viscous</i>), Coulant (<i>runny</i>)	Liquide (<i>liquid</i>), Collant (<i>sticky</i>), Fondant (<i>melting</i>), Crémeux (<i>creamy</i>), Onctueux (<i>unctuous</i>), Mou (<i>soft</i>), Pâteux (<i>pasty</i>), Coulant (<i>runny</i>)
G5	Brillant (<i>shiny</i>), Mou (<i>soft</i>), Ferme (<i>firm</i>), Crémeux (<i>creamy</i>)	Collant (<i>sticky</i>), Mou (<i>soft</i>), Crémeux (<i>creamy</i>), Tartinable (<i>spreadable</i>), Fondant (<i>melting</i>)	Collant (<i>sticky</i>), Fondant (<i>melting</i>), Crémeux (<i>creamy</i>), Pâteux (<i>pasty</i>), Liquide (<i>liquid</i>), Mou (<i>soft</i>)

Comparing product descriptions in the three steps show that some terms were in common regardless of the evaluation method such as: “Liquide, Ferme, Mou”, whereas some other terms were specifically used for a step, for instance “Sec” for visual, “Tartinable, Tranchable, Élastique, Moelleux” for In-hand, “Friable, Granuleux” for In-mouth step.

There are differences in product descriptions among clusters for In-hand and In-mouth evaluations. . For example G4 is the only group described as “Pâteux” by In-hand evaluation, however, this term is used for description of all the groups in In-mouth evaluation. The same difference can be observed regarding the term “Fondant” which was applied only for Group 5 from In-hand evaluation and for all the groups of In-mouth evaluation. This shows that some textural characteristic such as “Pâteux” and “Fondant” are easier to perceive In-mouth rather than In-hand. Despite of the differences in terms of description of the identified groups, the product groupings were very similar after tactile evaluations.

All the assessors could complete the test successfully and the number of products was not a limitation. However, the assessment of 11 panelists was eliminated due to their lack of repeatability verified by duplicate products.

Panelists’ declaration: The panelists declared that the products were not pleasant to taste and some panelists said that they had to spit out the product quickly after tasting. The panelists’ declarations also confirmed that the tastes of the provided products could cause some difficulties to characterize the model products, especially with consumers.

4. Overview and conclusion

The results confirmed that the experimental design on formulation made it possible to obtain a range of model products with a good variety of perceived textures. However, the product range varied from spoonable to sliceable; none of the texture extremities conditioned the clusters of HCA on products.

Three-step sorting made it possible to study texture perception at different stages of product consumption. In general, the results showed inter and intra individual differences for texture evaluation in three steps. Nevertheless, **analyzing the aggregated data yielded the same groups and proximities for In-hand and In-mouth evaluations. The differences of product description between two tactile evaluations showed that even though the panelists have used different descriptors, the products clusters remained similar.**

Based on the results of tactile evaluations, assessors’ declarations regarding the taste of the products and the industrial need for characterization of the provided model products, we decided to eliminate the In-mouth evaluation for further studies. This was done to simplify texture characterization for consumers and to eliminate the possible bias related to the taste of the products. One should consider that this decision was taken for this range of model products and on the basis of our objectives and the industrial needs. This could be a good solution for studying model products at preliminary stages with consumers. However, before simplifying the evaluation, we recommend that one should improve the conditions of the test by changing the whole tray and the code of the products for all the steps. This decreases the possible bias related to the panelist’s memory.

To conclude, the experimental design on formulation provided a good range of model products with varied textural properties at the sensory level. Three-step sorting showed that In-hand and In-mouth evaluations resulted in similar product clusters at the aggregated level. Hence, visual and In-hand evaluations were chose to describe our model products textures for the rest of the study.

II. Texture perceptual assessment by an individual approach

1. Objective

Various factors such as the way the panelist approaches the product, the testing condition, the evaluation procedure and the level of expertise can affect perception and description. Hence, the main aim in this part was to characterize the texture of a range of model processed cheeses using a **sensory methodology that takes the diversity** in terms of perception, description, and manipulation into account. The objectives are multiple:

- Study the interaction of one panelist with one product as well as the interaction of one panelist with several products. This aimed at investigating the changes in the assessor's perception and description of a product by itself and in comparison with other products.
- Improve the methodology to include more diversity in product evaluation while having an adequate control to know what changes and what stay constant. The goal was to involve some level of individual choices in testing conditions and maintain an adequate control to know what changes and what stays constant (diversity of testing condition). This part also aimed at providing extra information about the existing differences of evaluation procedures in order to enhance the further characterization of products by instrumental analysis.
- Finally, investigate the effect of prior expertise of panelists on product characterizations. Hence, the products characterization of consumers is compared to those of panelists with prior experience.

The texture evaluation in mouth was eliminated for this study based on the preliminary results. In the section below, the strategy to reach these objectives and the results are explained.

2. Materials and Methods

2.1 Products and test conditions

A set of 20 products were manufactured, sampled and sealed in small rectangular plastic containers (dimensions: 5.5 X 1.5 X 4.5 cm). Conditioning in the form of individual portions was applied in order to provide the same form of product presentation for all types of texture. This also made it possible to present the products in a package familiar to consumers. The products were then stored in a refrigerator at 4°C.

The samples were served at room temperature (25±2 °C). The containers were identified by letter codes and were presented either according to a balanced design or simultaneously. One product was duplicated in order to evaluate the repeatability of the panelists.

One of the objectives of this work was to use a methodology considering the variations in product handling into account. Therefore, panelists were provided with various types of bread and cutlery adequate for product evaluation. This gave them the options and freedom for choosing in some level their evaluation conditions. Since some of the products were spreadable, various types of bread (breakfast rusks, baguette, sandwich breads and mini-toasts) were placed at their disposal to provide a diversity of support from soft to hard textures. Metal knives and small spoons, paper plates and

napkins were supplied. Assessors were free to change their cutlery or bread anytime during the test. There was also a small bin in each sensory booth to throw away the container seals.

2.2 Assessors

Products were evaluated by two panels: consumer panel to obtain spontaneous and diverse perceptions of products, and expert panel to study the prior expertise effect on product characterization.

Hence, a group of 60 consumers was recruited by putting announcements in different places such as super markets, Ecole Centrale de Paris, AgroParisTech, the website of Société Scientifique d'Hygiène Alimentaire (SSHA) and by word-of-mouth. Since the products had to be manufactured, the number of panelists was limited by the available amount of products.

In addition to the availability and motivation of the assessors, the main criterion for recruitment was to select people who were consumers of cream cheese and processed cheese products. Another criterion was to select people with no experience in descriptive sensory analysis. The consumer group consisted of 80% females and 20% males, between 18 and 69 years old (mean age: 37 years old).

A panel of ten experts with high experience in both texture and sensory fields was also recruited from AgroParisTech staff. The expert group consisted of 50% females and 50% males, aged between 18 and 69 years (mean age: 47 years).

2.3 Procedure

The applied descriptive methodology consists of three steps that are explained below:

Step 1: Characterization of each product by an individual approach

The free comment method was applied in order to obtain the characterization of each product through an individual approach. This method was chosen for the following reasons: study the interaction of one panelist with one product, to achieve the consumers' terminology and finally to obtain a precise sensory profile of each product directly through consumers' perception. Moreover, this was a preliminary step and helped the consumers generate their own terminology.

The products were presented in a sequential monadic order (presenting products one by one) according to a balanced design. The panelists were asked to describe the products by observation and manipulation before tasting using as many terms as they wanted. Panelists were free to choose any type of bread or cutlery and to handle the products however they wished.

For each panelist and each product, a supplementary information sheet was completed by the animator to provide information about the variation of evaluation conditions (type of bread and cutlery used by panelists). All these data were collected by the animator indirectly and only through observation to avoid influencing the assessors.

Step 2: A synthetic characterization of all product using Flash Profile

In the second step Flash Profile was used to involve assessors in a more synthetic characterization of the products. The method was chosen to study the interaction of the panelist with several products, obtain the key characteristics for discriminating the products and quickly reach a relative sensory positioning of products.

The products were presented simultaneously. The panelists were asked to compare all the products and to generate a maximum of 5 key terms that they found important to describe the differences

among the products. Then, they had to immediately rank all the products for each attribute. Equal rankings were allowed. Panelists were free to manipulate the products however they wished.

The maximum of the 5 terms were applied on the basis of the preliminary study (Three-step sorting) in which a maximum of 5 terms were applied for descriptions, and 5 clusters of products were resulted through HCA analysis.

Step 3: Supplementary observations

In the third sensory step, the panelists were asked to describe three products one by one. While doing the evaluation, their hands were videotaped in order to study the different techniques and to gather extra information for instrumental characterization.

The three products were chosen to present the main differences in the product range. They were chosen from the three main HCA clusters of the preliminary study and were: P4 from cluster 1 (CL1), P2 from cluster 2 (CL2) and P18 from cluster 3 (CL3), Figure 6, page 60.

3. Data analysis

Several statistical methods were carried out to analyze the data. The applied statistical tools include the word-count method commonly used to treat free-comment data. Different multidimensional methods were used to represent **one data set** in a synthetic graphical form: Correspondence Analysis (CA) and Hierarchical Cluster Analysis (HCA). Other multidimensional methods allowed working on **several data sets** such as Generalized Procrustes Analysis (GPA). Moreover, pivot table function was used to synthesize the raw supplementary data collected regarding evaluation conditions in individual characterization of products.

The data from the different steps of the tests were collected on Microsoft Excel® spreadsheets. All multidimensional data treatments were performed using the XLSTAT® add in for Microsoft Excel® except the GPA on sensory data of Flash Profile that was performed using PrefStat® with MATLAB®.

3.1 Frequency-based analysis

Analysis of textual data: As panelists were asked to provide free comments for product characterization, it was necessary to standardize their comments for further analysis. According to Ten Kleij and Musters (2003) although adverbs, adjectives and negations are often eliminated in text analysis of free statements, they could be the most important information, in combination with the words they belong to. Therefore, instead of eliminating them, the word counting should be done by counting word combinations to see how often particular occurrences of words are used to describe each of the products. In addition, synonyms are an important aspect of panelists' vocabulary and their handling is generally subjective (ten Kleij & Musters, 2003). In this study, in order to prevent over interpretation or over grouping of modalities, we avoided regrouping terms unless they belonged together according to the criteria below. The actual word counting was done manually and the word counting was carried out as explained below:

1. Verifying typing and spelling mistakes.
2. Removing connectors and auxiliary terms when a panelist wrote a sentence instead of separate terms.

3. Reducing the derivatives of the same word such as “Ferme (Firm)” and “Fermeté (Firm).” Reducing or stemming the derivatives is not a subjective task and is straightforward (ten Kleij & Musters, 2003).

4. Grouping few words that are considered as synonyms free of any discussion such as: “Bulles d’air (Air bubbles)” and “Bulles (Bubbles)” or the terms referring to same intensity level terms like “Légèrement (Slightly)” and “Un peu (A little bit)”

The terminology, products’ main (common characteristics among products at the aggregate level) and specific characteristics (peculiarity of each product) were then analyzed for each panel separately. The results were then compared between both panels.

Terminological quantification for the entire product set:

The frequency of citation of all the terms by all the assessors over the entire product set was studied separately for each panel. This is to obtain the terms most frequently cited by the consumers (Consumers’ Terminology) and by the experts (Experts’ Terminology).

An arbitrary threshold of 10% was applied to eliminate the specific terms of individual assessors over the product set. The terms cited by more than 10% of assessors over product range were considered to drive each panel’s terminology.

Terminological quantification for each product:

The specific characteristics of each product were found by studying the terms cited by more than 10% of the assessors (> 6 consumers, > 1 experts), separately for each panel. The characterizations of the duplicate products were compared in order to evaluate the assessors’ repeatability.

Terminological comparison between two panels:

In order to compare the ranking of the terms most frequently cited between the two panels, the frequency of each term was defined as:

$$\text{Frequency} = \frac{\text{number of citation of a term}}{\text{maximum possibility of citation}}$$

Where;

$\text{Maximum possibility of citation} = \text{total number of panelists} \times \text{total number of products}$

3.2 Correspondence analysis

Correspondence analysis (CA) is a multivariate method which looks at the correspondence between row (sample) and column (qualitative data, presence-absence of attributes). In its original application, CA can be regarded in the light of performing a PCA, related to quantitative data, on two categorical variables which make up a two-way contingency table (McEwan et al., 1989).

CA, in a similar manner as PCA, represents graphically the rows and columns on a map showing the main components that we chose to retain. Contrary to PCA, the representation of rows and columns is simultaneous in CA because the method analyzes rows and columns equivalently. In CA, the interpretation of graphs is based on the examination of the relative contributions of each row and

each column on each component. For interpretation, we have to take into account only rows and columns having a relatively high contribution to the corresponding component.

In our study, CA was used to process the verbal data stemming from free comment method. A frequency-based table of the products and the most frequent terms (products \times most frequently cited terms \times frequencies) was established for each panel. Running CA on the contingency table of the most frequently cited terms was done to discriminate the products mainly based on their common terms (main characteristics). This was chosen rather than impacting the CA map configuration by specificities of one or a small number of products and masking their main differences.

In addition, a HCA was also carried out after CA on the chi-square distance table in order to estimate the sensory proximity of the products on the basis of the assessors' terminology (separately for each panel). Following the HCA, the profile of each cluster was built on the basis of the average term frequencies for each cluster (main characteristics of products).

3.3 Generalized Procrustes Analysis (GPA)

Generalized Procrustes Analysis (GPA, Gower, 1975) is applied when several configurations are to be compared. It was used to process Flash Profile data

The data table is in the form of a matrix X structured in k groups of variables, the matrices X_i . It includes n rows of individuals to be described (in our case, products). In columns there are the quantitative variables characterizing objects (in our case, sensory descriptors stemming from the Flash Profile). The number of columns of X_i is p_i .

The method applies several iterative stages of translation, rotation and scaling of individual data in order to minimize the distances between the various configurations and to calculate the mean positions of the products. A PCA on the average configuration shows a graphic representation of the results and consequently helps visualize the presence of a consensus between the individual data sets. It represents all the individual descriptors on a plot of variables.

Following GPA, two cluster analyses were carried out: one on the products' mean configuration coordinates to estimate sensory proximities and another one on descriptive term coordinates to identify common use of groups of terms.

The cluster analysis on the differentiating terms following GPA helps the semantic interpretation. The results are presented using the CONEPLOT graphical technique on the differentiating terms for the attribute biplot. For the products, an ellipse symbolizing the confidence area for product mean was computed with individual scores and is presented on the sensory map (Monrozier, Sieffermann, & Danzart, 2001).

3.4 Pivot table

To study the diversity of evaluation conditions the data were analyzed using a pivot table. The pivot table crossed assessors (consumers or experts) with each product for cutlery and breads separately.

4. Results & Discussion

In the following part the results are presented in three sections: Firstly, the consumers' characterizations of products are presented. Then, the results for experts' characterizations are presented. Finally, the last part compares the results of both groups to study the effect of expertise on product evaluation.

4.1 Consumers

4.1.1 Step 1: Characterization of each product by an individual approach

Consumers terminology

Personal characterization of consumers for each product allowed us to extract a rich lexicon of consumers' terminology. In total, the 60 consumers generated 5355 individual terms composed of 550 different terms (about 10 different terms per consumer).

Examining the terms generated by consumers showed that they successfully evaluated the product texture as they were asked to. It was observed that 86.4% of the total generated terms were related to texture and visual aspects (the terms of transparency, color and shape). Only 9.4% of the terms were related to other product names ("Fromage fondu (Processed cheese)", "Cancoillotte (Cancoillotte)", "Pommade (Pomade)"), hedonic terms ("Agréable (Pleasant)", "Appétissant (Appetizing)", "Attirant (Appealing)"), and containers filling terms ("Moitié vide (Half empty)"). Additionally, 4.2% of the terms were cited only once. Figure 9 shows the distribution of the different terms on a frequency basis.

In spite of the large diversity in terms, some of them were cited frequently by consumers. Among 550 different terms, the nine terms that were cited the most frequently to characterize the set of the model products were "Collant (Sticky)", "Brillant (Shiny)", "Jaune (Yellow)", "Lisse (Smooth)", "Compact (Compact)", "Dur (Hard)", "Etalable (Spreadable)", "Crémeux (Creamy)", "Facile à Tartiner (Easy to spread)". These terms were mainly those referring to product texture on the basis of either visual or handling aspects and one term was related to product color. A ranking of these terms and their frequency is given in Table 8.

These 9 terms corresponded to 35% of the generated terms that were related to texture and visual

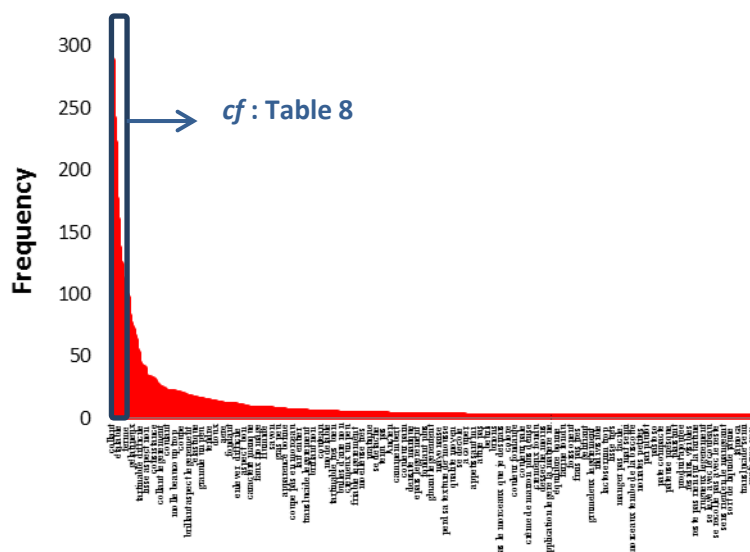


Figure 8: Distribution of total terms cited by consumers

aspects of the products. However, at first glance this percentage might not seem very high; considering the texture diversity due to the opposite characteristics of some products (sliceable to spoonable) or specific characteristic for others, some terms were applied only to a small number of products. Therefore, this percentage seems to be a reasonable result.

Table 8: Terms most frequently cited by 60 consumers. English translations in *italics*.

Terms frequently cited		Frequency
Collant	<i>Sticky</i>	288
Brillant	<i>Shiny</i>	241
Jaune	<i>Yellow</i>	222
Lisse	<i>Smooth</i>	176
Compact	<i>Compact</i>	160
Dur	<i>Hard</i>	137
Etable	<i>Spreadable</i>	126
Crémeux	<i>Creamy</i>	126
Tartine_facile	<i>Easy to spread</i>	126

Product main characteristics, positioning, semi-profile

The nine terms most frequently cited by consumers were then used in order to discriminate the products on the basis of their main common characteristics.

CA was carried out on the frequency-based table (frequencies \times products \times 9 most frequently cited terms) to obtain the products positioning based on the main characteristics. The results shows that the first three dimensions accounted for 88% of the information, from which, the first two dimensions accounted for almost 80% of the variance (respectively 63.5% and 16%). Further dimensions explained only a small proportion of variance (<5%), Figure 9.

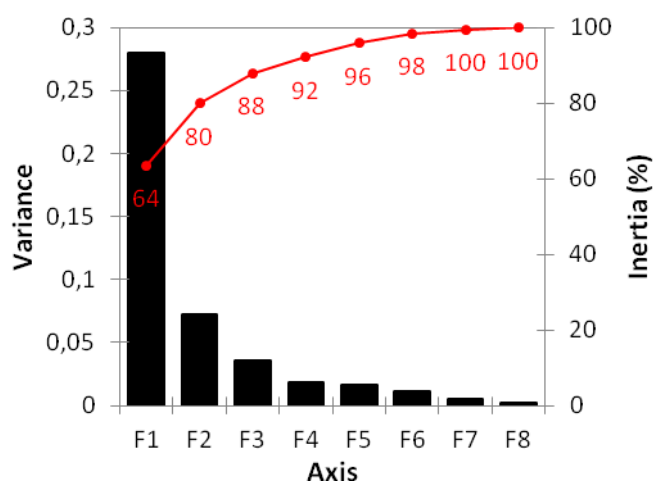


Figure 9: Distribution of the variance per dimension of Correspondence Analysis (Consumers)

Axis 1 represents mainly the terms “Dur (Hard), Compact (Compact)” versus the term “Crèmeux (Creamy)”. Axis 2 opposes the term “Crèmeux (Creamy)” to the term “Jaune (Yellow)”. The characteristics “Collant (Sticky)”, “Brillant (Shiny)” are figured in the third dimension, Figure 10.

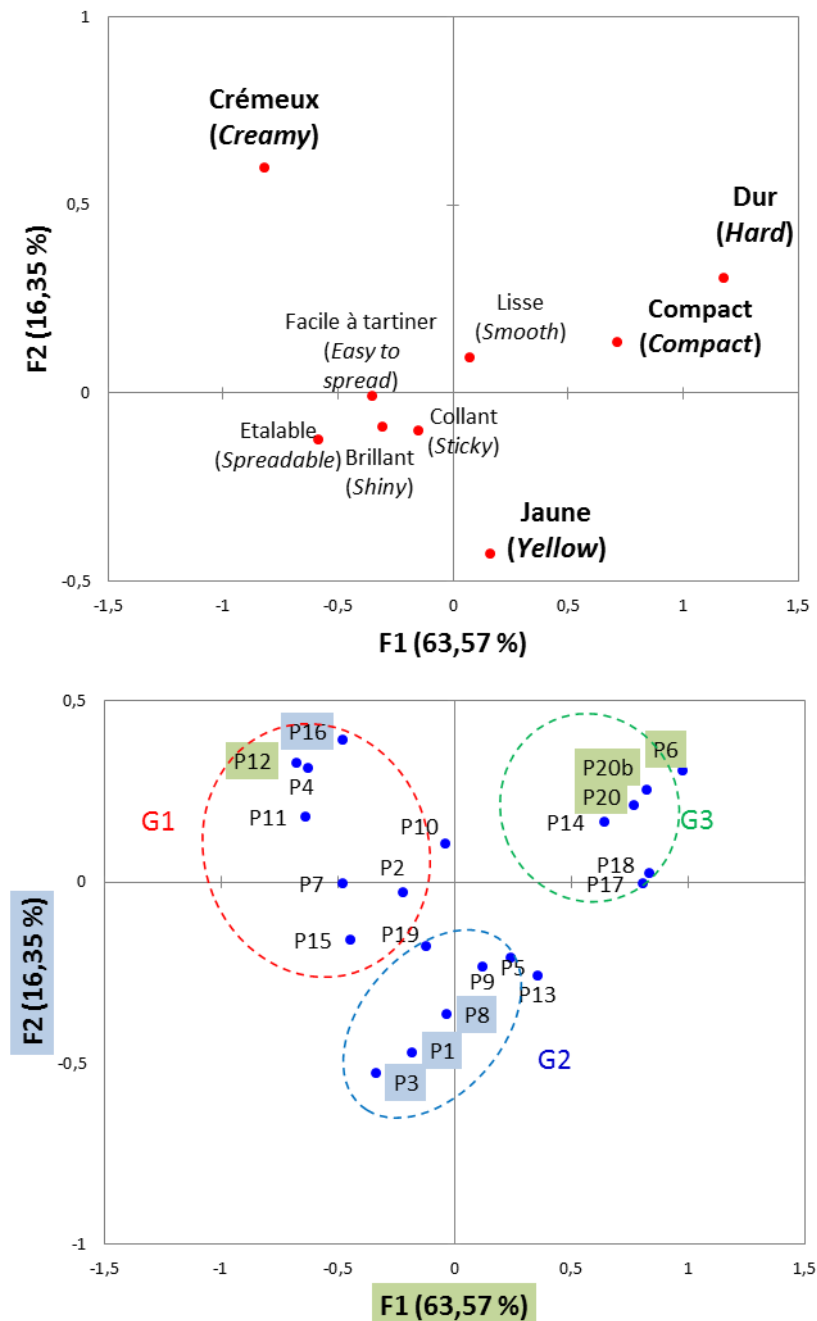


Figure 10: The first two dimensions of the sensory map from CA. G1, G2 and G3 correspond to the groups of product resulted from HCA (Consumers). The highlighted products and the terms in bold have high contributions to the F1×F2.

The products were split into three groups on the first dimension. Products P4, P7, P11, P12 P15 and P16 are positioned on the left side of axis 1. The products P12 and P16 were discriminated by consumers as being less “Dur (Hard), Compact (Compact)”, and more “Crèmeux (Creamy)”. Products

P6, P20 and P20b on the right side of axis 1, were predominantly described as being more “Dur (Hard), Compact (Compact)”, and less “Crèmeux (Creamy)” than the rest of the products. Axis 2 discriminates three products (P1, P3, P8) that were indicated as being more “Jaune (Yellow)” than the other products.

Hierarchical Clustering Analysis was performed after CA to help the identification of groups with similar/different sensory profiles, and give an idea of product discrimination.

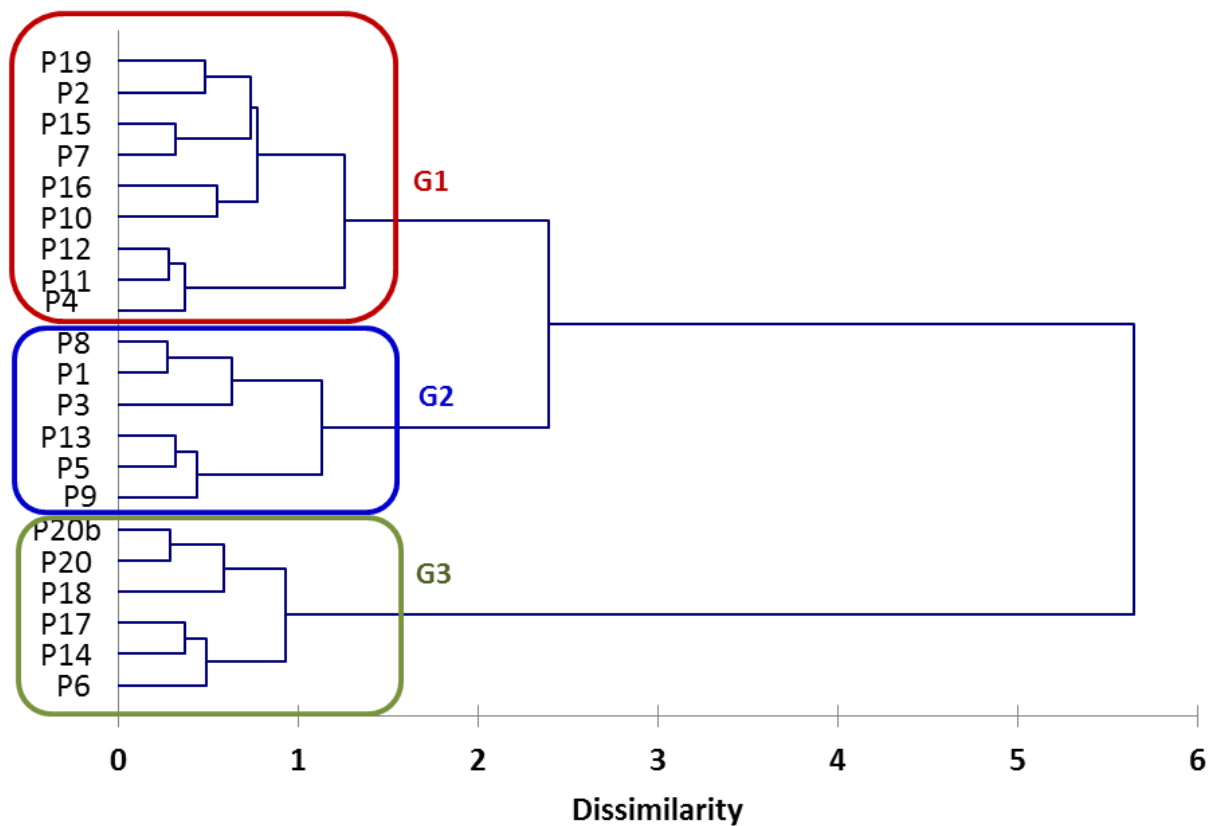


Figure 11: Dendrogram of the HCA after CA of products described by 60 consumers. Three groups of products G1, G2, G3.

Three main groups; G1, G2, G3, were obtained as shown in Figure 11. These groups are also shown on the CA plots in Figure 10. The groups of products were separated mainly along the first dimension of CA, mostly based on textural terms (Creaminess, Firmness). HCA resulted in the same groups of products as CA.

Following HCA, a semi-profile of each HCA group was built on the basis of the averaged frequencies of the 9 most frequently cited terms given by more than 10% of the consumers. This was aimed to summarize the main differences between the three product groups. Figure 13 depicts the semi-profiles for the three product groups resulting from HCA. The building of these semi-profiles for each group enabled us to discriminate them quickly on the basis of their main characteristics.

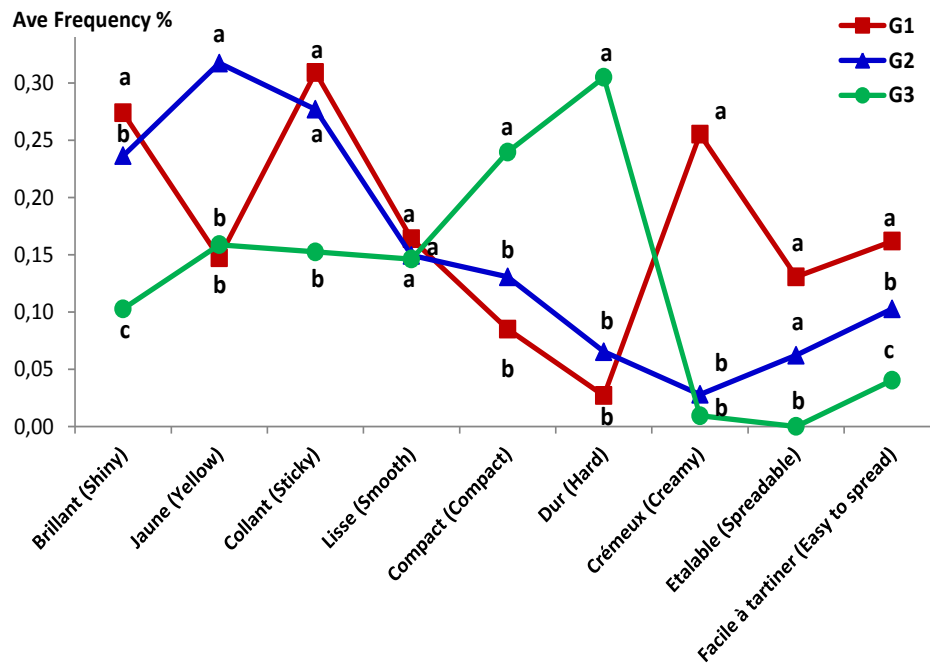


Figure 12: Aggregated frequency of mentioned terms for each of the clusters identified in HCA. The semi-profile of each HCA cluster on the basis of the averaged frequencies (Consumers). The different letters “a, b, c” referred to significance differences between the groups for each term (ANOVA, $p < 0.05$).

The best characteristics for discriminating the three groups are “Facile à tartiner (easy to spread)” and “Brillant (Shiny)”. The characteristic “Lisse (Smooth)” did not significantly distinguish the identified groups.

G3 is best discriminated from the G1 and G2 based on 6 attributes: “Brillant (Shiny)”, “Collant (Sticky)”, “Compact (Compact)”, “Dur (Hard)”, “Étalable (Spreadable)” and “Facile à tartiner (Easy to spread)” attributes. The products in G3 are mostly “Dur (Hard)”, “Compact (Compact)” and are the least “Facile à tartiner” and “Étalable (Spreadable)”. The G1 group contains the most “Crémeux (Creamy)” products. These products are also relatively most easily spreadable “Facile à tartiner” and visually shiny “Brillant”. The G2 is significantly discriminated from both G1 and G3 based on the spreadability characteristic “Facile à tartiner” and visual aspects “Brillant (Shiny)”.

The G1 and G2 both contain products that are “Brillant” (Shiny), “Collant (Sticky)”. However, the G3 is least shiny “Brillant” and sticky “Collant” in comparison with G1 and G2.

Furthermore, on the axis 3 of CA the product P10 was discriminated as being more “Collant (Sticky)” and less “Brillant (Shiny)” than the rest of the products, Figure 14.

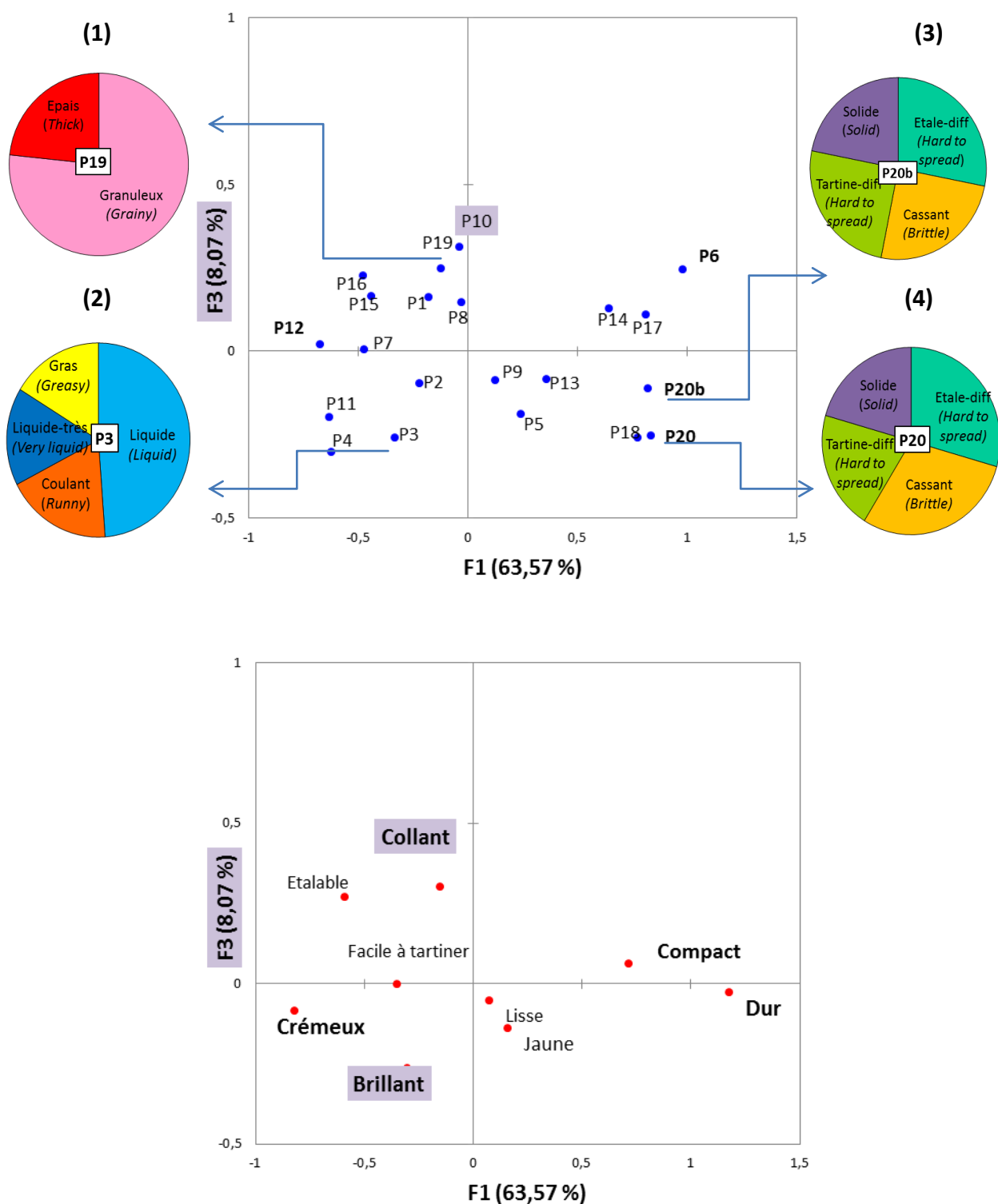


Figure 13: The first and third dimensions of the sensory map from CA. The attribute plot explains the main characteristics of the products. (1) to (4): The visual representations of P3, P19, P20 and P20b specific characteristics.

Specificities of each product

In addition to global characterization of products on the basis of the 9 most frequent terms, the specific terms for each product were also studied to better characterize them. Specific characteristics of each product were identified based on the frequency of the terms generated by more than 10% consumers per product.

By applying this threshold, 27 new terms that were used more specifically by consumers for product characterizations were achieved. These 27 terms represented 15.24% of the generated terms related to texture and visual aspects of products. Table 9 depicts the list of these specific terms used by consumers to describe one or several products and their translation in English.

Table 9: List of the specific terms generated by 60 consumers for various products. English translations in italics.

Specific terms		
1	Blanc	<i>White</i>
2	Cassant	<i>Brittle</i>
3	Très dur	<i>Very hard</i>
4	Epais	<i>Thick</i>
5	Difficile à étaler	<i>Hard to spread/flow</i>
6	Facile à étaler	<i>Easy to spread/flow</i>
7	Ferme	<i>Firm</i>
8	Gélatineux	<i>Gelatinous</i>
9	Liquide	<i>Liquid</i>
10	Très liquide	<i>Very liquid</i>
11	Mat	<i>Matt</i>
12	Mou	<i>Soft</i>
13	Onctueux	<i>Unctuous</i>
14	Pâteux	<i>Pasty</i>
15	Avec des points	<i>With points</i>
16	Solide	<i>Solid</i>
17	Bulles	<i>Bubbles</i>
18	Coulant	<i>Runny</i>
19	Très crémeux	<i>Very creamy</i>
20	Etale moyennement	<i>Spread/flow relatively</i>
21	Gluant	<i>Slimy</i>
22	Grumeleux	<i>Lumpy</i>
23	Granuleux	<i>Grainy</i>
24	Gras	<i>Greasy/Oily</i>
25	Mousse	<i>Foam</i>
26	Sec	<i>Dry</i>
27	Difficile à tartiner	<i>Hard to spread</i>

Among the 27 specific terms, 16 terms were used to describe more than one product (Table 9, terms 1–16). However, 11 other terms (Table 9, terms 17–27) were used more specifically to discriminate only one product from the rest. Table 10 gives the specific characteristics for each product, the number of quotation and their English translations in italics. It can be seen that 7 products “P9, P17,

P2, P3, P15, P19 and P20, P20b" were discriminated from each other and from the rest of the product set by their individual characteristics. For instance, the product P15 was the only product that was described as "Mousse" (Foam), "Bulles" (Bubbles), "Granuleux" (Lumpy) and "Gluant" (Slimy)." P19 was the only product that was described by 40% of consumers as being "Granuleux" (Grainy)". Visual representations of specific characteristics for some products are shown in Figure 14.

Additionally, some common characteristics among some products were also obtained. For instance, various products were cited as being "Epais" (Thick). The products P17, P18 and P20 were described as being "Difficile à étaler" (Hard to spread). The products P18 and P20 were the only products frequently described as being "Cassant" (Brittle). Two of the products with no texturing agent (P3, P4) were frequently cited as being "Liquide" (Liquid) and "Très-liquide" (Very liquid). Products P7, P11, P15, P8, P12 and P16 were described as "Facile à étaler" (Easy to spread). These products were mainly those with lower levels of concentration. These common characteristics among some products raise the question of the relationship between product description and formulation factors. Finally, the characterizations of the duplicate products showed a good repeatability for consumers' evaluations.

P1		P2		P3		P4		P5	
Terms	QN	Terms	QN	Terms	QN	Terms	QN	Terms	QN
gélatineux <i>gelatinous</i>	15	épais <i>thick</i>	8	liquide <i>liquid</i>	21	blanc <i>white</i>	11	épais <i>thick</i>	8
ferme <i>firm</i>	7			coulant <i>runny</i>	8	liquide <i>liquid</i>	10	ferme <i>firm</i>	8
				liquide-très <i>liquid-very</i>	7	onctueux <i>unctuous</i>	8	pâteux <i>pasty</i>	8
				gras <i>greasy</i>	7	liquide-très <i>liquid-very</i>	7		
P6		P7		P8		P9		P10	
Terms	QN	Terms	QN	Terms	QN	Terms	QN	Terms	QN
pâteux <i>pasty</i>	10	mou <i>soft</i>	11	étale-facil <i>spread-easy</i>	14	épais <i>thick</i>	10	étale-facil <i>spread-easy</i>	9
mat <i>matt</i>	8	liquide <i>liquid</i>	7	gélatineux <i>gelatinous</i>	12	pâteux <i>pasty</i>	9	ferme <i>firm</i>	9
épais <i>thick</i>	7	étale-facil <i>spread-easy</i>	7	pâteux <i>pasty</i>	9	ferme <i>firm</i>	8	épais <i>thick</i>	8
dur-très <i>hard-very</i>	7			épais <i>thick</i>	9	étale-moy <i>spread-ave</i>	8	pâteux <i>pasty</i>	7
				mou <i>soft</i>	7				
P11		P12		P13		P14		P15	
Terms	QN	Terms	QN	Terms	QN	Terms	QN	Terms	QN
étale-facil <i>spread-easy</i>	9	onctueux <i>unctuous</i>	12	épais <i>thick</i>	11	épais <i>thick</i>	12	mousse <i>foam</i>	16
mou <i>soft</i>	7	blanc <i>white</i>	11	étale-diff <i>spread-diff</i>	9	ferme <i>firm</i>	10	étale-facil <i>spread-easy</i>	8
		étale-facil <i>spread-easy</i>	9	pâteux <i>pasty</i>	8	pâteux <i>pasty</i>	10	mou <i>soft</i>	8
				avec des points <i>with points</i>	8	étale-diff <i>spread-diff</i>	7	granuleux <i>lumpy</i>	8
						avec des points <i>with points</i>	7	gluant <i>slimy</i>	7
								bulles <i>bubbles</i>	7
P16		P17		P18		P19		P20	
Terms	QN	Terms	QN	Terms	QN	Terms	QN	Terms	QN
blanc <i>white</i>	19	étale-diff <i>spread-diff</i>	13	étale-diff <i>spread-diff</i>	12	granuleux <i>grainy</i>	23	étale-diff <i>spread-diff</i>	10
étale-facil <i>spread-easy</i>	8	mat <i>mat</i>	11	dur-très <i>hard-very</i>	9	épais <i>thick</i>	7	cassant <i>brittle</i>	10
épais <i>thick</i>	7	ferme <i>firm</i>	8	solide <i>solid</i>	8			tartine-diff <i>spread-diff</i>	7
		sec <i>sec</i>	7	ferme <i>firm</i>	7			solide <i>solid</i>	7
				cassant <i>brittle</i>	7				
								P20 _b	
								Terms	QN
								étale-diff <i>spread-diff</i>	9
								cassant <i>brittle</i>	8
								tartine-diff <i>spread-diff</i>	8
								solide <i>solid</i>	7

Table 10: Specific characteristics of each product and their number of quotation (QN) on the basis of the 60 consumer perceptions and descriptions

Evaluation conditions

One of the objectives of this work was to use a methodology that considers the variation in products handling and includes some level of individual choices at testing conditions. Therefore, panelists were provided with various types of bread and cutlery adequate for product evaluation.

The supplementary data were analyzed using a pivot table to study the diversity for answering the following questions:

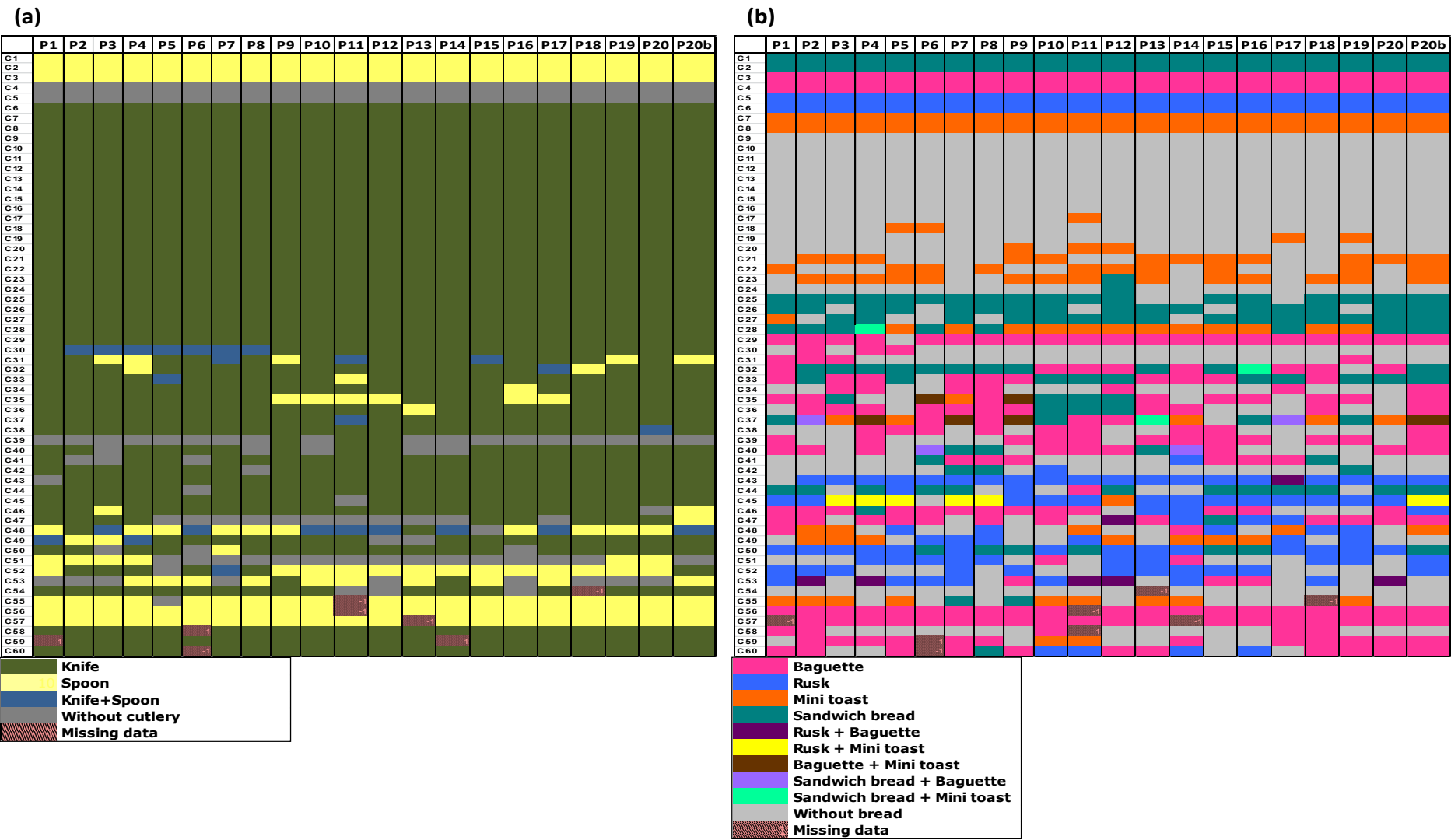
- *Did the consumers use one type of cutlery and/or breads during the test or did they change their evaluation conditions?*
- *Did the consumers adapt their evaluation method on the basis of product texture?*
- *Was there any specific evaluation method for a specific product?*
- *What were the tools and supports most often used by consumers?*

The result of pivot tables on cutlery is shown in Table 11, a. Concerning the cutlery, 50% of the consumers did not change the type of cutlery during the whole evaluation of 21 products whereas the other 50% have changed their cutlery once or several times during the test. In addition, 3% of consumers evaluated the products without using cutlery.

Concerning the type of the bread, more variation was observed during the test and even for one product evaluation, Table 11, b. Only 13% of the consumers evaluated all products using a single type of bread. The rest of the consumers had changed their type of bread several times during the test for a product or different products. 13% of the consumers did not use any bread for their evaluations.

As illustrated in Table 11, even though the consumers showed a tendency to change their evaluation condition during the whole test or even for one product, this adaption was not related to product texture. It can be seen that, there is no product that was evaluated by specific type of bread or cutlery (each column present a product and different color cods present the different types of bread or cutlery that were used by assessors). Knife was used by the majority of consumers for product evaluation. In cases where a support was used, the baguette was chosen by the majority.

Table 11: Pivots tables of evaluation methods (a) type of cutleries (b) type of breads. Each line corresponds to a consumer and each column to a product (60 lines × 21 columns). One product was duplicated. The color codes represent the different types of cutleries or breads used by a consumer for each product evaluation.



4.1.2 Step 2: A synthetic characterization of all products

The sensory description of the products range was carried out using Flash Profile. The task and the number of product did not seem to be a barrier to the consumer. The consumers took 1h-1h15 to do the task.

Key notions to synthetically discriminate the products

The synthetic characterization of consumers of all the products allowed us to quickly obtain the key characteristics that explain the major differences among the products. 90% of the consumers generated between 3-5 terms from which 50% of them cited the maximum of 5 terms. Only two consumers used one term to discriminate the products, Figure 14.

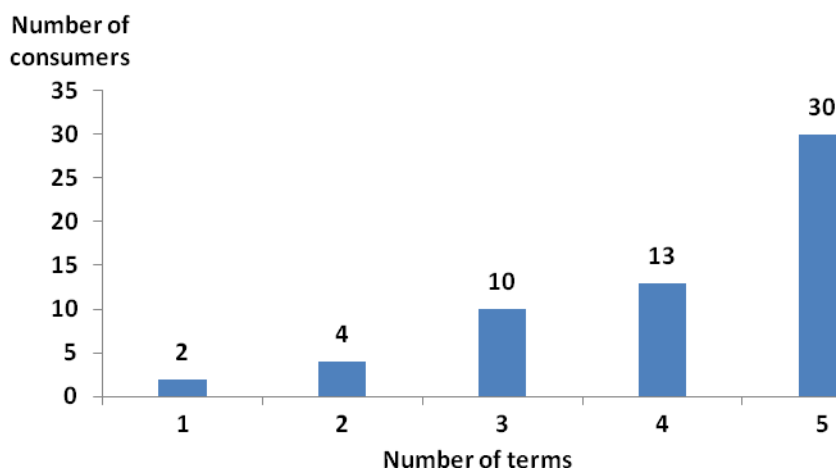


Figure 14: Number of key characteristics cited by each consumer

The consumers generated in total 242 individual terms composed of 87 different terms. Investigating the key notions showed that 10 different terms were used by more than 10% of consumers as key characteristics to discriminate the products. These 10 terms represent 76.5% of the total different terms, with 20% of the terms related to products color.

Figure 15 shows the important characteristics cited by more than 10% of consumers to discriminate the products. Nine terms were in common with terms identified in previous step as most frequently cited (Step1: Individual characterization of each product). However, the term “Granuleux (Grainy)” that was cited only for one product in previous step as a specific characteristic had become important once the panelists confront all the products. It can also be noted that the term “Collant” is the first texture-related terms mostly cited as a key characteristic to compare the products, Figure 15.

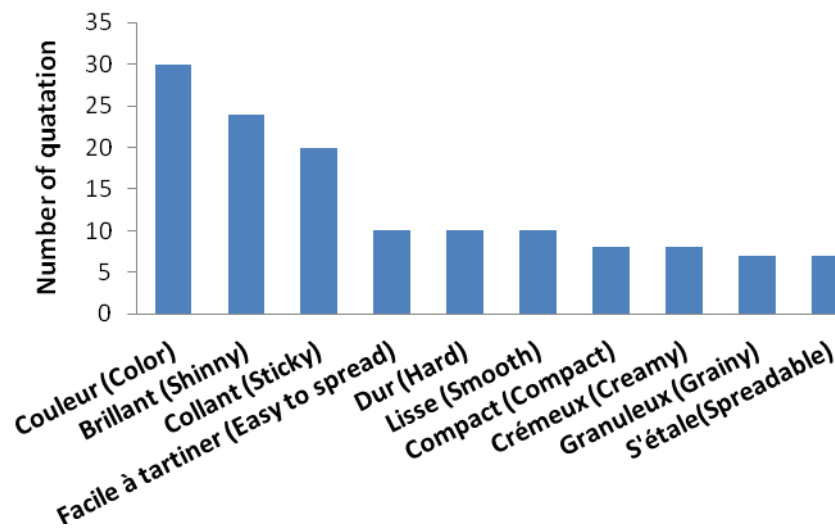


Figure 15: Important characteristics terms to discriminate the product cited by more than 10% of consumers

Individual PCAs was carried out on the result of each consumer. This dimensional differences show the perception differences among the consumers. The greater the number of important dimensions, the more the sensory information is rich. Figure 16 shows the distribution of the variance per dimension based on the individual PCAs.

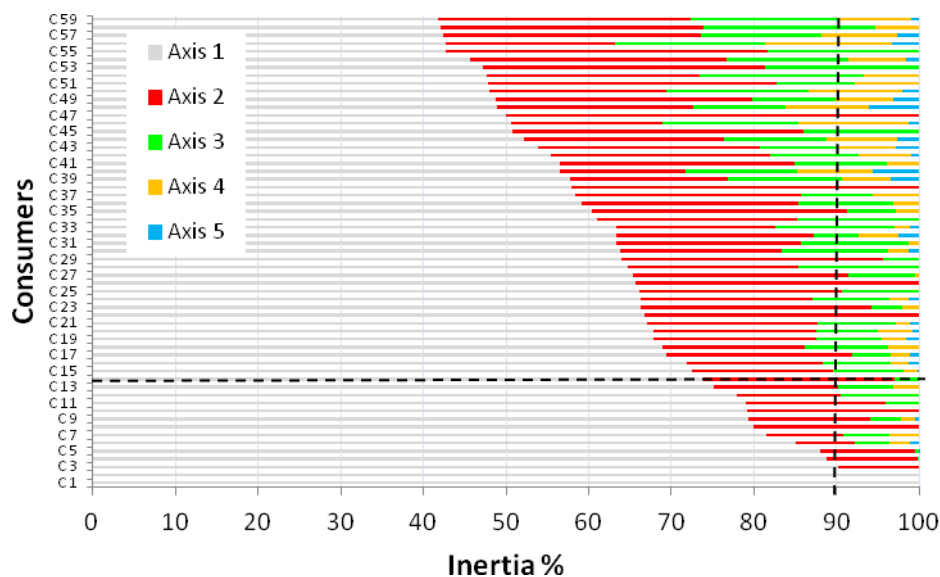


Figure 16: Distribution of the variance per dimension based on the individual PCAs (Consumers:C)

It can be seen that for about 60% of the consumers, 90% of the information is represented on 3 to 4 dimensions. However for the rest of the consumers, the first two axes represent the majority of the information. This dimensional differences show, on one hand, the perception differences among the consumers. On the other hand, it shows that the maximum of 5 terms that was set for description was sufficient for product characterization. Even though half of the consumers generated the

maximum of 5 terms, the fifth dimension either does not exist due to the correlation among the given terms or it represents only a small proportion of variance.

Product map and description

Running GPA on the individual data, allowed us to obtain an averaged sensory map. All of the variance of this configuration is explained by 5 dimensions of the GPA, Figure 17.

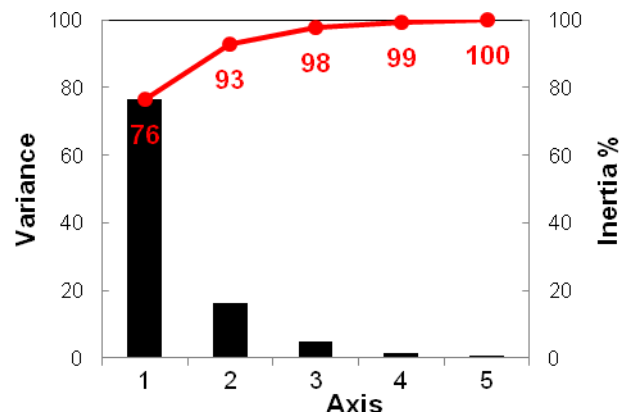


Figure 17: Distribution of the variance per dimension of GPA (Consumers)

The first two dimensions explained 93 % of the total variance, of which axis 1 provided 76 % of the data and axis 2, 16%. Further dimensions explained only a small proportion of the variance ($\leq 5\%$). Two dimensions are thus enough to describe the texture of the products. The averaged information, brought by the whole consumers, would be less rich than the individual information, which for more than half of them requires at least 3 axes to explain 90 % of the information.

To visualize the variability for each product confidence ellipses (interval of 95%) can be represented around the average point for each product. Figure 18 demonstrates the obtained ellipses on the first two dimensions of the sensory map. When two ellipses are superimposed, the two corresponding products are not significantly different. The size of the ellipses is related to the variability existing around the corresponding products: the bigger is the size, the more is the variability.

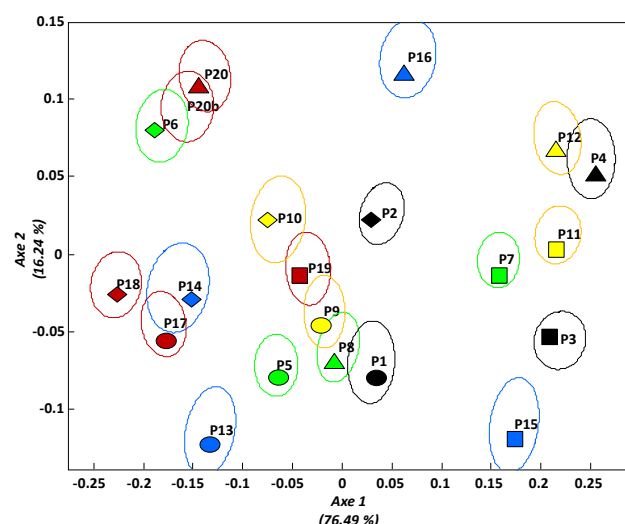


Figure 18: Representation of confidence ellipses around the GPA consensual consumers' configuration.

It can be seen that the size of these ellipses are globally small. The confidence ellipses of more than half the product are not overlapped (P1, P2, P3, P5, P7, P11, P13, P15, P16, P18, P19, P20,b). This shows that these products were well discriminated from each other. The assessors would thus have a similar vision of the main differences of the products range. Moreover, the close positioning and the overlapping of the confidence ellipse for the product in duplicate (P20,b) shows a good repeatability for consumer evaluation.

The first two dimensions of GPA explained 93 % of the total variance. Following the GPA, two cluster analyses were performed: one on the products mean configuration coordinates to estimate the sensory proximities of the products and to give an idea of product discrimination. Another HCA was carried out on the descriptive term coordinates to identify the groups with similar terms. The HCA on the products resulted in three main groups that are shown on the GPA plots in Figure 19.

The products are split into three groups on the first dimension. On the axis 1 a group containing 6 products (P3, P4, P7, P11, P12 and P15) is positioned on the right side and opposed to a group of three products (P14, P17, P18) on the left side. Axis 2 discriminates three products (P16, P20 (b), P6) and opposes them to two products (P13, P15). It can be seen that the HCA resulted in the same product proximities as GPA, Figure 19.

HCA clusters are mainly separated along the first dimension. Cluster 1 is composed of 6 products (P3, P4, P7, P11, P12 and P15). These products had mainly a lower level of concentrations. This cluster is better discriminated than the other clusters. Cluster 3 consists of 8 products (P6, P10, P13, P14, P17, P18 and P20,b). This cluster contains mainly the products with TA-4 (except diluted one) and the processed products (except the control). The HCA resulted in the same groups of product as GPA with the exception of P10. Clusters 1 and 3 are contrasted to each other on axis 1 of the GPA plot. The third cluster consisted of the rest of the products and is centrally located on the GPA map.

The results show that the textures differ with processing factor and dilution rather than the texturing agent family with and exception for TA-4 containing products. The presence of TA-4 had a marked impact on the texture similar to processing factor. The products containing TA-4 are mainly discriminated in a same group (cluster 3).

To describe the differences between the products, consumers cited 87 different terms with 10 terms cited at least by 10% of them. Since no common vocabulary was previously set between the panelists, citing of similar terms by two or more panelists does not guarantee the same meaning. The only feasible semantic interpretation consisted in grouping the terms that were used to differentiate the products in a similar way. Hence, a cluster analysis was carried on the terms coordinates following the GPA. The HCA resulted in 7 main groups of terms, Figure 19. The terms of each group were summarized based on the similar terms used at least by 10% of consumers in the same way. Two groups represent the main texture differences that can be summarized as “Dur-Compact (Segment 7)” and “Facile à tartiner-Collant-Crémeux (Segment 4)”. Three groups identify the visual terms and can be summarized as “Couleur Claire, Brillance, Jaune (Segment 1 & 3 & 6)”. The remaining clusters (Segment 2, 5) remained hard to interpret since it contained the terms that could not be intuitively summarized and related. For example, the segment 2 includes some hedonic terms like “Appétissant” cited only by 5% of consumers

On the CONEPLLOT each cone represents a cluster of differentiating terms identified by cluster analysis. The terms related to “Collant, Tartinabilité, Crémeux” of products are positively correlated and are on the right side of the axis 1. These terms are opposed to terms related to consistency such as “Dur, Compact” on the left side.

The group containing (P6, P10, P13, P14, P17, P18 and P20,b) was differentiated more often as being more firm than the rest of the products. This group is contrasted with products with lower levels of concentration (P3, P4, P7, P11, P12 and P15) that were described as being “Tartinable, Collant, Crémeux” and to a lesser extent “Brillant”. The rest of the products were discriminated on the second axis mainly through their visual aspect.

Among the consumers who cited the term “Collant”, 65% of them used this term in the same way for product evaluation (presented on the right side of the 1st component). 30% have used this term in opposite way most probably because they used the scale in opposite direction or because they had different perceptions. One consumer used it in perpendicular direction compare to others.

Three main groups of products were discriminated on axis 1. This axis opposes a group of terms related to consistency (Dur, Compact) to a group of terms that are positively correlated and presents more complex and multidimensional perceptions (Collant, Tartinable, Crémeux). The second axis opposes two products (P13 vs P13) based on the visual aspect of the products related to color and transparency: visual aspect “Couleur-Claire” versus visual aspect “Couleur Jaune”.

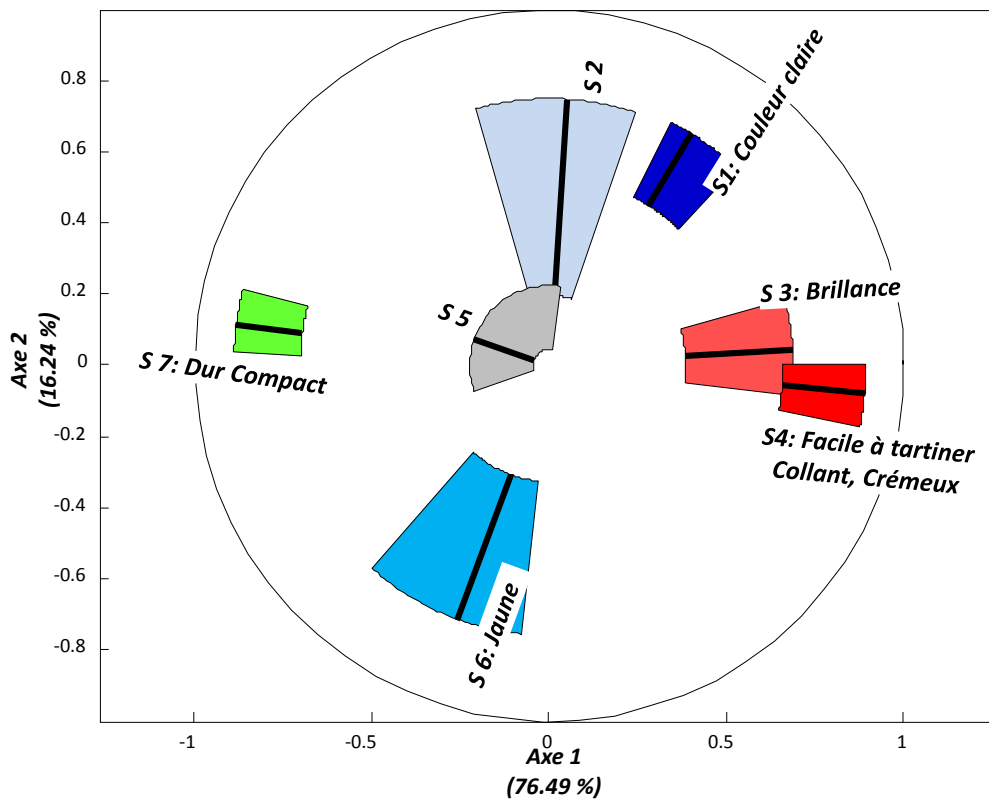
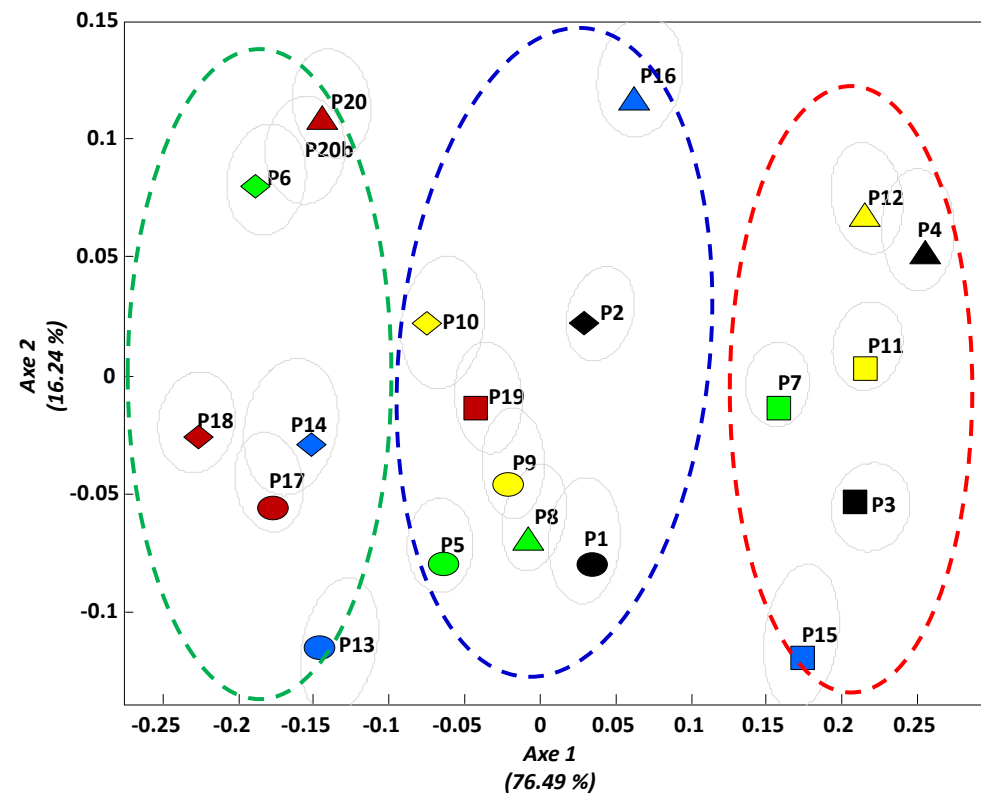


Figure 19: First two dimensions of the GPA plots (product map and CONPLOT) of the Flash Profile on total terms (Consumers).

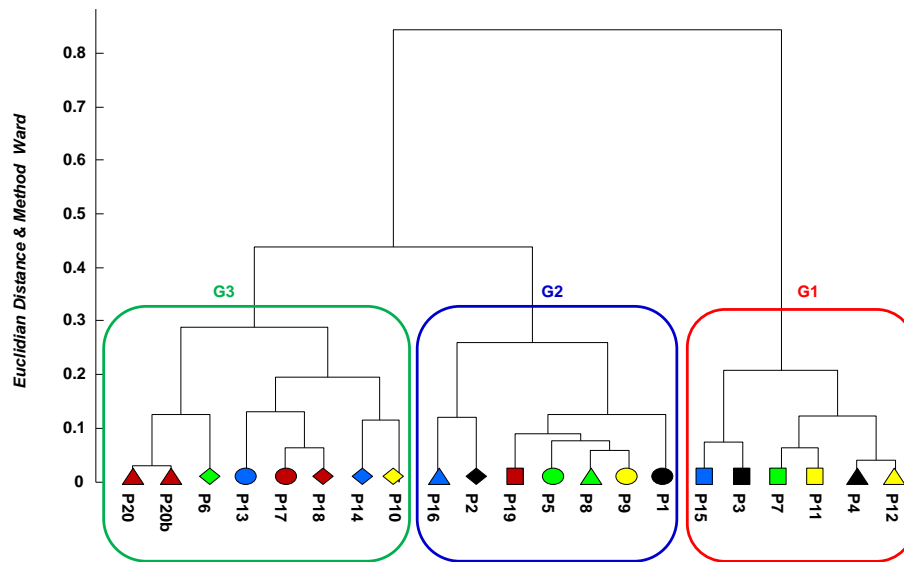


Figure 20: Dendrogram of the HCA on the products performed after GPA as described by 60 consumers. Three groups of products G1, G2 and G3.

Since about 20% of the key notions were related to visual aspect especially products' color, the data were reanalyzed by elimination of color-related terms (for example, Jaune, Blanc, Jaune à vert, etc). This aimed to identifying more texture related dimensions, if any.

Figure 21 shows the result of GPA on non-color-related terms. Once the color-related terms were eliminated, the second dimension only represents a 6% of information and discriminated 2 products (P10 and P16) versus 8 products (P1, P3, P5, P8, P13, P15, P17, P19), Figure 21.

The second axis represents the terms related to smoothness, and homogeneity. This axis was relative to smoothness and homogenous aspects of products. However, these terms were cited by less than 10% of the consumers. Hence, we are concerned about the interpretation of this axis. For these reasons, for the rest of study, we take the global characterization into account.

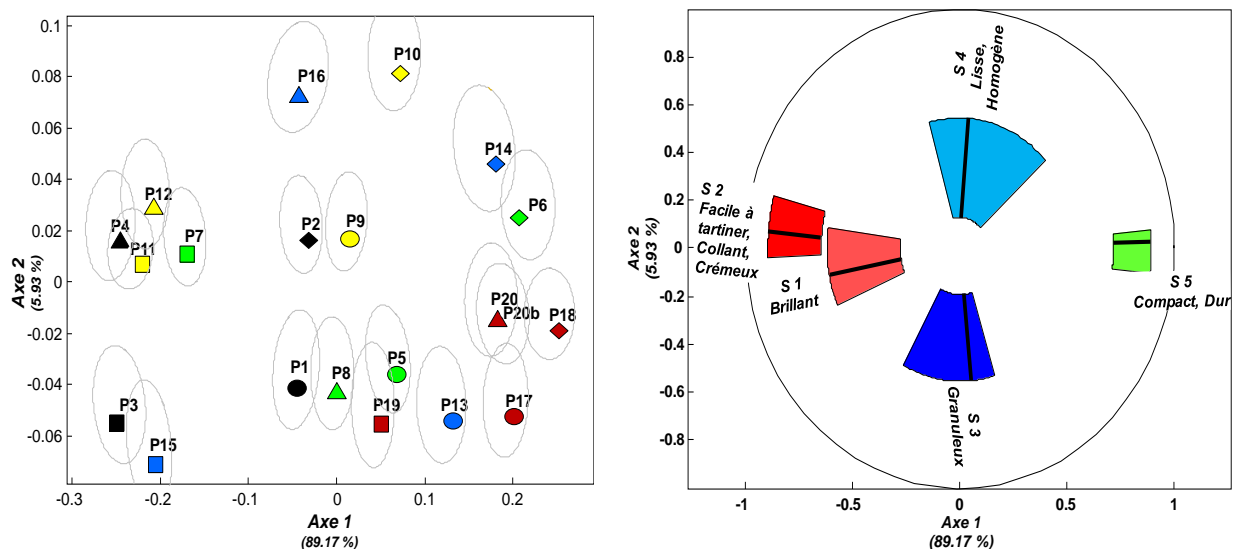


Figure 21: First two dimensions of the GPA of the Flash Profile without color-related terms (Consumers). The key notions for each HCA segments of attributes are presented on the attribute CONPLOT.

This shows that for consumers, there is only one texture-related dimension. This dimension represents the main information (90%) on products texture and discriminate the products according to their texture differences from “Dur, compact” to “Facile à tartiner, Collant, Crémeux”.

4.1.3 Combined approach – consumers results

Combining an individual and a comparative characterization of products by consumers’ personal approach made it possible to obtain very rich information concerning the consumers’ terminology, products’ main and specific characteristics, evaluation conditions, product positioning and the important sensory attributes. Table 12 demonstrates a summary of both approaches outcomes.

Table 12: Summary of the results of consumers’ characterizations.

	Free comment One panelist-One product	Flash Profile One panelist-Several products
Number of different terms	550	242
Descriptive terms over entire set (>10%)	Collant, Brillant, Jaune, Lisse, Compact, Dur, Etalable, Crémeux, Facile à tartiner	Couleur, Brillant, Collant, Facile à tartiner, Dur, Lisse, Compact, Crémeux, Etalable, Granuleux
Number of axes for 90% of info	4	2
Info represented on F1×F2	80%	93%
Products map and distribution	Similar distribution and positioning of products by both methods	
Explicative terms	Dur, Crémeux, Jaune	Collant, Facile à tartiner, Crémeux vs. Dur, Compact. Jaune vs. Claire

In contrary to conventional methods that eliminated the diversity by imposing a glossary of terms and specific manipulation instructions, by applying the free comment for individual characterization of each product we obtained a rich pool of consumers’ terms. Then by carrying out the frequency-based analysis we extracted directly a glossary of nine terms that were most frequently cited by consumers to describe the product range. Moreover, the main characteristics of products as well as the very specific characteristics of each product were obtained.

The individual characterization also helped the consumers to generate their own terminology and to get prepared for the more synthetic characterization of products using the Flash Profile.

In second step we asked consumers to compare the products based on the important characteristic for products discrimination. Through the comparative approach, we obtained the same terms that were most frequently cited in individual characterization in addition to one more characteristic: “Granuleux”. **The comparative characterization showed that the graininess characteristic which was one product’s specificity in monadic characterization had become an important characteristic for some consumers when they confronted all the products.**

Comparing the product maps obtained through the two approaches showed that:

The first two dimension of comparative characterization represents about 90% of and the first two dimensions in monadic characterization represents 80% of information. This could be explained by the fact that in the free comment approach, the assessors had characterized each product spontaneously and had cited a higher number of terms. However, in the comparative approach they had focused on the main and most important characteristics.

Nevertheless, comparing the first two components of product maps resulted from both approaches showed similar positioning for the majority of products with some exceptions (P2, P3, P13, P15 and P16). Comparing the HCA results on products from each approach showed globally similar product groupings with an exception for 6 products (P1, P2, P3, P10, P13 and P16). The products were better discriminated in the first two components of resulted map from Flash Profile.

Concerning the semantic description of the product maps, we observed that the first component of conplot in comparative characterization opposed the terms relative to “Dur, Compact” to the terms relative to “Tartinable, Collant, Crémeux”. The first component of monadic characterization opposed the products that were mainly “Dur, Compact” to “Crémeux”. The “Collant” characteristic was represented on the third component and discriminated the P10 product. On the second component of both approaches the products were mainly discriminated relative their differences in visual aspects.

Hence, in both approaches, the products were discriminated on the first axis relative to their texture-related terms and on the second axis relative to visual-related terms. The duplicate evaluation showed the repeatability and reproducibility of the consumers for a descriptive approach.

Consumers’ declaration: consumers were happy to do the second step because in the first step they had the impression that products were very similar. However presenting the entire set made them see how the textures were different once they could compare the products to each other.

To sum up, the free comments method provided consumers’ terminology and very detailed consumers-derived sensory images for each product. Flash Profile revealed extra information about the characteristic that could become important for comparing the products. The characteristic “Collant” was the most cited term by consumers for individual characterization of products as well as for comparison between the products.

Both approaches resulted in similar product maps with some differences for 6 products. The product map after Flash profile represented more percentage of information on the first two axes. In addition, the products were better distributed on the resulting map after Flash Profile. In both approaches, the first axis was relative to texture-related differences of products and the second axis was relative to visual-related terms. Re-analyzing the data based on the non-color-related terms confirmed that there is only one texture-related dimension for consumers. This dimension represents 90% of information and discriminate the products according to their texture differences from “Dur, compact” to “Facile à tartiner, Collant, Crémeux”. Hence, for the rest of the study, the original product map using all cited terms will be considered.

4.2 Experts

4.2.1 Step 1: Characterization of each product by an individual approach

Experts terminology

In total, the 10 experts generated 1421 individual terms composed of 230 different terms (about 23 different terms per expert). 93% of the generated attributes were related to texture and visual aspects (the terms of transparency, color and shape). Only 4% of the terms were related either to other product names such as: “Beurre (Butter)”, “Cancoillotte (Cancoillotte)”, or container filling terms such as: “Barquette completement rempli (Container filled completely)”. Additionally, 3% of the terms were cited only once. Figure 22 shows the distribution of the different terms on a frequency basis.

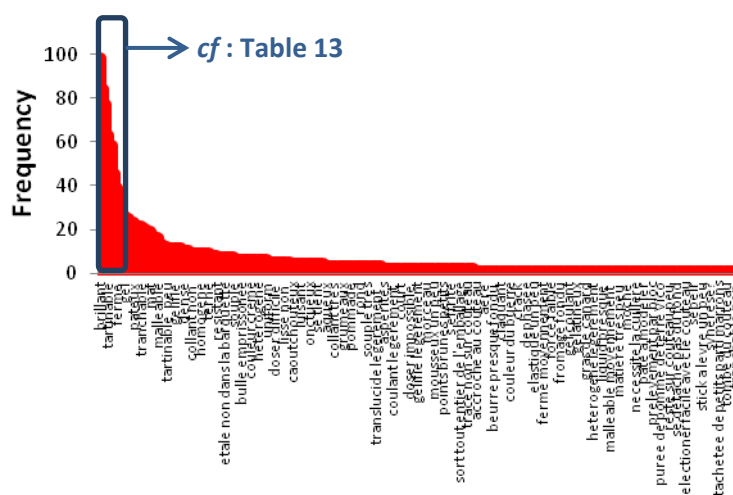


Figure 22: Distribution of total terms cited by experts

Among 230 different terms, the thirteen terms that were cited the most frequently to characterize the set of model products were “Brillant (Shiny)”, “Collant (Sticky)”, “Lisse (Smooth)”, “Tartinable (Spreadable)”, “Etalable (Spreadable)”, “Jaune (Yellow)”, “Ferme (Firm)”, “Mou (Soft)”, “Dur (Hard)”, “Gel (Gel)”, “Fillant (Filament)”, “Élastique (Elastic)”, “Pâteux (Pasty)”. These 13 terms corresponded to 46.5% of the generated terms related to texture and visual aspects, and 43% of total terms.

A ranking of these terms and their frequency is given in Table 13. The most frequently cited attributes were mainly related to product texture. A color-related term was also cited, “Jaune (Yellow)”.

Table 13: Terms most frequently cited by Experts. English translations in *italics*.

Terms frequently Cited		Frequency
Brillant	<i>Shiny</i>	98
Collant	<i>Sticky</i>	84
Lisse	<i>Smooth</i>	77
Tartinable	<i>Spreadable</i>	63
Etable	<i>Spreadable</i>	58
Jaune	<i>Yellow</i>	45
Ferme	<i>Firm</i>	39
Mou	<i>Soft</i>	28
Dur	<i>Hard</i>	26
Gel	<i>Gel</i>	26
Filant	<i>Filament</i>	25
Elastique	<i>elastic</i>	24
Pâteux	<i>Pasty</i>	24

Product main characteristics, positioning, semi-profile

The thirteen terms most frequently cited by the experts were used to discriminate the products on the basis of their main common characteristics.

CA on the frequency-based table (frequencies/ products/ 13 most frequently cited terms) shows that the first five dimensions accounted for 86% of the information, from which, the first two dimensions accounted for almost 60% of the variance (respectively 44% and 15.5%). Further dimensions explained only a small proportion of variance ($\leq 5\%$), Figure 23.

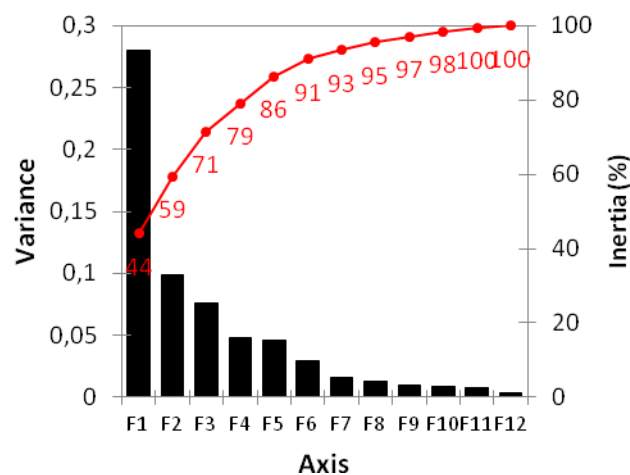


Figure 23: Distribution of the variance per dimension of CA.

Axis 1 represents the terms “Ferme (Firm)”, “Dur (Hard)” and “Gél (Gel)”. Axis 2 represents the term “Pâteux (Pasty)”. Figure 24 illustrates the first two dimensions. The characteristics “Jaune (Yellow)” is presented on axis 3. The attributes “Élastique” (Elastic) and “Filant” (Filament) are figured in the

fourth and fifth dimensions with a small percentage of information. Hence only the first two dimensions are presented.

The products were split into three groups on the first dimension. Products P2, P3, P4, P7, P11, P12, P15 and P16 are positioned on the left side of axis 1. Products P17, P18, P20 and P20b on the right side of axis 1, were predominantly described as being more “Dur (Hard)”, “Gél (Gel)” than the rest of the products. These products were best discriminated by the experts. Axis 2 represents the products P8, P10, P19 that were indicated as being more “Pâteux (Pasty)” versus P12.

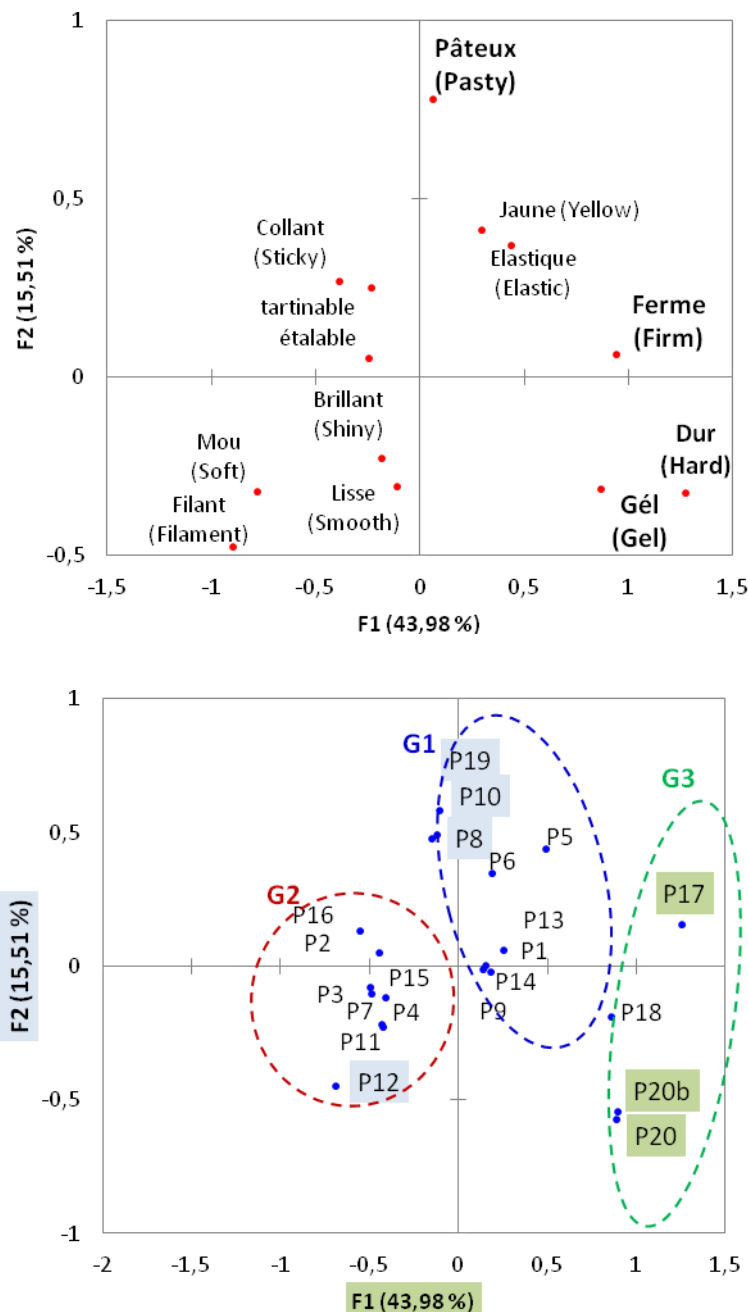


Figure 24: The first two dimensions of the sensory map from CA. G1, G2 and G3 correspond to the groups of product resulted from HCA (Experts). The highlighted products and the terms in bold have high contributions to the F1×F2.

Hierarchical Clustering Analysis was performed after CA to help the identification of groups with similar/different sensory profiles, and give an idea of product discrimination.

Three main groups; G1, G2, G3, were obtained after HCA as shown in Figure 25. These groups are also shown on the CA plots in Figure 24. The groups of products were separated mainly along the first dimension of CA, mostly based on Firmness-related terms and on the axis 2 by Pastiness characteristic.

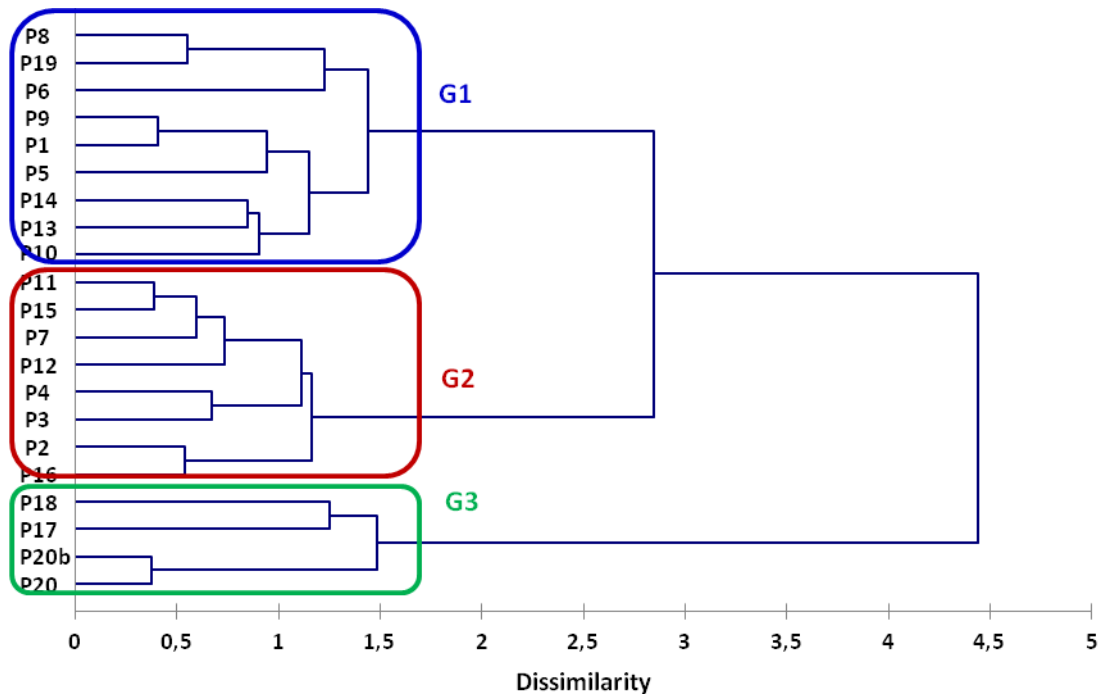


Figure 25: Dendrogram of the HCA after CA of products described by 10 experts. Three groups of product G1, G2 and G3.

Following HCA, a semi-profile for each HCA cluster was built on the basis of the averaged frequencies of the 13 most frequently cited terms. The aim was to summarize the main differences between the three product groups. Figure 26 depicts the semi-profiles of these groups.

Ten over thirteen frequent terms discriminate the three groups significantly. It can be seen that the profile of G3 products is better discriminated from both G1 and G2 products by 5 terms: “Dur, Ferme, Gél, Collant, Tartinable”.

G1 contains the most “Filant (Filement)” and “Mou (Soft)” and least “Dur (Hard)” products. G2 is discriminated from G1 and G3 as being “Pâteux (Pasty)”. The G3 group is differentiated as being mostly “Dur (Hard)”, “Ferme (Firm)”, “Gél (Gel)” and the least “Collant (Sticky), Tartinable (Spreadable), Étalable (Spreadable)”. G1 and G2 both contain products that are “Brillant (Shiny)”, “Collant (Sticky)”, “Tartinable (Spreadable)” and “Étalable (Spreadable)” and are discriminated from G3. The best characteristics for discriminating the three groups are “Dur (Hard)”, “Ferme (Firm)” and

“Gél (Gel)”. The characteristic “Lisse (Smooth)”, “Élastique (Elastic)” and “Jaune (Yellow)” do not significantly discriminate the identified groups.

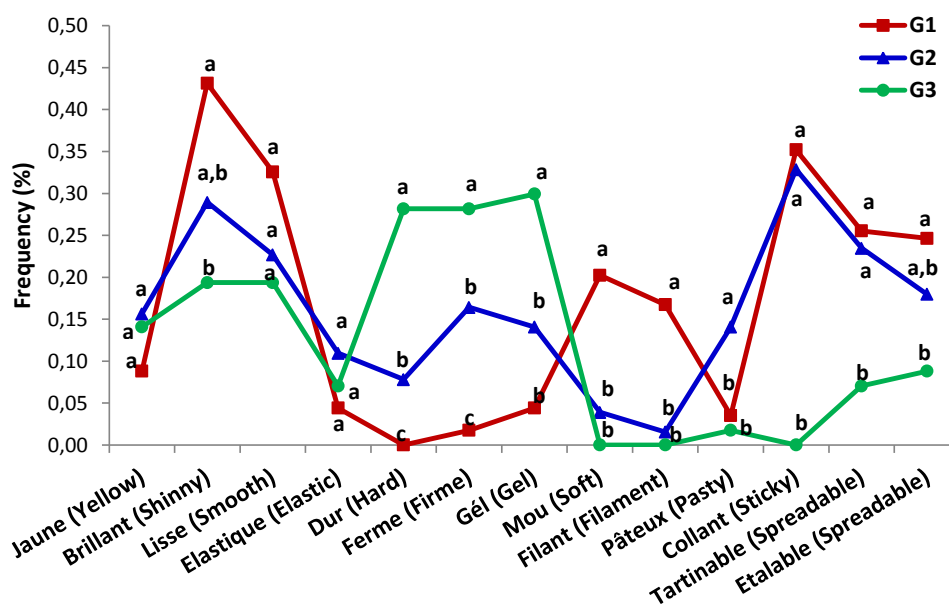


Figure 26: Aggregated frequency of mentioned terms for each of the clusters identified in HCA. The semi-profile of each HCA cluster on the basis of the averaged frequencies (Experts). The different letters “a, b, c” referred to significance differences between the three groups for each term (ANOVA, $p < 0.05$).

Specificities of each product

In addition to global characterization of products on the basis of the 13 most frequent terms and in order to better characterize them, the specific terms for each product were also studied. Therefore, specific characteristics of each product were identified based on the frequency of the terms generated by more than 10% experts per product. By applying this threshold, 48 new terms were identified as being more specifically applied by experts to characterize the products. These 48 terms represented 17.3% of the generated terms related to texture and visual aspects of products. Table 14 gives the list of these specific terms used by experts to describe one or several products and their translation in English.

Among the 48 specific terms, 22 terms were used to describe more than one product (Table 14, terms 1–22). However, the 26 other terms (Table 14, terms 23–48) were used more specifically to discriminate only one product from the rest. Table 15 shows the specific characteristics for each product, their number of quotation and their English translations in italics.

It can be seen that 15 products “P3, P4, P5, P7, P8, P9, P10, P11, P12, P13, P15, P18, P19 and P20, P20b” were discriminated from each other and from the rest of the product set by their individual characteristics. For instance, the product P15 was the only product that was described as “Mousseux” (Foam), and “Léger” (Light), P11 was described as being “Souple” (Flexible), P12 as being “Humide” (Humid), etc.

Some characteristics were in common among some products. For instance, five products were cited as being “Épais (Thick)”. Product P18 and P20, were the only products frequently described as being

“Cassant (Brittle)”. Two products with no texturing agent, P3 and P4, were frequently cited as being “Liquide” (Liquid). Finally, the characterizations of the duplicate products showed a good repeatability.

Table 14: List of the specific terms generated by 10 experts for various products. English translations in *italics*.

Specific terms		
1	Adhère	<i>Adhere</i>
2	Beurre	<i>Butter</i>
3	Blanc	<i>White</i>
4	Brilliant_peu	<i>Shiny_a little</i>
5	Brilliant_très	<i>Shiny_very</i>
6	Bulles	<i>Bubbles</i>
7	Cassant	<i>Brittle</i>
8	Collant_peu	<i>Sticky_a little</i>
9	Compact	<i>Compact</i>
10	Compact_peu	<i>Compact_a little</i>
11	Consistance	<i>Consistent</i>
12	Coolant	<i>Flowing</i>
13	Crémeux	<i>Creamy</i>
14	Dense	<i>Dense</i>
15	Épais	<i>Thick</i>
16	Étale au fond	<i>Spread on the bottom</i>
17	Étale_diff	<i>Spreadable / flow_diffcultly</i>
18	Étale_facil	<i>Spreadabl / flow_easily</i>
19	Étale_non	<i>Spreadabl / flow_non</i>
20	Ferme_très	<i>Firm_very</i>
21	Fluide	<i>Fluid</i>
22	Granuleux	<i>Grainy</i>
23	Gras	<i>Fat</i>
24	Grumeaux	<i>Lumps</i>
25	Hétérogène	<i>Heterogeneous</i>
26	Homogène	<i>Homogenous</i>
27	Homogène_non	<i>Homogenous_non</i>
28	Humide	<i>Humid</i>
29	Léger	<i>Light</i>
30	Liquid	<i>Liquid</i>
31	Lisse_non	<i>Smooth_non</i>
32	Malleable	<i>Malleable</i>
33	Mat	<i>Mate</i>
34	Mou_très	<i>Soft_very</i>
35	Mousseux	<i>Foam</i>
36	Se coupe	<i>Cuttable</i>
37	Se coupe_facil	<i>Cuttable_easily</i>
38	Se decolle d'emballage	<i>Deboned from package</i>
39	Sec	<i>Dry</i>
40	Solide	<i>Solid</i>
41	Souple	<i>Flexible</i>
42	tartine_diff	<i>Spreadable_diff</i>
43	tartine_facil	<i>Spreadable_easily</i>
44	tartine_peu	<i>Spreadable_less</i>
45	tranchable_très	<i>Sliceable_very</i>
46	Tranchable	<i>Sliceable</i>
47	Translucide	<i>Transparent</i>
48	Visqueux	<i>Viscous</i>

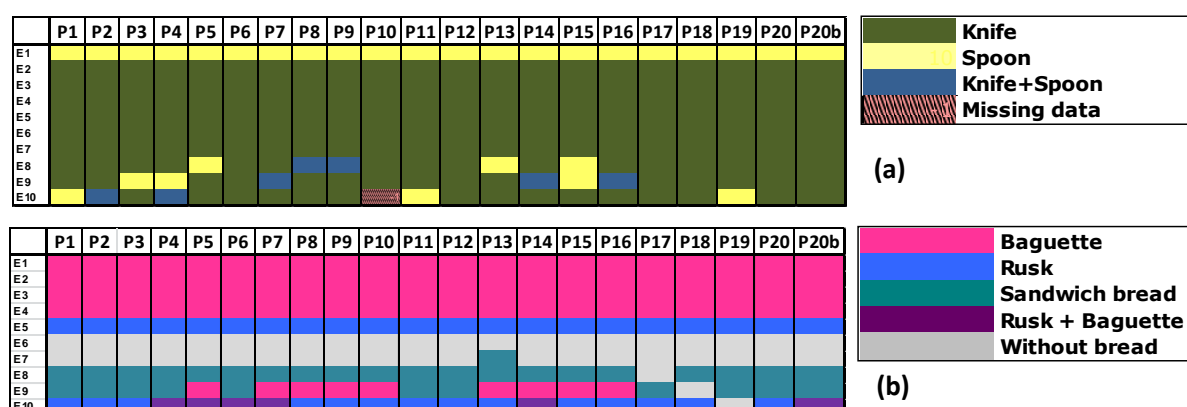
P1			P2		P3		P4		P5					
Terms	QN		Terms	QN	Terms	QN	Terms	QN	Terms	QN				
malléable	<i>malleable</i>	3	blanc	<i>white</i>	3	bulles	<i>bubbles</i>	3	crèmeux	<i>creamy</i>	5	étaie_diff	<i>spread_diff</i>	2
translucide	<i>transparent</i>	3	épais	<i>thick</i>	2	hétérogène	<i>heterogenous</i>	2	fluide	<i>fluid</i>	5	sec	<i>dry</i>	2
consistance	<i>consistency</i>	2	étaie_diff	<i>spread_diff</i>	2	homogène_non	<i>homogenous_non</i>	2	coulant	<i>flowing</i>	3			
épais	<i>thick</i>	2				liquide	<i>liquid</i>	2	mou_très	<i>soft_very</i>	3			
									blanc	<i>white</i>	2			
									liquide	<i>liquid</i>	2			
P6			P7		P8		P9		P10					
Terms	QN		Terms	QN	Terms	QN	Terms	QN	Terms	QN				
granuleux	<i>grainy</i>	3	visqueux	<i>viscos</i>	3	lisse_non	<i>smooth_non</i>	3	collant_peu	<i>sticky_a little</i>	2	gras	<i>fat</i>	4
mat	<i>matte</i>	3	crèmeux	<i>creamy</i>	2	translucide	<i>transparent</i>	3	consistance	<i>consistency</i>	2	beurre	<i>butter</i>	2
compact	<i>compact</i>	2	translucide	<i>transparent</i>	2	compact_peu	<i>compact_a little</i>	2	se coupe	<i>cuttable</i>	2	brillant_peu	<i>shiny_a little</i>	2
ferme_très	<i>firm_very</i>	2				se coupe	<i>cuttable</i>	2	malléable	<i>malleable</i>	2	compact	<i>compact</i>	2
malléable	<i>malleable</i>	2				épais	<i>thick</i>	2	tranchable	<i>sliceable</i>	2	consistant	<i>consistency</i>	2
						mat	<i>matte</i>	2	translucide	<i>transparent</i>	2			
P11			P12		P13		P14		P15					
Terms	QN		Terms	QN	Terms	QN	Terms	QN	Terms	QN				
crèmeux	<i>creamy</i>	5	crèmeux	<i>creamy</i>	3	épais	<i>thick</i>	2	mat	<i>matte</i>	2	mousseux	<i>foam</i>	3
adhère	<i>adhere</i>	3	blanc	<i>white</i>	2	tartine_diff	<i>spread_diff</i>	2				léger	<i>light</i>	2
brillant_très	<i>shiny_very</i>	2	étaie_facil	<i>spread_easily</i>	2	translucide	<i>transparent</i>	2				tartine_facil	<i>spread_easily</i>	2
souple	<i>flexible</i>	2	humide	<i>humide</i>	2							tranchable	<i>sliceable</i>	2
translucide	<i>transparent</i>	2												
P16			P17		P18		P19		P20					
Terms	QN		Terms	QN	Terms	QN	Terms	QN	Terms	QN				
blanc	<i>white</i>	4	mat	<i>matte</i>	4	cassant	<i>brittle</i>	3	granuleux	<i>grainy</i>	5	cassant	<i>brittle</i>	3
épais	<i>thick</i>	3				ferme_très	<i>firm_very</i>	3	grumeaux	<i>lump</i>	3	étaie_non	<i>spread_non</i>	3
beurre	<i>butter</i>	2				se coupe	<i>cuttable</i>	3	translucide	<i>transparent</i>	2	blanc	<i>white</i>	2
gras	<i>fat</i>	2				tranchabe_très	<i>sliceable_very</i>	3				se coupe_facil	<i>cuttable_easily</i>	2
homogène	<i>homogenous</i>	2				dense	<i>dense</i>	2				étaie au fond	<i>spread over</i>	2
tartine_facil	<i>spread_easily</i>	2				étaie_diff	<i>spread_diff</i>	2				tartine_peu	<i>spread_a little</i>	2
						mat	<i>matte</i>	2				tranchable	<i>sliceable</i>	2
						solide	<i>solid</i>	2						
											P20b			
											Terms	QN		
											cassant	<i>brittle</i>	4	
											blanc	<i>white</i>	2	
											se coupe	<i>cuttable</i>	2	
											dense	<i>dense</i>	2	
											se decolle	<i>detachable</i>	2	
											solide	<i>solid</i>	2	
											tranchable	<i>sliceable</i>	2	

Table 15: Specific characteristics of each product and their number of quotations(QN) on the basis of the 10 experts perceptions and descriptions

Evaluation conditions

Results of evaluation conditions by experts are visualized in Table 16. It can be seen that the majority of experts (70%) did not change their cutlery during the evaluation of all products. Concerning the type of the bread, 60 % of the experts used one type of bread during the whole evaluation. However, 30% to 40% of the experts showed that they also have a tendency to adapt their evaluation conditions if they were given the choice. However, this change was not related to product texture and was assessor-dependent. It can be seen that none of the products were evaluated with a specific type of bread or cutlery by all the assessors, Table 16. The majority of the judges used a knife as cutlery and baguette as bread.

Table 16: Pivots tables of evaluation methods (a) type of cutleries (b) type of breads. Each line corresponds to an expert and each column to a product (10 lines × 21 columns). One product was duplicated. The color cods represent the different breads or cutleries used by an expert for each product characterization.



4.2.2 Step 2: A synthetic characterization of all products

Key notion to synthetically discriminate the product

Ten experts generated individual lexicons using 4 or 5 attributes, Figure 27. In total, 47 terms were generated with 29 different terms.

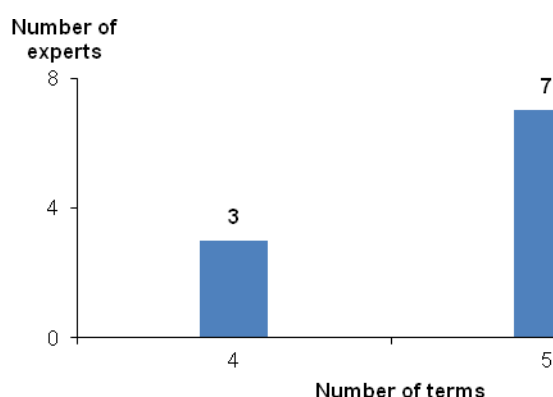


Figure 27: Number of key characteristics cited by each expert

Investigating the key notions (terms given in Flash Profile as important characteristics to compare the products) showed that 10 different terms were used by more than 10% of the experts as key

characteristics to discriminate the products. These 10 attributes consisted of 74.5% of the total different terms among which 14.2% were color-related terms.

Figure 28 shows a ranking of these terms.

Seven terms were in common with terms identified in the previous step as most frequently cited (Step1: Individual characterization of each product). However, two terms “Compact, Tranchable” that were cited more specifically for a limited numbers of products in the previous step (monadic characterization) have become important for product comparisons.

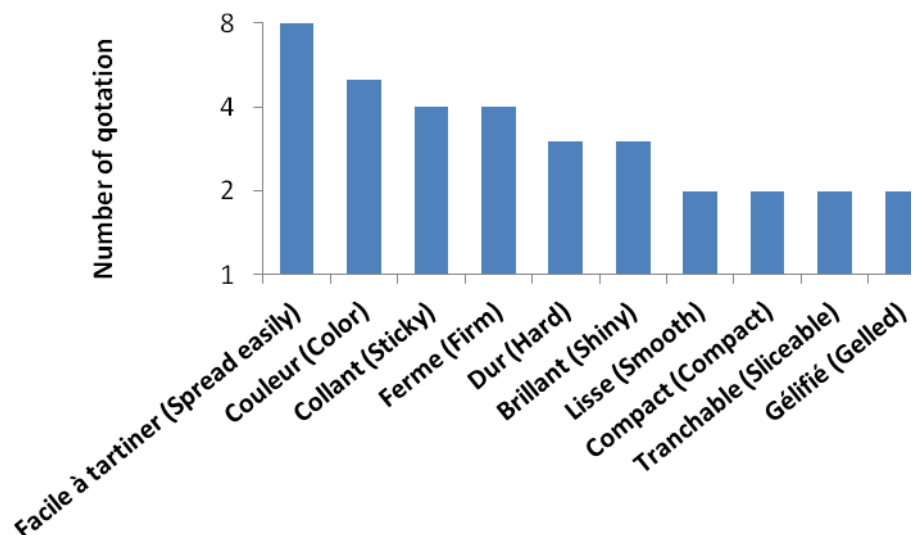


Figure 28: Important characteristics to discriminate the product cited by more than 10% of experts

Individual PCAs were carried out on the results of each expert. Figure 29 shows the distribution of the variance per dimension based on individual PCAs.

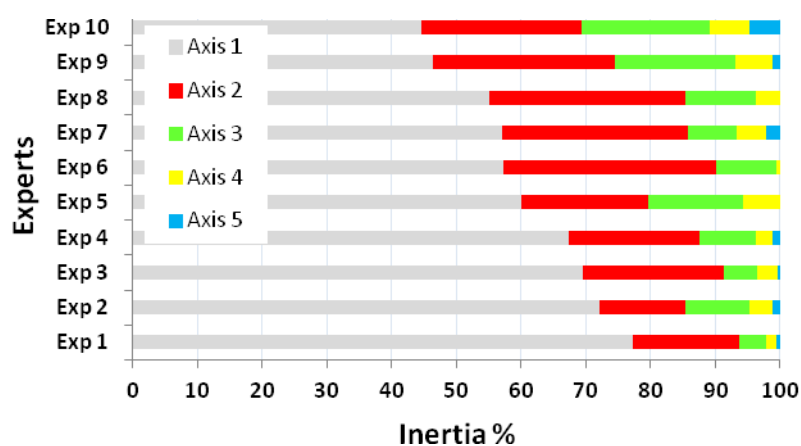


Figure 29: Distribution of the variance per dimension based on the individual PCAs (Experts: Exp)

It can be seen that for 7 experts, 90% of the information is represented on the 3 first dimensions. However for the 3 other judges, the first two axes represent more than 90% of the information. Even though the majority of the experts generated 5 terms, some were correlated which explains the low number of dimensions. This confirms that those 5 terms seem sufficient for product characterization.

Product map and description

The total variance was explained by five dimensions of the GPA. The first two dimensions explained 87% of the total variance (73 % on the first axis). Further dimensions explained only a small proportion of variance (<5%), Figure 30.

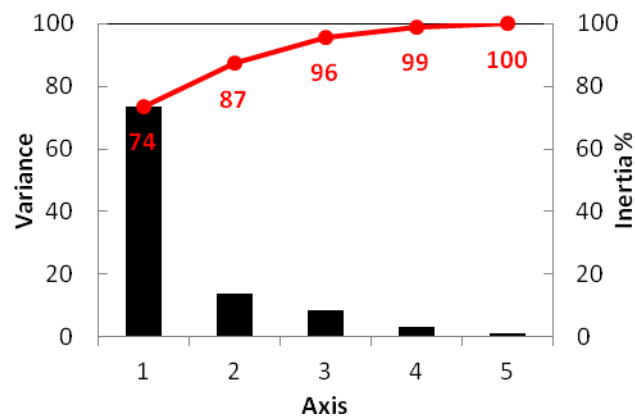


Figure 30: Distribution of the variance per dimension of GPA (Experts)

The confidence ellipses (interval of 95 %) are shown on Figure 32 for the first two dimensions of the sensory map.

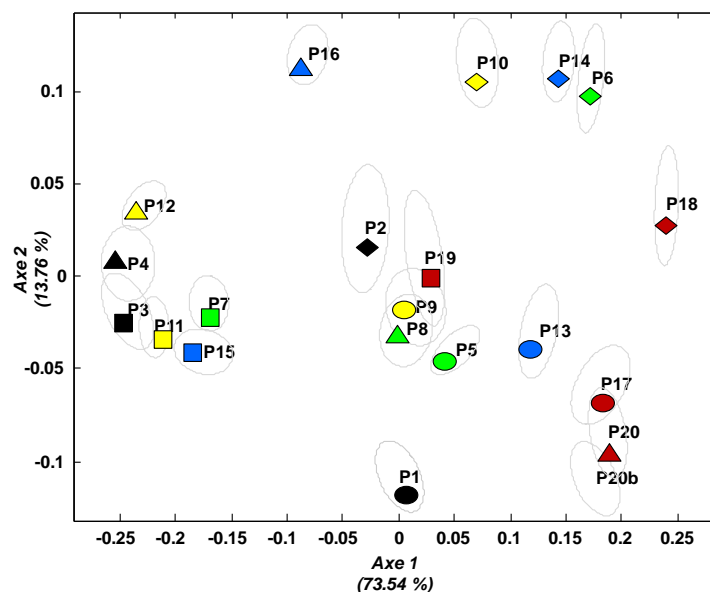


Figure 31: Representation of confidence ellipses around the GPA consensual, experts' characterization.

It can be seen that the sizes of these ellipses are globally small. The confidence ellipses of more than half the products do not overlap (P1, P2 P5, P6, P7, P10, P13, P14, P15, P16, P17, P19). The products P17 and P19 are not well represented on these dimensions and were better discriminated on further dimensions. Moreover, the close positioning and overlapping of the confidence ellipse for the duplicated product (P20,b) show a good repeatability of experts' evaluations.

The first two dimensions of GPA explained 87% of total variance, Figure 32. Following the GPA two cluster analyses were carried out: one on the products and another one on cites terms.

The Cluster analysis grouped the products into three main clusters, Figure 33. These groups are reported on the product map, Figure 32. Cluster 1 was composed mainly of products with lower concentration: P3, P11, P7, P15, P4 as well as product P11. This cluster was better discriminated by the experts. Cluster 2 was a group of P6, P13, P14, P17, P18 and P20,b products. Clusters 1 and 2 were opposed to each other on axis 1 of the GPA plot. The third cluster consisted of the rest of the products that were centrally located on the GPA map. Axis 2 opposes 4 products at the top (P6, P10, P14 and P16) versus three different products at the bottom (P1, P17 and P20,b).

Cluster analysis was also carried out on the terms following the GPA and 5 main segments of terms were obtained. We summarized these segments based on the terms cited by more than 10% of the experts in the same way as for consumers. Therefore, three segments were summarized as "Tranchable-Dur (Segment 6)," "Gelifié (Segment 7)" and "Tartinable" (Segment 4). The segments are transferred on the CONEPLLOT, Figure 32. Four segments (Segments 1, 2, 3 and 5) remained hard to interpret.

Products P6, P13, P14, P17, P18 and P20,b were described as being more "Tranchable-Dur" than the rest of the products. These products were opposed to 6 products (P3, P4, P7, P11, P12, P15) with lower concentration that were more often described as being "Tartinable". On the second dimension, P17 and P20,b were opposed to P16 and are differentiated from the rest of the products as being the most "Gélifié".

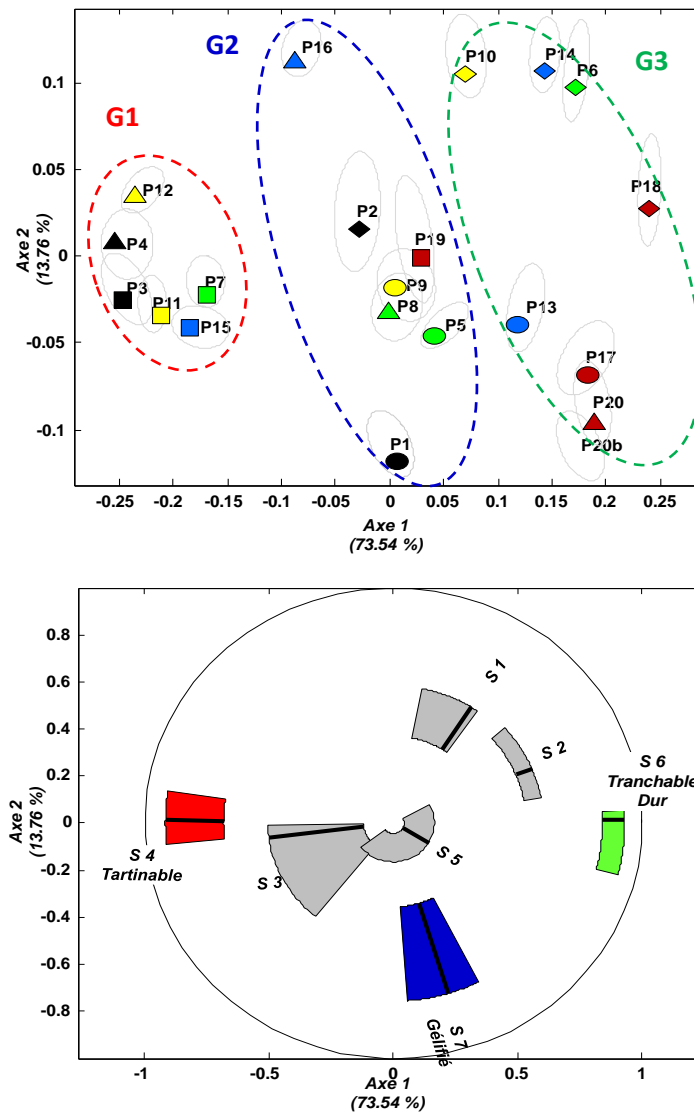


Figure 32: First two dimensions of the GPA of the profile Flash (Experts). The key notions for each HCA segments of attributes are presented on the attribute CONPLOT.

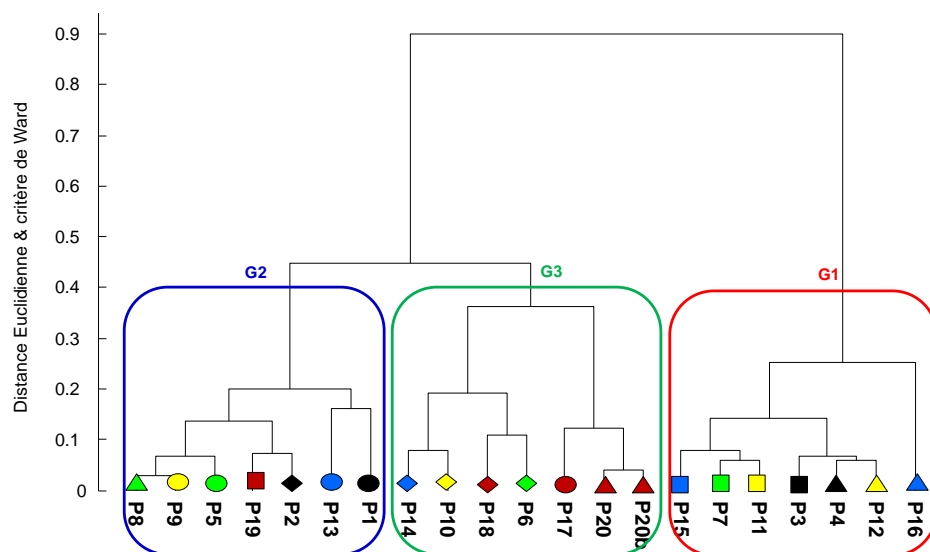


Figure 33: Dendrogram of the HCA after GPA of products described by 10 experts. Three groups of product G1, G2 and G3.

4.2.3 Combined approach – Experts results

A summary of both approaches' outcomes, monadic characterization followed by Flash Profile, is presented in the table below (Table 17).

Table 17: Summary of the results of experts' characterizations.

	Free comment One panelist-One product	Flash Profile One panelist-Several products
Number of different terms	140	29
Descriptive terms over entire set (>10%)	13 terms: Brillant, Collant, Lisse, Tartinable, Etalabl, Jaune, Ferme, Dur, Gel, Mou, Filant, Elastique, Pâteux	10 terms: Jaune, Collant, Facile à tartiner, Ferme, Dur, Brillant, Lisse, Gélifié, Compact, Tranchable
Number of axes for 90% of info	6	3
Info represented on F1×F2	59%	87%
Products map and distribution	Differences in products positioning on first two axes. Better distribution of products for comparative characterization	
Explicative terms	Ferme, Dur, Gél Pâteux	Tranchable, dur vs. Tartinable. Gélifié

More terms were cited in monadic characterization, as they could give as many terms as they wanted. The comparison of the terms cited by more than 10% of the assessors over the product range showed that some terms were specifically used for the monadic characterization such as: "Filant, Elastique, Pâteux". However, "Compact" and "Tranchable" that were identified as specific characteristics of a few products in monadic characterization became important characteristics for comparing the products.

Comparing the two configurations showed that the first two axes represent 60% of information in monadic characterization of products versus 90% in comparative characterization. This could be due to the important number of terms that were cited in monadic characterization of products.

Comparing the product maps resulting from the two methods showed differences regarding products positioning and distribution on the both first two dimensions. These differences were more important on the second axis. For example, the second axis of the monadic characterization discriminated three products (P8, P10, P19), whereas the second axis of the comparative approach discriminated seven products (P6, P10, P14, P16 versus P1, P17 and P20,b). The products containing TA-4 (Group 3) on CA map were better discriminated through monadic characterization. On the contrary, the diluted products (Group 1) were better discriminated in the comparative study. Overall, the products were better distributed on the sensory map of the comparative study.

Comparing the explicative terms of CA and GPA showed that the first component of CA discriminated the products described as "Ferme, Dur, Gel" and the first axis of GPA opposed the products described as being "Tranchable-Dur" to products mainly described as "Tartinable". This axis was relative to products firmness in both approaches. The second axis of GPA discriminated three products as being

“Gélifié” whereas the second axis of CA discriminated three products as being “Pâteux”. This can explain the differences between the perceptive maps especially on the second axis.

To sum up, in the same way as for the consumers, the combination of free comments and Flash Profile provided rich information about the experts’ terminology and revealed the characteristics that become important for them in product comparisons. The characteristic “Collant” was the mostly cited term by experts for individual characterization of products. It was cited in the second rank after “Facile à tartiner” as a key characteristic for comparison of the products.

The resulting maps from the two approaches showed some differences in terms of products positioning as well as explicative terms. This highlights the important differences of experts’ perceptions once they evaluate the products one by one versus a comparative approach. The first two components of the both product configurations discriminated the products relative to texture differences.

4.3 Comparison of the characterization of products by consumers versus experts

In this section the results of the evaluations by both panels are compared based on: the dimensionality of product space, the degree of similarity between the product maps (configuration outcome), the terminology, the number of descriptors generated and the descriptive characterization outcome. **This was aimed to investigate the effect of prior expertise on product evaluations.** Table 18 shows a summary of the results for both groups of panelists (Consumers versus Experts).

4.3.1 Comparison of consumers and experts evaluations using free comment approach

Terminology

In average, experts cited a greater number of terms over the entire set than consumers (142 vs 92 terms /assessor). Comparing the terminology (terms most frequently cited over entire set) of both panels showed that 7 terms were in common: “Collant, Tartinable, Étalable, Dur, Lisse, Brilliant, Jaune”. The first two terms most frequently cited were the same for both groups: “Collant” and “Brillant”. Some terms were more specific to each panel. Attributes “Gel, Filant, Elastique” were only used by experts. Indeed, none of the consumers cited these terms to characterize any of the products. Consumers cited the term “Compact” more frequently and used it to characterize 12 products. On the contrary, experts used this term more specifically and only for two products (P8 and P10). This arises the question of the difference in the definition of this term between the two panels.

Table 18: Summary table of the results for products characterizations by 2 panels (60 consumers versus 10 experts).

	“Free comment method” Monadic characterization One panelist – One product		“Flash Profile method” Comparative characterization One panelist – Several products	
	Consumers	Experts	Consumers	Experts
Av. total terms (term/assessor)	90	142	4	5
Av. different terms (terms/assessor)	9	23	2	3
Number of terms most frequently cited over the entire set (>10%)	9 terms: Collant, brillant, jaune, lisse, dur, étalable, facile à tartiner Crémeux, compact	13 terms: Brillant, collant, lisse, tartinable, étalable, jaune ferme, mou, dur, pâteux, Gel, Filant, élastique	10 terms: Couleur, brillant, collant, facile à tartiner, dur, lisse, compact, crémeux, s'étale Granuleux	10 terms: Facile à tartiner, couleur, collant, ferme, dur, brillant, lisse, gélifié, Compact, tranchable
Product space dimensionality “individual”	—	—	For 60% of panelists 90% of info on 3 axes	For 70% of panelists 90% of info on 3 axes
Product space dimensionality “Panel”	100% info on 7 dimensions	100% info on 11 dimensions	100% info on 5 dimensions for both panels	
Number of axes presenting 90% of info	4 axes	6 axes	2 axes for both panels	
% of info represented on F1×F2	80%	59%	93%	87%
Products distribution (F1×F2)	Better distribution for consumers. Differences in product distribution on both axes		Globally similar distribution positioning of product. Some differences on axes 2 for 5 products.	
Summarized attributes explaining the product map	Dur, compact, crémeux, jaune, <i>collant, brillant</i>	Dur, ferme, gel, pâteux	Facile à tartiner, collant, crémeux, dur, compact, brillant, lisse, couleur	Tartinable, tranchable, dur gélifié
Terms best discriminating the 3 HCA semi-profiles	Facile à tartiner, brillant	Dur, ferme	—	—
Evaluation conditions “Individual choices”	Consumers showed more variations. Observed differences were depended on panelists and not products		—	—

Product maps based on frequent terms/main characteristics

The dimensionality of the product space was lower for the consumers (7 vs. 11 dimensions). The consumer characterization resulted in a product map with more information on the first two components (80% vs. 59%). In addition, the distribution of products on consumers map was better than the one of experts. This difference is related to the greater diversity of cited attributes, not too correlated, by the expert panel.

The products positioning on the first two components were different between the two panels, Figure 35. The first two components of CA discriminated and opposed the products P6 and P20 to P12 and P16 for consumers, whereas it opposed P17 and P20 to P12 for the experts. This component was relative to “Dur” and “Crémeux” characteristics for consumers and to “Dur, Ferme, Gel” characteristics for experts. The differences on the second component were more important. This component discriminated three products (P1, P3, P8) relative to their yellow color for consumers, whereas it discriminated three products (P8, P10, P19) relative to their pastiness for experts.

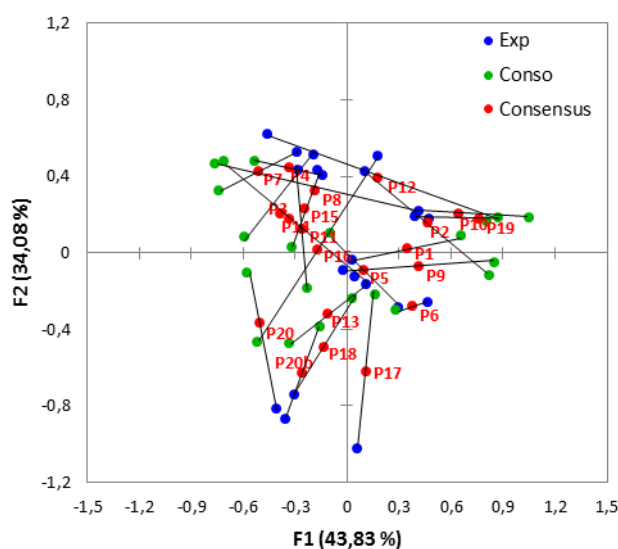


Figure 34: Results of the GPA comparing the product characterizations by the consumer and the expert panels using free comments. Representation superimposed the 20 consensual (●) different products and partial products seen by the consumer (●) and by the expert (●) panel on the first two components.

Evaluations conditions

Investigating the individual differences in evaluation conditions showed that both panels had a tendency to change their testing conditions during their evaluation. However, bigger variations were observed for consumers. For both panels, the differences in options depended on the panelist rather than on the product texture.

We can thus conclude that, not only the consumers had used the objective terms related to texture and visual aspects for products discrimination, but also the majority of the terms they cited frequently were similar to experts' terminology (ex: Collant, Brilliant). However, they did not cite some attributes that were applied by experts. In fact, the experts' terminology was richer but some of their attributes were either not relevant to consumers or were specialized and technical terms applied in their field. Finally, the term "Compact" was used differently by the two panels. This poses the questions concerning the different definition of this term for the two panels.

Concerning the product map after monadic characterization of products, for the majority of the products there was a big difference between the evaluation of both panels in terms of products positioning and discrimination as well as the explicative terms. The first two components of product map through consumer evaluations represented 20% more of the information. Moreover, the products distribution was better in the consumers' map compared to the experts' map.

Concerning the evaluation conditions, consumers showed greater diversity than experts. For both panels, the variations were panelist-dependent rather than product-dependent. This shows that the differences between the products do not dictate differences in evaluation conditions.

4.3.2 Comparison of consumers and experts evaluations using the Flash Profile approach

Key characteristics to synthetically discriminate the product

In average, experts cited slightly more terms than for consumers (5 vs 4 terms / assessor). In both groups, 10 different terms were cited by more than 10% of the assessors. The majority of these terms were in common between experts and consumers, except 4 terms. The terms "Granuleux, Crémeux" were found to be important characteristics for consumers only, while "Gélifié, Tranchable" were only relevant for experts.

Product map and description

The individual dimensionality of only a small proportion of the experts was higher than consumers (70% vs 60%). However, at panel level, the dimensionalities of the product spaces were the same for both panels.

A GPA was carried out on both data sets in order to compare product configurations of consumers versus experts, Figure 36. On the first axis, the projections of configurations of consumers and experts panels coincide practically perfectly. On the second axis, the projections of the configurations coincide well for the majority of the products. However, some slight differences were observed for 5 products (P3, P14, P15, P18 and P20,b).

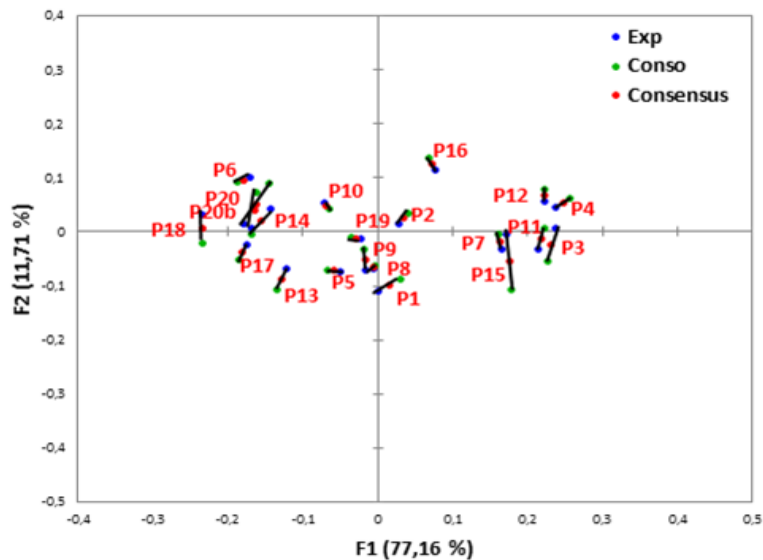


Figure 35: Results of the GPA comparing the product characterizations of the consumer and expert panels using Flash profile. Representation superimposed the 21 consensual (●) products and partial products seen by the consumer (●) panel and by the expert (●) panel on first two components.

Semantic characterization of products showed certain similarities in the sensory description of products between the two panels. In both panels, P6, P13, P14, P17, P18 and P20(b) products were opposed to products P3, P4, P7, P11, P12, P15 products. These products were differentiated respectively based on their hardness and spreadability by both panels. For consumers, attributes relative to stickiness and creaminess were correlated to attributes relative to spreadability. 14 consumers over 20 used the attribute “Collant (Sticky)” in the same way for their evaluations. However, no agreement was found among the 4 experts who used this attribute for their evaluations. For experts, creaminess was not a key characteristic to discriminate the products. Moreover, the consumer evaluations discriminated the products on the axis 2 based on the visual aspect while the experts discriminated the products based on texture differences relative to “Gélifié”. This could explain why there are more differences between the product maps on the second axis. Therefore, for both panels the first component was explained by similar notions. However, the second component was related to visual aspect for consumers and texture-related terms for experts.

The product map after comparative characterization showed that the consumer derived map represented 20% more of the information on the first two components. Moreover, the products distribution was slightly better in the map derived from consumers than from experts. The projections of product configurations of both panels coincide well on first two axes with some slight differences on the axis 2 for 5 products (P3, P14, P15, P18 and P20(b)). The first axis discriminated the products relative to their texture differences for both panels. However, the second axis was related to visual aspect for consumers and to textural differences for experts. In fact, for consumers, there was mainly one texture-related dimension that represented the most of the information.

5. Discussion and conclusion

The main goal of the first part of this work was to characterize the texture of 20 model processed cheeses through an individual approach that takes the diversity in perceptions, applications and vocabularies into account. Hence, to obtain spontaneous perceptions of products and include their diversity, the products were evaluated by consumers.

Using free descriptive comments provided a rich pool of terms. Running a frequency-based analysis allowed us to discriminate the product characteristics at the individual and aggregated levels. Applying a 10% threshold reduced the total number of distinct terms cited to describe the products from 550 to 36 (9 main and 27 specific characteristics) across the entire product set. These terms represent 50% of all the terms that are related to in-hand texture and visual aspects of products. Previous studies on characterization of processed cheese using classic methods reported only 4 to 9 descriptors for texture description of processed cheese (Adhikari et al., 2009; Drake et al., 1999c; Everard et al., 2007; Fagan et al., 2007; Muir et al., 1997; Pereira et al., 2002; Piska & Štětina, 2004). The richness of descriptors in the free comment method gives an accurate description of each product by means of consumer terms. Our results depict that albeit the important diversity of terms generated, the main and the specific terms cited for product characterization by consumers were mostly related to the visual or in-hand textural aspects of products.

By comparing the elicited terms in our study to other studies on processed cheese characterization using classic approaches, we identified that some terms in our study are the same as the terms evaluated by experts such as: “Collant” (*Sticky*), “Lisse” (*Smooth*), “Crémeux” (*Creamy*), “Tartinable” (*Spreadable*) (Adhikari et al., 2009; Drake et al., 1999c; Everard et al., 2007; Fagan et al., 2007; Muir et al., 1997; Pereira et al., 2002; Piska & Štětina, 2004). Nevertheless, some other terms like “Compact” (*Compact*) or “Mousse” (*Foam*) were only reported in our method. However, some of the texture descriptors reported in conventional methods, such as Elasticity/Springiness did not appear to be relevant for consumers. This is also in agreement with our observation regarding the experts’ characterizations. The experts did not use the term “Compact” as frequently and freely as consumers in individual characterization of each product. Conversely, the term Elastic was one of the terms that only experts cited and they used it quite frequently.

The consumer terminology collected in our study is quite similar to terms reported in other studies using frequency-based methods. Lawless et al. (1995) studied cheese perception using the sorting method. They found that 17 terms were most frequently listed to describe the cheese groups. Texture-related terms consisted of Open (presence of holes or cracks), Firm, Chewy, Spreadable and Smooth. These terms are close to our results except for the terms Open and Chewy. That could be due to differences in the types as well as the diversity of cheeses. Consumer characterizations of semisolid dairy desserts had demonstrated that consumers discriminated products mainly on the basis of their color and texture (González-Tomás & Costell, 2006). Regarding color, the products were discriminated on their level of yellowness. Regarding texture, the products were discriminated using terms such as: Jelly, Thick, Compact, Fluid, Liquid, Soft, Earthy, Grainy, Rough, Smooth and Thin. This was in agreement with our results and it can be seen that although the product ranges are not the same, some texture terms are common, for instance: “Compact” (*Compact*), “Lisse” (*Smooth*), “Mou” (*Soft*), “Épais” (*Thick*), “Liquide” (*Liquid*). In another study using the free listing method to identify consumers’ texture vocabulary on milk dessert, Ares et al. (2011) reported 13 terms that were elicited by more than 10% of the consumers. The elicited terms were similar to those reported by González-Tomás & Costell (2006) and those in our study. These different studies showed that using consumers in a descriptive procedure not only allows for product characterization, but also shows that the identified terms for texture description are quite similar from one study to the other.

In fact, in a conventional approach, diversity is eliminated by imposing a glossary of terms and specific manipulation instructions. However, in our free-text comment method, consumers were free to use their own terminology and use any type of manipulation they wanted. As discussed in other studies, although analyzing free comments is tedious and time consuming (Lahne et al., 2014; Symoneaux et al., 2012), applying frequency-based analysis makes it possible to extract directly a glossary of consumer terms rather than imposing it. Campo et al. (2010) and Lawrence et al. (2013) suggested that the richness of consumers' terminology in frequency-based methods reduced the risk of "forcing" panelists to score one or more descriptors highly when there is a descriptor deficiency in conventional consensus-based methods. Even though texture evaluation does not seem to be an easy task for consumers, this study shows that it is possible for them to illustrate the main and specific texture characteristics of products. According to Ares, Giménez, & Bruzzone (2011), aside from identifying consumers' terminology, frequency-based methods can most likely provide information about the relevant characteristics of the products and their importance for consumers. These methods can be used as complementary methods with a classic profile or they can replace it when the classic profile is not feasible (Symoneaux et al., 2012).

In our study, running CA on the contingency table of the most frequently cited terms helped discriminate the products mainly based on the terms in common among the products (main characteristics). Additionally, studying individual product characteristics allowed us to obtain a very detailed consumers-derived description of each product and its specificities. Therefore, a sensory image of each product and the product positioning were achieved on the basis of descriptors relevant to consumers. According to Bruzzone et al. (2012), the consumers' wide variability and their lack of training and consensus compared to trained panelists can be compensated by their larger number (50-150 consumers).

Using the free comment method with assessors with prior expertise resulted in a richer and more detailed terminology. However, their results differed from the consumers'. Some attributes used by experts were not cited by consumers. This could be due to the fact that experts consider some differences that are irrelevant to consumers (Ares et al., 2010b; Bruzzone et al., 2012). Another explanation is that their terminology may be different from the terms used by consumers (ten Kleij & Musters, 2003). Or experts define more finely the products characteristics. Moreover, the perception of assessors with prior expertise could be different from consumers. The distinct characterization of Group 3 in monadic characterization showed the effect of their expertise on discrimination of these types of products.

On the other hand, the use of Flash Profile also revealed interesting extra information on the terminology of each panel. Even though the terminology study is not the main concern of Flash Profile (Dairou & Sieffermann, 2002), investigating the key characteristics cited by at least 10% of assessors revealed characteristics that can become important in comparing the products. The differences observed in terminology can be explained by the differences in evaluation approaches (comparative vs. monadic sequential). This results in differing contexts of evaluation. This is in agreement with the methodological differences reported by Delarue & Sieffermann (2004) in characterization of fruit dairy products using conventional and Flash Profile method.

The use of Flash Profile for the characterization of the products gave a rapid access to their sensory positioning. The resulting sensory maps were very similar between the two panels. Comparing the sensory maps from the two methods showed consistent results for consumers. Nevertheless, the experts' results presented some differences. This could be explained by the differing evaluation methods. According to Delarue & Sieffermann (2004), in the sequential monadic approach, each product is evaluated in comparison with the assessor's representation of the product space, which is

either linked to what they have been taught previously or to his/her experiences. Since memory is not involved in the same way in comparative and monadic approaches, the effect of prior expertise on product characterization could be more pronounced in monadic characterization. **Hence, working with trained or experienced panelists could lead to the risk of losing part of the information related to consumers' perceptions.**

In addition, the repeatability of the assessors was also investigated by presenting one product in duplicate. The characterizations of the duplicated product showed a good repeatability for consumer and expert evaluations in terms of main and specific characteristics as well as product positioning.

Furthermore, including the diversity of personal choices in testing conditions revealed interesting information regarding the inter-individual diversity. It showed that despite the large variation between the testing conditions among assessors, the differences are panelist-dependent rather than product-dependent. We can conclude that the differences between the products were predominant over the differences in evaluation conditions.

The results showed that the applied method made it possible to take a large variety of perceptions, testing conditions, evaluation and descriptions into account. Despite the large variety of terms, gathering the product sensory characteristics directly from panels, and especially consumers, leads to a predominant use of objective terms. Combining the free-text comment method with Flash Profile enabled us to investigate one panelist–one product interaction as well as one panelist–several products interactions. This approach allowed us to obtain the main and key characteristics of the entire range of products, as well as specificities of each product. **This study demonstrates the interest of using consumers for product characterization on the basis of their daily lexicon. It also investigated how prior expertise in descriptive analysis modifies the perception and description of products. It showed that the consumers and the expert characterizations are not contradictory, and in general the experts characterization do not bring new information.**

In conclusion, we think it would be misleading to consider the free methods as a substitute for conventional profiling to give an accurate description of the products. These methods do not fulfill exactly the same objectives. **The conventional methods are certainly the most accurate profiling technique to date. However, the free methods could be of great help, for example, in language development. Furthermore, when product positioning and discrimination are of prime concern, profiling techniques based on free choice of attributes are preferable to those involving the development of consensual attributes.**

In brief:

- The free comment method brought interesting information on the terminology and each product characteristics. Concerning products discrimination, it revealed important differences between the product maps from consumers and experts on the first two components.
- The use of Flash Profile for the characterization of the products was faster in terms of evaluation as well as data analysis and gave a rapid access to sensory positioning of products. The product maps after both panels' evaluations resulted in similar product positioning with some differences for 5 products.
- The important differences that were observed between the product maps for the two panels using the free method were not observed in characterization by Flash Profile. The product maps after Flash Profile were very similar to each other and were also close to the resulting map from consumer evaluations using free comments method. This shows the effect of pre-expertise and the difference of perception in monadic characterization of products between experts and consumers. Moreover, the resemblance between the product maps of consumers and experts in comparative evaluation confirm the reliability of consumers in using a descriptive approach. Since the products were better discriminated in sensory maps after the Flash Profile for both panels compared to the maps resulted from free method the product map after comparative study will be taken into account for the rest of the study.
- Some differences were noted regarding the explicative terms. For consumers, only the first axis was related to their texture differences. However, the first two axes were related to texture related terms for experts. However, the experts had discriminated the products on the second component relative to the "Gélifié" characteristic which was irrelevant to consumers. Nevertheless, the product map achieved by both panels through comparative study will be considered for the correlation study.

Part 4: Towards instrumental assessments

One of the main objectives of this study was to govern the instrumental assessment based on the results of sensory evaluation. This aimed at inspiring instrumental measurements by selecting the appropriate methods and improving the test conditions with the hope of better predicting sensory perceptions (especially multidimensional ones) through physical factors.

The sensory results were taken into account from two aspects to move toward the instrumental assessment: the descriptive terms and the Supplementary observations (*cf. Part3 - (II) - 2.3 - Step 3*).

In this part we explain how the different sensory information was used to choose a limited number of adequate instrumental methods and conditions for product evaluation. First, the way in which the sensory descriptions were treated will be explained. Second, the information extracted from “Supplementary observations (*cf. Part3 - (II) - 2.3 - Step 3*)” will be considered.

1. From free descriptive terms to physical factors

In brief, the following approach was applied in this part:

- A priori categorization of the cited terms following a logical hypothesis of the similar physical phenomena underlying the terms.
- Validation of the pre-identified categories by 6 experts using the same approach
- Proposal of physical tests that permit to evaluate the identified categories and
- Improve the test conditions based on the “Supplementary observations” from sensory evaluation.

Characterizing the products using the free comments method resulted in a long list of terms for both consumers and experts. Firstly, we investigated whether we could regroup the cited terms within categories representing similar physical properties of products. This aimed at having a defined strategy regarding the selection of adequate methods for instrumental assessment. This aimed to select the instrumental methods that are appropriate to measure the perceived properties, in general, with a focus on more complex properties.

In order to address these issues, we decided to work on the experts’ list of terms from sensory free comments (*cf. Part 3– (II) – 4.2.1: Step 1: Characterization of each product by an individual approach*). This was done for two reasons: the experts’ list consisted of fewer terms (230 versus 550 for consumers) but included all the terms cited by at least 10% of consumers for each product.

The terms were regrouped in different categories, a priori, according to the common underlying physical factors. Since we were interested in terms related to product handling, the visual terms were separated, even if they could possibly give information about product texture. Hence, texture-related terms presenting similar products behavior, and possibly similar/closer physical properties were regrouped together. 6 categories emerged from this a priori sorting. They were defined as: “Fermeté (Firmness)”, “Élasticité (Elasticity)”, “Fluidité/Viscosité (Fluidity/Viscosity)”, “Tartinabilité (Spreadability)”, “Cohésion (Cohesion)”, “Adhésion (Adhesion)”.

These identified categories were coherent with the sensory descriptors evaluated in classic sensory profiling and with mechanical properties reported in literature (cf. Table 3 and Table 4).

The six identified categories represent are close to the descriptors widely evaluated in classical profiles for texture characterization of the same type of products. For instance, the descriptor firmness/hardness, adhesiveness/stickiness, cohesiveness, elasticity/springiness are the descriptors evaluated in several studies on various types of cheese characterization either through non-oral or oral conventional evaluations (Adhikari et al., 2009; Breuil & Meullenet, 2001; Brighenti et al., 2008; Drake et al., 1999b; Kealy, 2006; Melito, Daubert, & Foegeding, 2013; Ritvanen et al., 2005). The category “spreadable” represents the descriptors “spreadable” or “difficultly to spread” evaluated in texture characterization of semi-solid foods or cream cheese (Brighenti et al., 2008; van den Berg et al., 2008). Finally, the category “fluidity” possibly represents the descriptor “viscosity” that was evaluated for characterization of yogurt (Ilan et al., 2011).

Five of the proposed categories (Adhesion, Cohesion, Elasticity, Fluidity, Firmness) represent similar mechanical parameters that Szczesniak (1963) extracted from the TPA method to evaluate the mechanical characteristic of texture (Adhesion, Cohesion, Elasticity, Viscosity, Hardness).

Since this limited number of categories was found to be reliable for categorization of the terms, we decided to validate them through an evaluation by 6 experts.

Therefore, six experts with experience in both sensory and texture sciences were recruited from AgroParisTech or collaborators. The experts were provided with the 230 terms and the 6 pre-identified categories. An extra category was also provided to place the terms that the expert could not sort in any of the six pre-defined categories.

Experts were asked to sort the terms that presented similar physical properties in the corresponding category. If they could not place a term in any proposed category, they should place it in the undefined category. Each term could be sorted only in one category.

The validation step was meant to answer the following questions: *Are the proposed categories efficient for sorting terms based on their similar physical properties? Is it possible to sort all the terms cited by 10% of assessors in predefined categories? Are there categories that should be modified, eliminated or added? What is the nature of the terms in undefined category? What are the attributes that the experts agreed less or disagreed for their sorting? Do all the experts use all the proposed categories for their sorting?*

The goal was to maximize the objectivity of the sorting task and to give robust results.

1.1. Results & Discussion

A term was assigned to a category only if more than 50% of the experts ($n > 3$) had placed it in the same category. Furthermore, the distribution of the terms per category for each expert was investigated to check if all the experts found all the categories adequate for sorting. The contribution (number of terms) of each expert to each category was also investigated to check if the categories were equally useful for all the experts.

By applying the threshold $n > 3$ for assigning a term to a category, 70% of the terms were assigned to one of the proposed categories (defined/undefined). However, decreasing the threshold to $n = 3$,

the percentage of the terms assigned to one of the suggested categories (defined/undefined) increased to 90%, Figure 36.

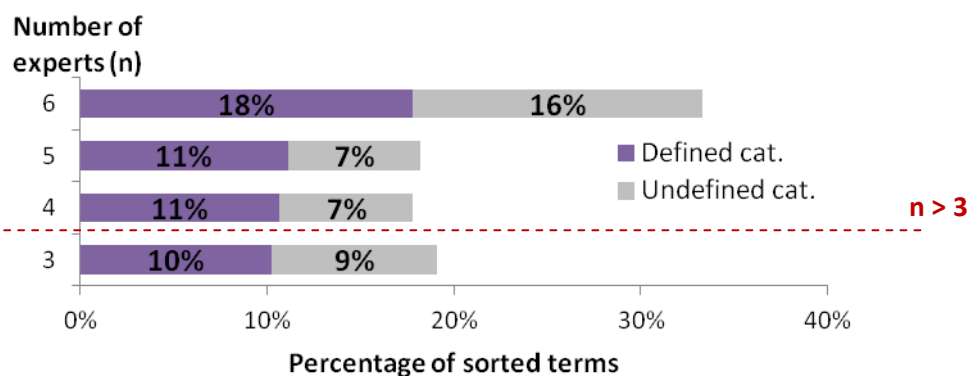


Figure 36: Percentage of the terms assigned to the same categories by $n \geq 3$ experts.

The 6 experts were unanimous on sorting 34% of the terms, Figure 36. Among those terms, about half were sorted in “defined” categories and the other half in the “undefined” category. 4-5 experts were in agreement on sorting of about 35% of the terms. They sorted about 20% of those terms in “defined” categories and about 15% in the “undefined” one. It can be seen that the experts had less agreement on sorting of about 20% of the terms. These terms were sorted by 3 experts in the same categories (10% defined and 9% undefined). Finally, for the last 10% of the terms, the experts did not agree.

The percentages of terms sorted in defined categories, by more than 3 experts ($n > 3$), shows that **all the defined categories were in general used for terms sorting**, Figure 37. However, the important percentage of terms in undefined category arise the question regarding the nature of these terms and the sufficiency of the proposed categories. This will be discussed further.

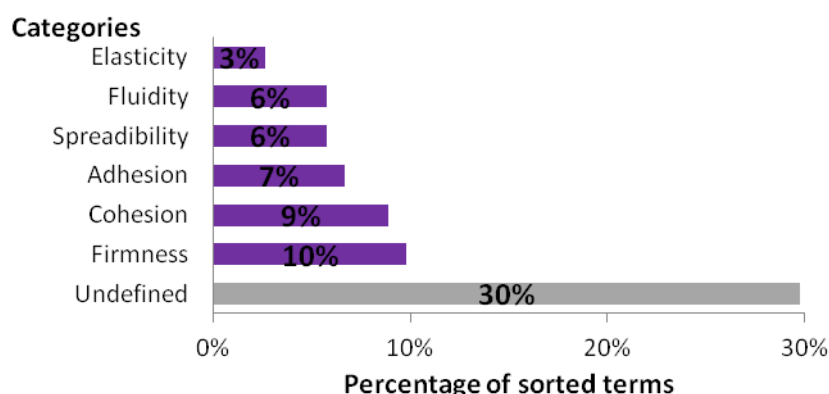


Figure 37: Percentage of terms assigned by more than three experts in each category

Figure 38 depicts some examples of the terms sorted in the same defined categories by more than half of the experts ($n > 3$). The terms placed in these categories showed that all the texture-related terms that were cited by more than 10% of both panelists groups (consumers and experts) were sorted in the same categories with only a few exceptions: “Compact, Crémeux, Gel, Lisse, Pâteux,

Épais, Homogène, Malléable”. This shows the high adequacy of the proposed categories for terms classification.

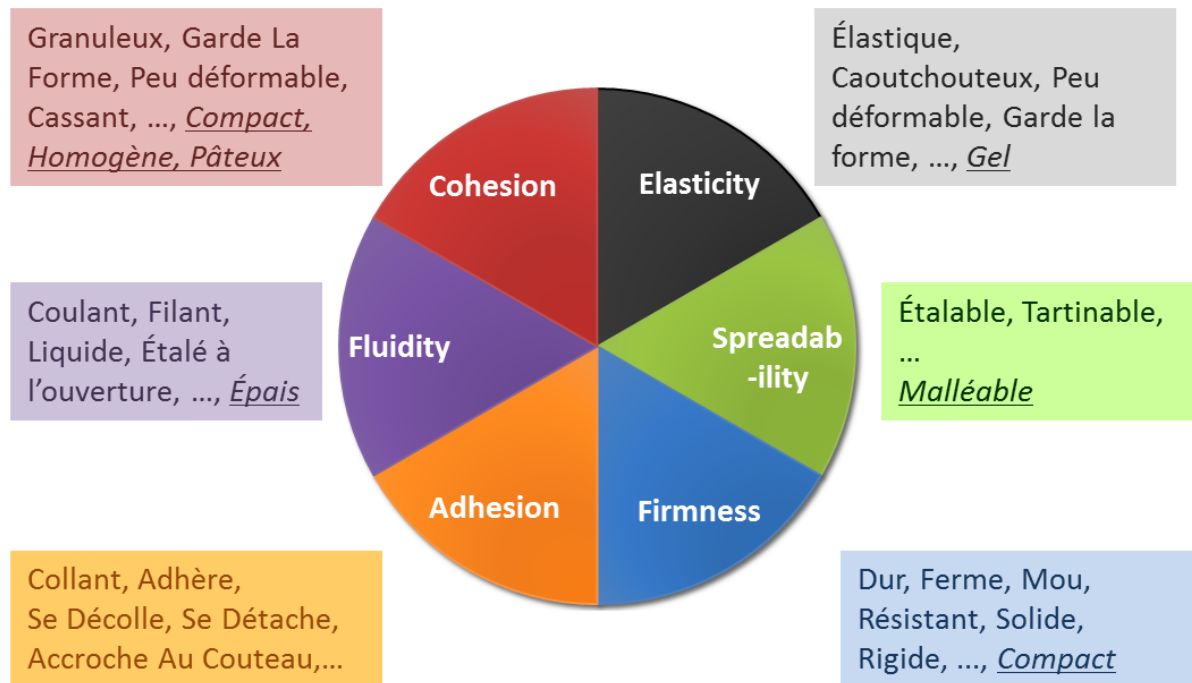


Figure 38: Example of terms sorted by more than 3 experts ($n > 3$) in each of the predefined categories. The terms sorted only by three experts ($n = 3$) are presented in *italic* and are underlined.

Investigating the terms for which experts were less in agreement ($n = 3$) showed that they are mainly texture-related, including the terms “Compact, Crémeux, Gel, Pâteux, Épais, Homogène, Malléable”.

The term “Compact” was sorted in the Firmness category by 3 experts and in the Cohesion category by 3 other experts. This shows that either the physical notion underlying this term was different for these experts or this term could be related to both categories. However, the expert had to choose only one.

Three experts agreed on sorting the term “Pâteux, Homogène” in the Cohesion category, the term “Gel” in Elasticity category, the term “Épais” in Fluidity category and the term “Malléable” in Spreadability category. The term “Crémeux” was placed in undefined category. This could be due to the fact that the experts considered this term as hedonic or they related this term to different or several physical properties.

Hence, we can conclude that, in general, the experts have used the proposed predefined categories for their sorting and agreed with the prior categories. The lower agreement of experts for sorting some texture terms is most probably due to the fact that the terms can be related to several categories rather than the lack of the proper category. Indeed, even though the experts did not agree on assigning these terms to the same categories, the majority of them used one of the defined categories for their sorting, except for the term “Crémeux”.

Analyzing the terms sorted in the “undefined” category by more than three experts ($n > 3$) shows that: this category mainly consists of the terms describing the visual aspect (12% of total terms) related to optic properties, color and shape of the products (respectively 6%, 5% and 1%), other products’ name (5%), irregularity-related (3%), fat-related (2%), moisture-related (1%) and some other terms (4%). Some examples of these terms are given in Table 19.

Table 19: Terms sorted in undefined category by more than 3 experts

Terms sorted in undefined Category	
Visual aspect	Jaune, brillant, rond...
Moisture-related	Imbibé...
Irregularity-related	Bulle...
Fat-related terms	Gras...
Other product’s name	Mayonnaise...
Others	Claquant, crémeux

The percentages of the texture-related terms on the basis of same physical properties stay very low. Hence, the proposed categories are sufficient.

Finally, comparing the numbers of terms placed in each category by each expert showed that all the experts used all the categories for sorting the terms. Firmness, Fluidity, Adhesion and Elasticity categories were similarly used by the expert. Three experts showed more latitude to place more terms in the Cohesion and Spreadable categories. Investigating their sorting showed that these experts had put the terms related to other products’ names (such as “mayonnaise” or “Nutella”) in these categories. They declared that they tried to interpret these terms.

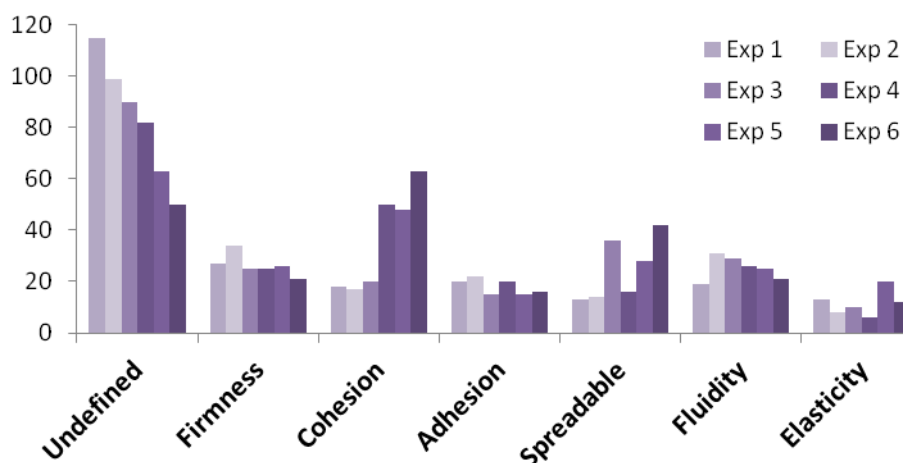


Figure 39: Number of terms sorted by each expert in each category

To conclude based on the results of validation, the proposed categories are sufficient and adequate for sorting the terms since:

- All the categories were useful for all the experts to sort the terms.
- The majority of the texture-related terms were sorted in the defined categories, and a very low percentage of texture-related terms were put in undefined category.
- The terms for which experts did not agree were still sorted in the defined categories showing that they could possibly refer to more than one category.

Furthermore, as already discussed, these categories correspond to both sensory and instrumental factors already reported in literature.

1.2. From categories to instrumental methods

Regrouping texture terms in categories was done with two goals: to identify categories based on the common underlying physical properties and to then identify and select relevant instrumental methods for characterization of each category. Hence, once the categories have been validated, the remaining question is: *What are the mechanical characterizations that correspond to each category?*

Herein, the methods that can be applied to characterize each category as well as the corresponding physical parameters are presented, Figure 41.

The literature review showed that the **Firmness** category contains terms that have been characterized by both fundamental and empirical rheological methods such as: dynamic test in oscillation, creep-recovery test, compression test, TPA test, torsion test and penetrometry (Adhikari et al., 2009; Berg et al., 2008; Breuil & Meullenet, 2001; Brown et al., 2003).

The **Elasticity** category contains terms that have been characterized mainly through the TPA method, however, the torsion test and fundamental rheology like dynamic test can also be applied (Brown et al., 2003; Drake, et al., 1999b,c; Everard et al., 2007).

The **Fluidity** category includes terms that can be characterized by small strain rheological methods such as oscillatory tests or large strain methods such as viscosimetry tests (Ciron et al., 2011).

The **Spreadability** category has been characterized through spreadability tests (a type of extrusion or back extrusion, TPA and oscillation tests (Brighenti et al., 2008; Tamime et al., 1999) .

Finally, the TPA method has been mainly applied for the characterization of **Adhesion** and **Cohesion** categories in cheese-like products. Tack measurement has been largely applied for characterization of other products but less for cheese. Some authors reported correlation between the factors obtained after Oscillation and torsion tests and these sensory perceptions (Adhikari et al., 2009; Brown et al., 2003; Childs et al., 2007; Everard et al., 2007; Goldner et al., 2012; Melito et al., 2013; Rogers et al., 2009).

As it can be seen in Figure 41, several methods are applicable for characterization of these categories, from which some can be more generally applied (oscillation tests) while others are more appropriate for specific category (viscosimetry test).

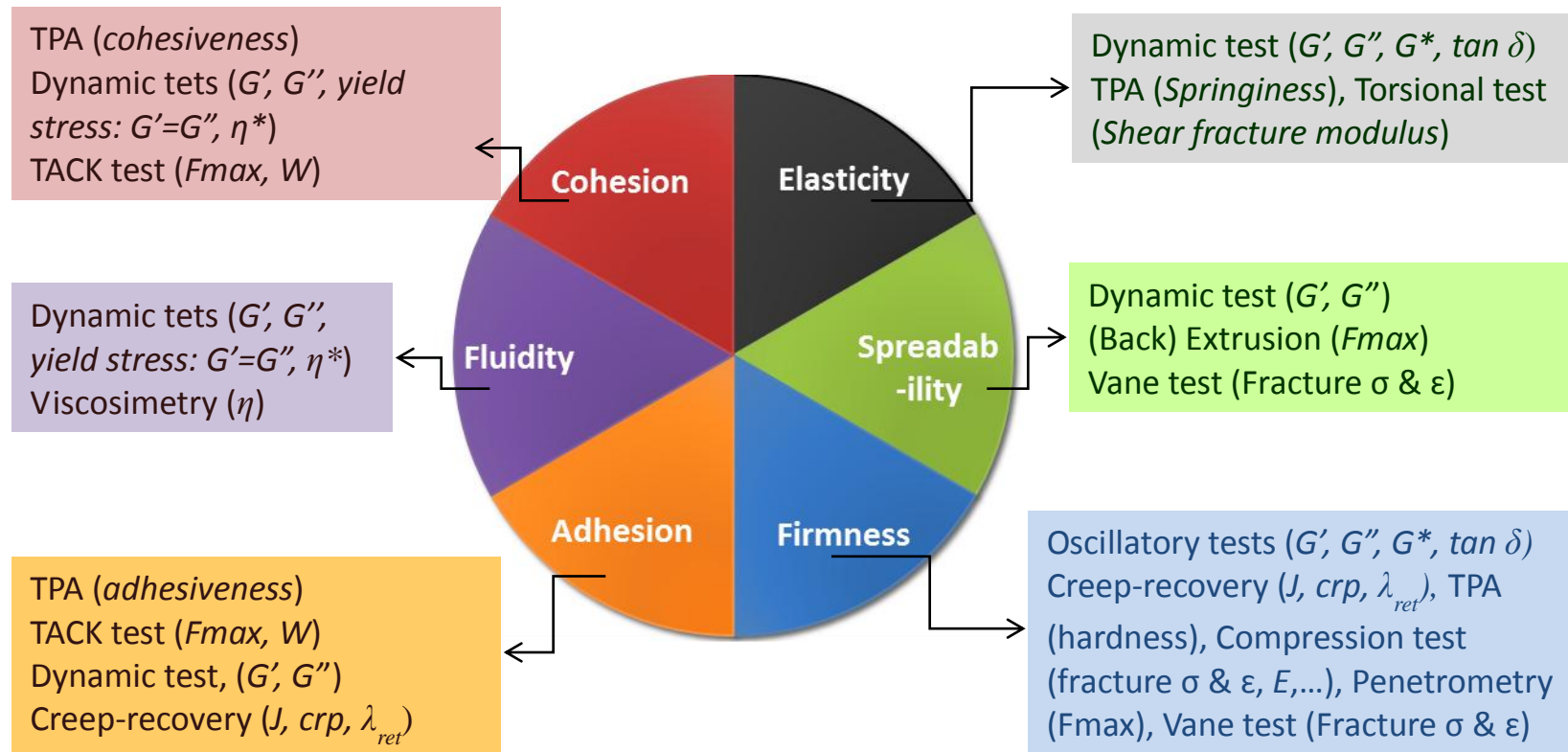


Figure 40: Instrumental methods that could be applied for each category characterization from literature analysis

As explained at the beginning of this part, to make an informed choice on methods and assessment conditions, two sensory aspects were taken into account: descriptive terms and supplementary observations. In the following part, the results for “Supplementary observations” are presented.

2. Supplementary observations from sensory evaluations

The aim of this supplementary step in sensory evaluation was to inspire the instrumental part and extract extra information to possibly help for the selection of appropriate test conditions. Therefore, the procedures of product handling of panelists were studied for three atypical products (P2, P4 and P18).

Product P2 described as being “Épais (thick)”, P4 as being “Facile à tartiner (easy to spread)” and P18 as being “Dur (hard)”. These three products were selected as representing the three main groups of sensory characterization.

The recorded films were analyzed to answer the following questions: *What are the different main types of handling procedure? Is there a specific type of procedure for the evaluation of specific product/terms? Finally, what factors can be taken into account for product implementation or test conditions in the instrumental part?*

2.1. Evaluation procedures of consumers and experts

Inter and intra variation of product handling by panelists was investigated through the recorded film for the three presented products. The behavior of panelists and their interaction with different products showed that the manipulation can possibly change for a panelist based on the product and among the panelists. These Supplementary observations revealed interesting information regarding the description, the different manner of handling, the deformation degree and the link between them.

Concerning the description of products by consumers, two different ways of description were observed:

- The consumers, who firstly observe, manipulate and deform the product in different ways and then, at the end of all manipulation, they describe the product. Therefore, there is two phases: first, manipulation followed by description. For these panelists it is not evident if the descriptive terms is related to a specific manipulation or it is an overall perception.
- The consumers who generate one or some terms through one gesture. This group evaluates the products sequentially and generates their terms. For example, one panelist evaluated surface and wrote “compact”, and then unmolded the product and wrote “demoulable”.

75% of the consumers manipulated the product first in different ways (crushing/mixing, spreading,...) and then described their perceptions. This made the analysis of the films more complicated because the parameters involved in a descriptor generation were not very evident.

Analyzing the recorded films of **experts’ manipulation and description** of products showed that: 6/10 experts described the products in a sequential way. The 6 experts were those working in the rheology domain. However, the rest of the experts firstly manipulated the products and then describe it at the end.

Concerning the manipulation of products by consumers, various types of handling were observed: crushing, mixing, spreading, touching the surface, pouring the product from spoon/ knife/ its

container, whittling the surface, unmolding and crushing by hands. However, among these different manipulations, three types of manipulation were notable:

- The consumers who completely crushed their products and then either spread it or not.
- The consumers who simply took or cut a piece of product and then spread it on the bread.
- The consumers who evaluated the product by simply penetrating a knife within it or by touching the product surface.

Among these three main manners of manipulation, half of the consumers characterized all the three products by same handling gesture and did not change their behavior according to product texture. For example to characterize the 3 products they simply spread them and generated various characteristics through the same gesture while the other half handled the three products differently. For example, P2 was spreaded while P18 was cut into pieces.

These various handling procedure resulted to different level of product deformation and destructurization. The level of product deformation varied between the consumers and between the products. For example, for the consumers who crushed the products before spreading, the level of deformation was very important. On the contrary the consumers who spread the product deformed the product to a lower level and finally those who evaluated the products by touching its surface did not affect the structure.

Similar variations were observed between the products. For instance, the product P18 presenting a harder texture than P2 and P4 was spread by applying a higher degree of force/deformation by 42% of consumers. It seems that these assessors applied more important force to achieve the same thick, smooth and homogenous surface as P2 and P4 on the bread.

Since the deformation degrees were not the same between the consumers, the physical states of same product changed more or less while it was being evaluated. The P18 product was either spread by around 40% of the consumers, crushed by 30%, or simply touched unmoulded or cut into pieces by the rest of them. Figure 41 shows the state of product P18 right before spreading by two different consumers showing the different physical stat of the same product.



Figure 41: Physical state of P18 product manipulated by two different consumers right before spreading.

The experts manipulation method and deformation degree were not the same neither. Half of the experts spread the product without pre-deforming while the other crushed the product and then either spread it or not. Only one expert evaluated all the three products in the same way, showing that the experts have more tendency to adapt their manipulation based on the product textures.

Concerning the consumers' manipulation-description of products, no matter the product handling method used and deformation level, some terms were generated at the same time and through the

same handling gesture. For example the term “Tartinable, Collant”, “Tartinable, Crémeux” or “Collant, Crémeux” were generated by one third of the panelists, right after spreading of the products (P2 and P4 products) and at the same time. This shows that these multidimensional sensations can possibly be inter related for these assessors. 30% of consumers simply touched the surface of the product and cited the terms “Collant”, “Compact”, “Dur”. Finally, 8% of consumers evaluated the amount of product on the knife and generated the term “Collant”.

The manipulation-description of the experts showed that four experts evaluated “Collant, Tartinable” at the same time and through the same gesture. Two experts evaluated the stickiness of the products to the knife (product left-over on the knife) and on the bread after spreading. They described the products as “Collant au couteau” and “Collant”. Two other experts evaluate the products’ surface by simply touching it and generated the terms “Collant” and/or “Filant”.

To conclude, the observation of evaluation methods (from consumers and experts) revealed the factors that could be considered for running the instrumental assessments in the conditions closer to sensory evaluations:

- **The first factor concerns the time scale.** As can be expected the time of deforming or manipulating the product through one movement was very short. This condition is in contrast to what is classically done in instrumental assessments by applying long time for example in dynamic oscillatory test. In this type of characterization the product behavior is only a function of the time, however, the applied time scale is longer than the sensory evaluation time scale. Among the article that we had confronted only Rogers et al. (2009) had used a short time scale in the oscillatory tests.
- **Another factor concerns the physical state of products.** The results showed three different levels of deformation for products. The panelists who simply evaluated the surface, those who directly spreaded the product and finally the panelists who completely mixed and deformed the products and then either spread it or not. **The Supplementary observations revealed that three different physical states of product could be taken into account for instrumental analysis: initial state (at-rest) and deformed product at two levels.**
- Comparing the evaluation of the different products showed differences in terms of the **magnitude of the force applied on the products**. The panelists applied more important level of force for spreading the P18 products (hard) probably to reach the product same quality on the bread, however this observation stayed qualitative.
- Finally, analyzing the film permitted to **estimate linear rate of spreading**. This estimation is very basic and not necessarily precise since it is only based on the observation of panelists (36 panelists × 63 products) who spread their product on rusk or mini toast (with recognizable area) and without considering the amount of product (product thickness on the bread). Nevertheless, this simple evaluation showed that the spreading rate of panelists were around 50 mm/s. Calculating the equivalent angular velocity for vane geometry with 10mm radius revealed that the estimated rate is at least 10 times more than what is reported for vane test to measure the fracture point of material in the literature (Truong et al., 2002; Truong & Daubert, 2000; Truong & Daubert, 2001).

The test conditions applied in previous studies seem to be far from sensory evaluation of products even through hand evaluation in terms of product implementation, time scale, applied rate and force. After the assessment of both sources of sensory information, the last step which involves the selection of the instrumental methods and the test conditions is explained below.

3. Conclusion: Selection of instrumental methods and conditions

Classifying terms on the basis of the common physical properties summarized the rich vocabulary of free sensory characterization in 6 defined categories corresponding to applicable instrumental methods. In addition, the Supplementary observations revealed some interesting information regarding product description and handling. These sensory sources of information allow us to have a clear strategy to choose instrumental methods. Based on the results we wanted to select a limited number of methods efficient for assessment of all the defined categories with a focus on three categories of our interest: “Adhesion”, “Cohesion” and “Spreadability”. The reason we wanted to focus on these categories is that they include the terms that are more weakly or not correlated with mechanical properties. Furthermore, the Adhesion category includes the term most frequently cited by both panelist groups over our range of products: “Collant”.

Among the various methods presented in Figure 41, **dynamic oscillatory test was selected as it covers all the categories, is applicable to all type of products and provides information about product structure. Penetrometry test was kept as it is the reference method in the Supplier Company. The vane test and back extrusion were selected as complementary methods to characterize the fracture and the properties of products at large deformation. Finally, the Tack measurement was selected for adhesion properties of the products.** Tack method has been widely used in other food product such as cereal based products for adhesion measurement. However, it has been used very rarely for cheese characterization. In a study on cheese, Rogers et al. (2009) have applied this method and reported a very high but negative correlation between the tack parameter and sensory perception of stickiness. They explained that one of the possible reasons for the negative correlation is the differences in the unchewed adhesion (adhesion between the unchewed cube and probe) and sensory breakdown adhesion. Furthermore, the Supplementary observations showed the same gesture of panelists for in-hand product evaluation. We decided to not use the TPA method for it had been used in many studies in the past and did not result in good correlation for the properties related to adhesiveness and cohesiveness. Moreover, the method adequacy has been questioned in several studies as explained before.

Apart from determining the best methodologies to employ, characterizing the products under conditions close to sensory evaluation was our other objective. Therefore, based on the Supplementary observations, the oscillatory test will be carried out in a short time scale for characterization of the products at rest. The products will be implemented at two physical states: pre-manipulated and extruded. Finally, the angular velocity corresponding to the estimated spreading rate will be used for vane test.

In this study, we asked experts to sort the terms in the predefined categories that were found to be efficient for our list of terms. Nevertheless, it would be interesting in future work to ask the experts to make their own groups of terms presenting the same physical properties and to define them afterwards. That way, the sorting logic would be built on physical properties. This could provide common categories and maybe other possible categories. **To sum up, this approach made it possible to make an informed choice of methods by taking the sensory results and product handling into account. It also brought the free sensory and the instrumental languages closer together for better communication between both domains.**

Part 5: Instrumental assessment

The main objective of this part was to characterize the products through instrumental assessment based on the sensory results and observations. In part 4, we presented the strategy for the selection of the methods appropriate for the characterization of the identified perceptions. Herein, we present the corresponding methods more precisely, the materials, the stemming parameters that eventually would establish the correlation with sensory data, as well as the statistical tools.

In total, five types of methods were preselected:

The **fundamental dynamic tests** were selected to determine the texture properties in general and more specifically for the sensory perceptions related to *Firmness*, *Elasticity*, *Cohesiveness*, *Spreadability* and *Fluidity*. These tests permit to characterize the products in linear domain (at-rest) and at the limit of non-linear domain to estimate a yield stress values.

The empirical **penetrometry test** was chosen to determine the texture properties at large deformations. In addition, it is the reference method to validate the reproducibility of production in the Supplier Company. This method can possibly characterize the sensory perceptions related to *firmness*.

Other selected empirical methods for investigating the products' behavior during important deformations and break down were **back-extrusion and vane tests**. These tests were picked to characterize the sensory perceptions related mainly to *Spreadability*.

Finally, the **tack method or adhesion test** was picked for characterization of the texture for sensory perception related to *stickiness* and *cohesiveness* properties.

The choice of the instrumental methods and conditions involved two constraints:

1. The **important number of products** did not permit an extensive characterization using too many different methods.
2. The **important texture variation of products** (liquid, semi-liquid, solid) made the method selection limited to those that would be applicable over the product set. Hence, it is worth noting that for this reason, the empirical tests that involved compression were not picked because certain products in our set tend to deform under their own weight. Conversely, the solid gelified products do not allow conventional viscometric measurements.

In fact, we wanted to characterize a set of product with a very important variation of textures through a limited number of same instrumental methods.

Therefore, the feasibility of applying the selected methods over the product range was studied in a preliminary study. Based on the results of the pre-study, two of the selected methods were eliminated: vane and back-extrusion tests. The vane test was eliminated for practical problems. This method was not applicable over the entire set. Indeed, the product conditioning did not permit to maintain some of the products adhered to the container. So, products were slipping during the test in the selected conditions. In addition, there was some instrumental limitation for applying the selected testing conditions (high angular velocity) for the products that were highly structured

(overload limit of stress). On the other hand, the factors resulted from this test did not bring new information in compare to the other rheological characterizations (yield stress measured at the end of the linear domain in dynamic test). The back extrusion method was also eliminated through the pre-study for not bringing extra information compared with the dynamic test and penetrometry tests. Hence, these two methods were eliminated for further characterization of the whole set.

In this part, we present the tests that were carried out for the whole range characterization: Dynamic test, penetrometry and tack test. Firstly, for each experiment the materials, methods and the obtained parameters are explained. Secondly, the results are separately presented. Finally, the interest of performing rheological tests together with tack test for a better characterization of products is discussed and the product map through instrumental characterization is presented.

Moreover, attention is given to characterization of the products through the tack method. Hence, the interest of applying this method together with rheological characterizations is investigated more particularly for some sub-sets of products. The results for sub-sets are then discussed.

In order to take different levels of product break down during sensory evaluations into account the products were characterized at different physical state: at rest, slightly destructured (referred as “*Non-Extruded*” products) and highly destructured by an extrusion process and called “*Extruded Products*”). Therefore, in the final section of this part, the results for characterization of the extruded products in comparison to *Non-Extruded* ones (*Non-extruded* vs. *Extruded*) is discussed.

1. Rheological measurements

Two types of rheological tests were done over the entire set: dynamic test and penetrometers. Rheological methods were carried out at small strain in order to characterize the viscoelastic properties of the products within the linear region. Furthermore, the yield stress that marks the limit between the small and the large strain areas was also studied. These methods were completed by penetrometry test to characterize the product at large strain. In total, 17 parameters were either extracted or calculated, Table 20.

1.1. Small amplitude oscillation test

1.1.1. Materials

The viscoelastic properties of products were measured using a controlled stress rheometer (MCR 301, Anton Paar, Germany).

Geometry selection and cell characteristics

In the literature, plate-plate geometry has been used on different types of cheeses to characterize their structure by small amplitude oscillatory tests (Brighenti et al., 2008; Brown et al., 2003; Rogers et al., 2009; Subramanian & Gunasekaran, 1997), and vane-in-cup geometry has been used to determine the yield point or failure stress of various materials (Daubert et al., 1998; Truong et al., 2002; Truong & Daubert, 2001). However, the dynamic stimulations created by vane-in-cup geometry can also be used to study the viscoelastic properties of the materials. This geometry has been used in dynamic oscillatory test for characterization of yoghurts (Guggisberg et al., 2009).

In our study, due to the important texture diversity of products, using the plate-plate geometry could disturb the products structure to a more or less important extent during the set-up of the product on

the rheometer. Therefore, we decided to use the vane geometry for its advantage of minimal disturbance of the products during the insertion of the tool. Using the vane-in-cup geometry is less restricting than plate-plate geometry since the samples are not subjected to normal forces.

Hence, the oscillatory tests were carried out using a six-blade vane geometry, with an inner radius of 11 mm and a height of 16 mm (FL100, Anton Paar, Germany). In addition, in order to directly run the test on the product without any pre-handling, the products were conditioned in cylindrical container (radius of 16.5 mm and a height of 69.5 mm) and were directly placed inside the sampler holder. Strain and stress were obtained using geometrical constants calculated by Couette analogy.

Plate-plate stainless-steel geometry ($\phi = 24.96$ mm, PP 25, Anton Paar) was used to measure the rheological properties of the *Extruded* products. Since the products were preliminary extruded and subjected to large deformation, the texture destruction related to implementation becomes negligible.

1.1.2. Methods

The non-destructive oscillatory test was applied to measure the viscoelastic properties of the products at-rest.

The vane probe was lowered at rate of 1mm/s (trigger force of 10N) within the samples and stayed constant for 1 min before starting the measurement. For all the products and all the repetitions, marks in line were placed across the product and on the product container to verify the slippage of the products during the experiments.

Strain sweep

A strain sweep from 0.01 – 500% at an angular frequency of 10 Hz (equivalent to 63 rad/s) was performed to determine the range of linear viscoelastic response in where the storage and loss modulus (G' and G'') are independent of the strain magnitude. The choice of running the test at higher frequency (shorter time scale) derived from the observations in sensory evaluations.

From this experiment the yield stress (indicates the least deformation at which the first breaks within the product occurs) was determined. The yield stress can be identified by crossing point of G' and G'' modulus. After this point the loss moduli start to be higher than storage modulus, Figure 42.

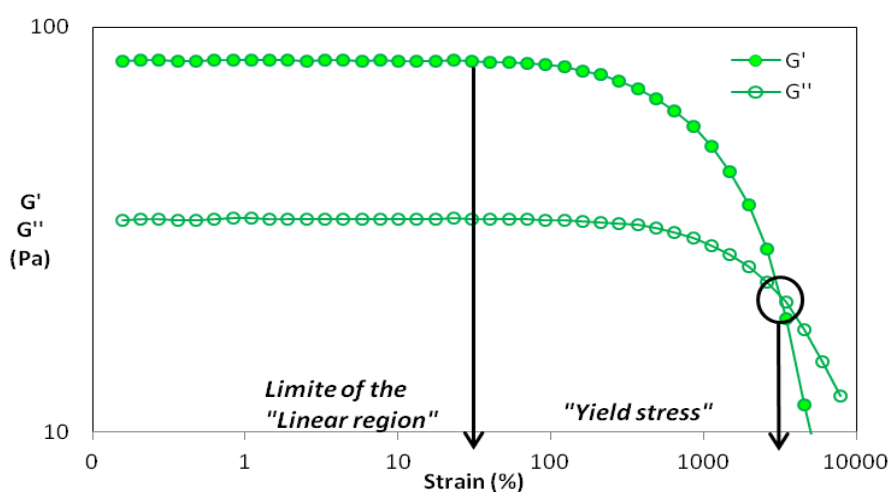


Figure 42: Example of strain sweep curve. Determination of the linear region and the G' and G'' cross-over (yield stress).

Frequency sweep

The viscoelastic characteristic of products was determined by small amplitude oscillatory test within the linear region. The variation of the frequency permits to obtain the spectra of G' and G'' and characterize the structure of the products and the interactions between G' and G'' over a wide range of frequency.

In practice, a sinusoidal strain is applied to the sample that induces some level of stress through the product. The magnitude and the time lag of the stress transmission depend on the viscoelastic nature of the product. By investigating these factors, various material functions can be defined, such as storage modulus (G'), loss modulus (G''), complex viscosity (η^*) and complex modulus (G^*). From which, G^* and η^* are the functions calculated based on G' and G'' values.

Table 20 gives the definitions and the equations for calculation of these functions.

The frequency sweep was performed within the linear viscoelastic region at 1% constant strain in the range of 0.1-10 Hz (equivalent to 0.6 – 63 rad/s). Figure 43 shows an example of the resulting spectra.

The different variables defined in Table 20 were studied at two different frequencies (2 and 10Hz equivalent to 12 and 63 rad/s).

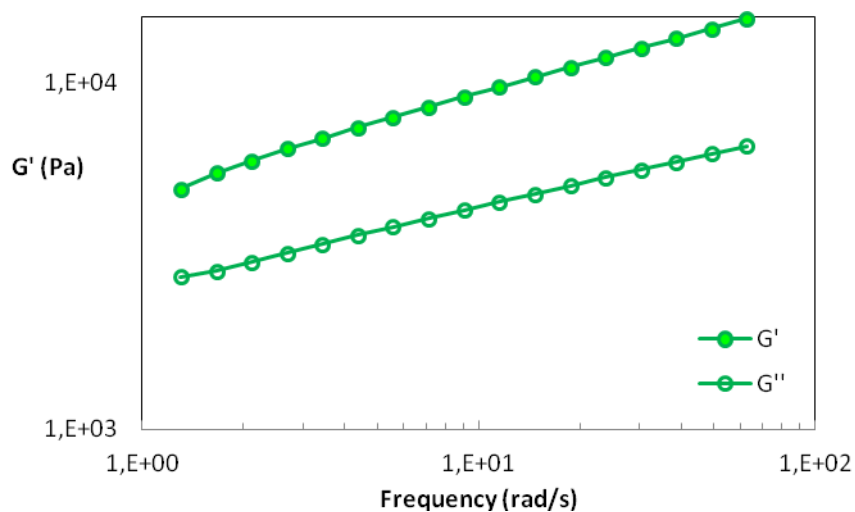


Figure 43: Example of frequency spectra from 0.6 to 63 rad/s (0.1-10 Hz).

1.2. Penetrometry test

The rheological measurements in the linear and the beginning of the non-linear region were completed by penetrometry to characterize the products' texture at large strain.

1.2.1. Materials

A sphere shape probe ($\phi=4$ mm) was chosen due to its advantages of eliminating the friction forces and giving a more reliable result for penetration force. A texture analyzer (TAXT2i) equipped with 5kg Cell was used to measure the force of penetration. Products were conditioned in round

containers ($\phi = 90$, $h = 30$ mm) and at least five repetitions were performed for each product from the same container.

1.2.2. Method

The probe was lowered with the velocity of 0.2 mm/s. The force of penetration starts to be recorded when the trigger force of 0.005 N was registered. The penetration depth was 15mm and the average force at steady-state of Force-Distance curve was determined as the penetration force (F_{penetro}), Figure 45.

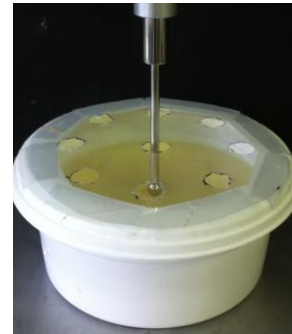
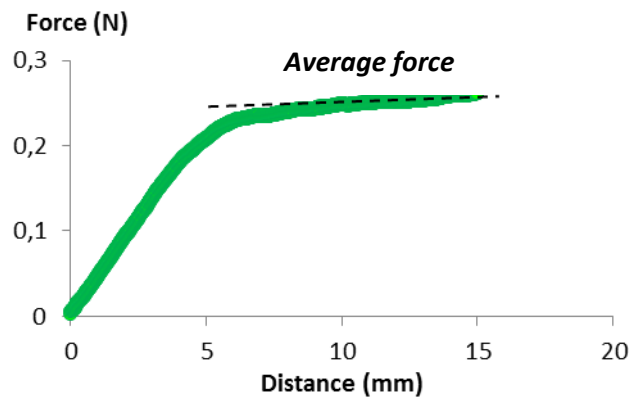


Figure 44: In left, example of Force-Distance curve of penetration test. In right, the image of penetrometry test.

Table 20: Typical output from different rheological characterizations: a frequency sweep, strain sweep and penetrometry tests. σ is stress, γ is strain, δ is phase angle and ω is frequency.

	Code	Definitions	Equations	Unity
Frequency sweep test	G'	Storage modulus	$G'(\omega) = \frac{\sigma_0}{\gamma_0} \cos \delta$	Pa
	G''	Loss modulus	$G''(\omega) = \frac{\sigma_0}{\gamma_0} \sin \delta$	Pa
	$\tan \delta$	Phase lag	$\tan \delta = \frac{G''(\omega)}{G'(\omega)}$	–
	G^*	Complex modulus	$G^* = \sqrt{G'^2 + G''^2}$	Pa
	η^*	Complex viscosity	$\eta^* = G^* / \omega$	Pa.s
	$n_{G'}$	Slope of G'	–	–
	n_{η^*}	Slope of η^*	–	–
	$\tan \delta_{\text{Min}}$	Minimum $\tan \delta$	–	–
	$\tan \delta_{\text{Max}}$	Maximum $\tan \delta$	–	–
Strain sweep test	σ_s	Yield stress	Stress corresponding to G' and G'' cross over	Pa
	γ_s	Least strain makes the product to break	Strain corresponding to G' and G'' cross over	%
Penetro test	F_penetro	Penetration force	Average force at flatten top of the curve	N

2. Tack measurement

Tack test, also referred as adhesion testing, was carried out in order to characterize the adhesion properties of the entire product range with various textures (liquid, semi-liquid-solid).

2.1. Materials

The adhesion properties were measured using a rheometer (MCR 301, Anton Paar, Germany). A flat-ended stainless-steel probe ($\phi = 24.96$ mm, PP 25, Anton Paar) was connected to a force transducer measuring the acting force on the probe. The stainless-steel probe was chosen to represent the materials (metal knife or spoon) used by the majority of assessors for sensory evaluations. The lower platform was thermostatically controlled with a Peltier system.

Product implementation: Due to the texture diversity of the products, it was not possible to simply prepare sample with regular size and shape. A sample holder with an area larger than the probe ($\phi = 30$ mm, $h = 4.5$ mm) was fabricated and placed on the lower platform of rheometer, into which the same volume of sample was loaded for each product. The products were directly spreaded on and into the sample holder. Then the surface was evened with a razor, Figure 45. This method was carried out on original products as well as the products which were first extruded.

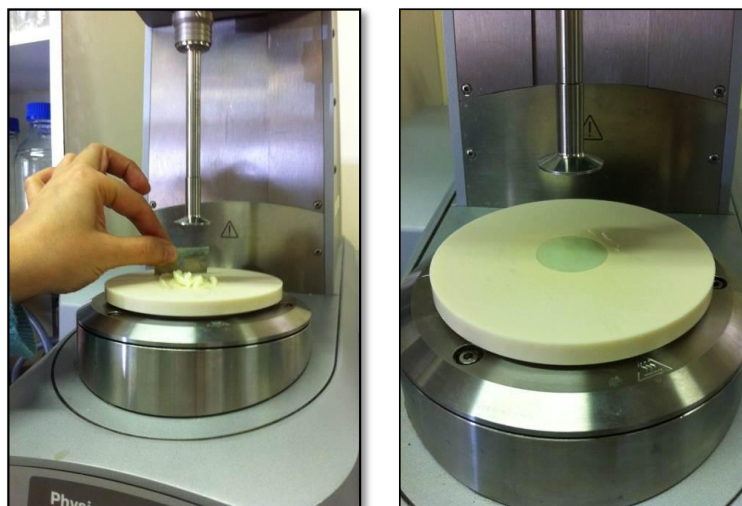


Figure 45: Sample implementation into sample holder

2.2. Method

Measuring position: Fixing a predefined force to put the probe and the product into contact, has been used in several studies (Childs et al., 2007; Ghorbel et al., 2003; Melito et al., 2013).

In our study, the choice of the protocol and testing conditions involved two constraints:

3. The **important texture variation between the products (inter-variations).**
4. The **variation of the surface quality between different implementations of the same product (intra-variations).**

For these reasons, it was not possible to achieve an optimum force in order to put the probe with all type of products (liquid, semi-liquid and solid) in a good contact. In a study using the tack method to characterize the fluid foods stickiness, Chen et al., (2007) have used a predominant distance rather than a predominant force in order to put the probe and the products into contact. Therefore, we decided to ensure the good contact between the probe and products in the same way by using a predominant distance. It is worth noting that this conditioning can also be justified by the sensory “Supplementary observations”. Indeed, the sensory “Supplementary observations” showed that the panelists had applied more important deformation for spreading the harder product most likely to achieve the same thickness and/or surface quality of the product on the bread as for the easily spreadable products.

Therefore, the probe-product contact was controlled by applying a predefined distance corresponding to sample holder height (4.5mm). This gap put the probe and the product in measuring position while minimizing the squeeze of the liquid samples. To ensure a complete contact a compression phase was then applied. Figure 46 demonstrates the protocol of the test.

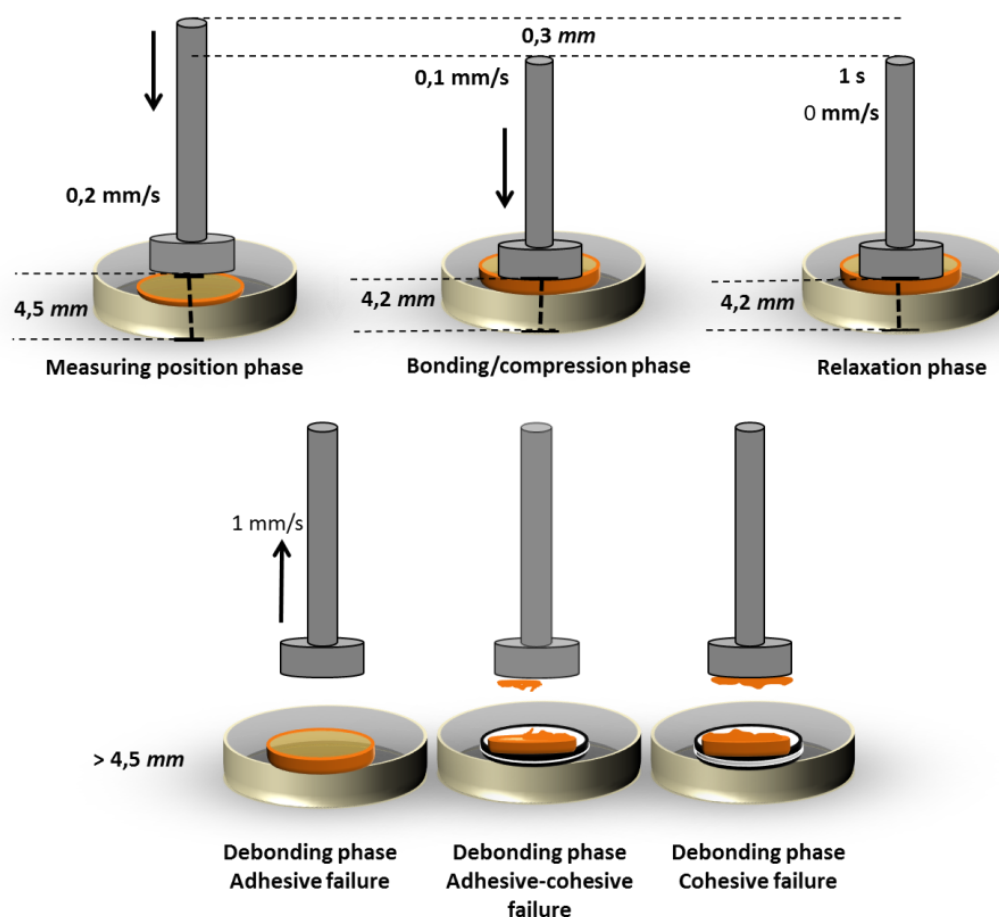


Figure 46: Tack test protocol and the three types of failure in “Debonding phase”.

Prior to the ‘bonding phase’ the flat-ended stainless-steel probe was lowered with the rate of 0.2 mm/s to 4.50 mm onto and into the surface of the sample. Once the distance of 4.50 mm was reached the data-acquisition started. Then, the probe descended further with the constant rate of 0.1 mm/s from 4.50 mm to 4.20 mm position to obtain a complete contact for all type of textures

("bonding/compression" phase). This compressing phase was necessary to overcome the inhomogeneity of the products' surface and ensure the complete contact. Moreover, the approaching rate was controlled by a trigger force of 0.1N in order to avoid the destructurization of the products while implementation. The probe was then held constant for 1 s at this distance ("relaxation" phase). Finally, the probe was moved vertically upward at a predefined constant rate of 1 mm/s ("debonding" phase). All the tests were performed at 25°C. In the literature, the adhesiveness had been reported either as the maximum tensile force or the work of separation (Dunnewind et al., 2004; Kilcast & Roberts, 1997). The work done until the maximum force was also reported for the determination of stickiness of fluid foods by Chen et al. (2007). Certain authors have explained that the work of separation is being a better representative of adhesiveness than the maximum force (Ghorbel et al., 2003). The total work of separation has been defined as the total energy of separation over the contact surface (probe surface).

Adhesiveness is not only related to the bonding between the probe and the material surface, but also on the mechanism of failure of this bond. The failure mechanism can be classified to three major modes that can take place during probe withdrawal (Adhikari & Howes, 2003): "**Adhesive failure**" results in a clean separation of probe, "**Cohesive failure**" occurs when the probe surface remains completely covered with the residue material, "**Adhesive–Cohesive failure**" occurs where the cohesive and adhesive modes exist together. According to Hosney & Smewing (1999), to measure the adhesiveness obtaining a clean separation is imperative.

Therefore, for the products with adhesive failure the surface contact (probe surface) is the same and the work of adhesion (W), the ratio of measured energy (E) over same surface contact, is a good index of stickiness. However, for products with different types of failure, the initial and final contact is not the same, the contact surface for the product with Adhesive-Cohesive failure decrease as part(s) of the surface gets covered with product left-overs. Therefore, the measured energy does not represent the work of adhesion for products with different types of failure. For this reason, in our work we will report the adhesiveness as the energy of separation rather than the work of separation. However, we take two other parameters (adhesive surface and residue) into account in order to include the differences in surface contact area and probe states between the products.

The product adhesiveness was also evaluated subjectively after each test as the presence of covered surface versus cleaned surface (qualitative data). A picture of probe surface was then taken at the end of each experiment. The pictures were then analyzed by ImageJ software in order to quantify the proper surface of the probe after debonding phase.

The experimental contact surface is defined as the adhesive surface (S_{adh}):

$$S_{adh} = \frac{\text{Clean surface of the probe at the end of the test}}{\text{Initial contact surface of the probe}}$$

And it varies between 0 and 1:

- $S_{adh} = 0$ → For the products with cohesive ruptures
- $S_{adh} = 1$ → For the products with adhesive ruptures
- $0 < S_{adh} < 1$ → For the products with both types of rupture

The product left-over on the probe at the end of the test was also weighed using an analytical balance (Mettler AE240, IET) with 0.01 mg accuracy in order to better discriminate the products.

Figure 47 demonstrates an example of the resulting force as a function of distance (Force-Distance) curve from this measurement with the various factors that were extracted.

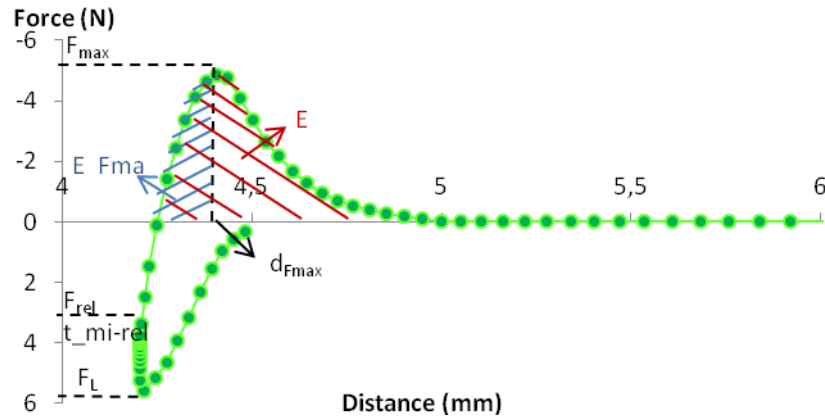


Figure 47: Example force–distance profile. The tensile force is plotted against the distance, where the starting point was the thickness of the sample between the two plates. The tests were conducted at 1 mm/s and at room temperature of 25 ± 2 °C.

In total, 10 parameters were obtained from this measurement. Seven parameters were directly extracted from the curve, one parameter (the ration between the energy to reach the maximum force and the total energy) was calculated, and two supplementary parameters (adhesive surface and residue) were obtained from the probe stat after the debonding, Table 21.

Table 21: Ten instrumental parameters stemming from tack probe test.

Code	Phase interval	Definition	Unit
F_L	Compression phase	Force load	N
F_{rel}	Relaxation phase	Force after relaxation	N
t_{mi-rel}	Relaxation phase	Time t half F_{rel}	s
F_{max}	Debonding phase	Debonding force	N
d_{Fmax}	Debonding phase	Distance at F_{max}	mm
E_{Fmax}	Debonding phase	Separation energy till F_{max}	J
E	Debonding phase	Total separation energy	J
E_{Fmax}/E	–	Ratio of energies	–
S_{adh}	At the end of debonding	Proper surface /total surface	–
Res	At the end of debonding	Product left-over on the covered area of the probe	g/mm ²

The data of force and energies are transformed to logarithmic scale for a better presentation of results.

3. Products extrusion

The rheological and tack measurements were also carried out on highly destructure products by pre-extrusion of the products. For extruding, about 50 ml of products were initially conditioned in cylindrical containers that were modified by piercing a small hole ($\phi = 3.9 \text{ mm}$) in the center of their base. Then, the base of the container was covered with a piece of aluminum foil scotch resistant to water, heat and moisture.

Materials for extruded products: The extrusion was carried on using a texture analyzer (TAXT2i) equipped with 25 kg cell and piston shape probe. The dimensions of the piston are represented in Figure 49. The products were extruded, right before the tack and dynamic tests, into small plastic cups and were covered by plastic wrap. Once a product was extruded, immediately the tack measurement was carried out followed by dynamic test. These measurements were carried out at least three times, every other time. The effect of time on reproducibility of the measurement was verified thanks to the repetitions. The duration of the tests for a product was about 1h.

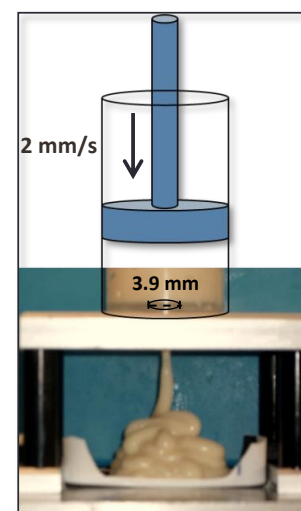


Figure 48: Products extrusion

Tack test: The adhesive properties of *Extruded* products were measured in the same way as for the *Non-Extruded* products.

Rheological Characterization: A small amount of extruded samples was placed on the lower platform of the rheometer. The geometry was slowly (1mm/s) pushed down (gap size 1 mm). Excessive products' pieces were trimmed off carefully with a spatula. A small water container was placed close to the sample without touching it and the sample was covered to prevent its dryness and to maintain the equilibrium. This stage was followed by relaxing the sample for 1 min to reduce the stresses while sample handling. The Peltier plate ensured the temperature remained at 25°C during the experiments. All rheological measurements were done in triplicate.

4. Data analysis

A two-way ANOVA with interaction, considering rheological factors and products as factors, was applied to each mechanical characteristic. The Fisher test was used to calculate the minimum significant difference. A limit level of significance $\alpha = 0.05$ was used.

The tack data were analyzed in general by analysis of covariance (ANCOVA). Like ANOVA it determines if there are significant differences between n object ($n=2$), except that it takes into account simultaneously the qualitative and quantitative factors. ANCOVA evaluates how much the two variables change together and how strong is the relationship between them. A two-way ANCOVA with interaction, considering force load (F_L) and products as factors, was performed for each mechanical characteristic. The Fisher test was used to calculate the minimum significant difference. A limit level of significance $\alpha = 0.05$ was used.

The instrumental data were analyzed by standard Principal Component Analysis (PCA) followed by cluster analysis.

PCA is a type of multidimensional methods which allow to analyze several variables simultaneously and to take into account their correlations. The data are in the form of a matrix X which includes in row n "individuals" that we want to describe (for example, products) and in columns p quantitative variables which characterize the individuals (for example, the instrumental variables). The variables of the matrix are centered and most of the time reduced. This is made in order to avoid favoring artificially certain variables expressed in different units.

Then, a transformation of the initial variables allows identifying new non-correlated variables called principal component or axis. The objective of PCA is to summarize the variability between the individuals in a minimum of dimensions with a minimal information loss. The representation of the results is in the form of two two-dimensional graphs: the factorial plan of the projection of variables (circle of correlations) and the factorial plan representing the address and coordinates of the individuals in the space. This representation allows to visualize easily the correlation between certain variables and to have an explanation on the position of the individuals in the space according to variables: The orthogonal projection of an individual on a variable gives an indication onto the intensity of the value obtained by the individual on this variable with regard to the other individuals.

A Hierarchical Cluster Analysis was also carried out after PCA on the products to find the groups of products close to each. The HCA after the variable was carried out in the same way.

The multivariate analysis was used to firstly eliminate the variables that bring redundant information for each test separately. Then, the instrumental product map was achieved by running the analysis on averaged data of selected parameters. All calculations were carried out with XLSTAT-Pro software, v.2011 (Adinsoft, Paris, France).

The pictures taken in tack test were analyzed using Image J free software (<http://rsbweb.nih.gov/ij/>) frame per frame.

5. Results and discussion

In this part, we are interested in each instrumental measurements and the information they bring us for products characterization.

Firstly, the results of rheological measurements (dynamic and penetrometry tests) and secondly the results of tack measurement are presented. For each test, the number of variables will be separately reduced in order to select the parameters that do not bring redundant information. The product map after each method will be presented.

Then, we explore in detail the interest of using the tack method in addition to rheological measurements for products characterization. The instrumental map for the entire product set will be presented.

Greater emphasis will be given to the probe tack test, since one of the objectives was to better characterize products adhesiveness through instrumental testing. Therefore, the results will be discussed more specifically for some sub-sets of product showing less adhesive differences.

Herein, the results for *Non-extruded* products are presented first followed by the results for the *Extruded* products.

5.1. Products discrimination through rheological measurements

Three types of measurements were carried out for rheological characterization of products: oscillatory test, strain sweep and penetrometry. Various parameters has been either directly extracted or calculated from these measurements to compare the products. The results are presented in the section below.

5.1.1. Studied parameters

Fourteen parameters were obtained from the frequency spectra presenting the products rheological characteristics in linear region. Two parameters were obtained from the strain sweep; these factors mark the nonlinear region. Finally, one parameter was obtained from the penetrometry method to characterize the products at large deformation, Table 22.

Table 22: Range of the rheological parameters measured at two frequencies, 2 and 10 Hz.

Parameters	Definition	Min	Max	Max/Min	Unit
G'_2	Storage modulus	965	127510	132	Pa
G'_{10}	Storage modulus	1380	145750	106	Pa
G''_2	Loss modulus	310	18540	60	Pa
G''_{10}	Loss modulus	485	21180	44	Pa
$\tan \delta_2$	Phase lag	0,15	0,60	4.0	-
$\tan \delta_{10}$	Phase lag	0,15	0,57	3.8	-
G^*_2	Complex modulus	1015	128850	127	Pa
G^*_{10}	Complex modulus	1475	147280	100	Pa
η^*_2	Complex viscosity	70	8765	125	Pa.s
η^*_{10}	Complex viscosity	23	2345	102	Pa.s
$n_{G'}$	Slope of G'	0,10	0,35	3,5	-
n_{η^*}	Slope of η^*	-0,90	-0,64	0,7	-
$\tan \delta_{Min}$	Minimum $\tan \delta$	0,14	0,54	4	rad
$\tan \delta_{Max}$	Maximum $\tan \delta$	0,17	0,60	3,5	rad
σ_s	Yield stress	112	8580	77	Pa
γ_s	Strain correspond to σ_s	23	55	2,4	%
$F_{penetro}$	Penetration force	0.02	1.5	75	N

It can be observed that some parameters are range only by a factor of 5 across the products ($\tan \delta$, $n_{G'}$, n_{η^*} and γ_s). However, the other parameters range by a factor greater than 40 (G'' , σ_s and $F_{penetro}$) and even 100 (G' , G^* , η^*). Also, it can be seen that the variation is more important at lower frequency than at higher frequency (G'_2 vs G'_{10} , G''_2 vs G''_{10} , G^*_2 vs G^*_{10} , η_2 vs η_{10} , $\tan \delta_2$ vs $\tan \delta_{10}$). This shows that the viscoelastic properties of the products are more different at long time. The products have a more solid-like behavior at lower frequency or under long time observation.

The important variation of storage modulus among the products shows that products consistency is different. The variations of complex modulus and complex viscosity follow the storage modulus variation. However, comparing the slope of complex viscosity (n_{η^*}) to the slope of elastic

component ($n_{G'}$) shows that the variation of complex viscosity in time is less different among the products.

It can also be seen that the variation of the stress at which products start to break (σ_s) is about 30 times greater than its corresponding strain. This shows that at about same strain some products flow more easily than the others and demonstrates the difference of cohesiveness between the products.

To conclude, the model products present a large variation in terms of storage modulus and complex properties, with viscous properties that depends less on frequency.

5.1.2. Multidimensional study

PCA was carried out on the average data in order to select the rheological data that are not strongly correlated and do not bring redundant information. The first three axes explained 96 % of the information (76, 14 and 5 % respectively). Further dimensions explained only a small proportion of variance (<5%). Based on the rule of eigenvalue value superior to 1, the first two axes with 90 % of the variance are presented, Figure 50.

The multidimensional analysis made it possible to easily visualize the correlations among the various parameters. The first axis of PCA opposes the first two main groups of rheological parameters. A HCA was carried on parameters and resulted in three main clusters. These clusters are reported on PCA plot, Figure 50. It can be seen that there is a strong correlations among various variables.

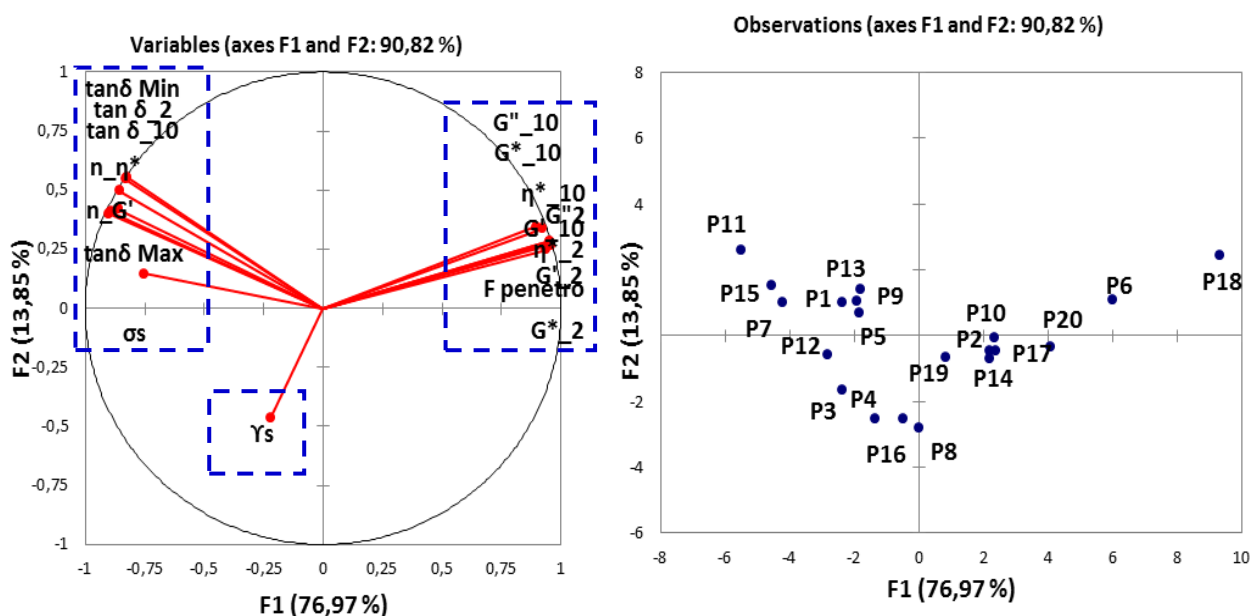


Figure 49: The PCA results on the data of rheological measurements. In left: the correlation circle for variables. In right: the products positioning on the first two components. The HCA results on the variable are presented on the correlation circle.

Axis 1 represents the storage and complex modulus on the right side versus the slopes, phase angles and yield stress on the left side. All these factors are related to viscoelastic properties of product in non-destructive area and are highly correlated to each other. Axis 2 of PCA represents the phase angles and the loss modulus that have bisector contribution to the first and second dimensions.

Finally, the only parameter that contributes to the third axis is the minimum strain at which the product starts to flow (γ_s).

The variables belonging to the same group are correlated and can bring same information for the relative positioning of products. Hence, among the correlated variables those that do not bring redundant information were chosen from each HCA group in order to describe the products range.

The HCA on the PCA coordinate resulted to three main groups depicted on the PCA plot, Figure 50.

A group of HCA consists of 8 variables (G' , G'' , G^* , η^*) at both studied frequencies (2 and 10 Hz). All these factors were either measured or calculated for the products property at rest and were all highly correlated ($\alpha = 0.9$). This seems logical since G^* and η^* are the functions calculated based on G' and G'' values: $G^* = \sqrt{G'^2 + G''^2}$ and $\eta^* = G^* / \omega$.

Hence, we decided to keep the storage modulus at higher frequency (G'_{10}) because it is directly measurable, discriminates better the products and corresponds to a frequency close to that applied in sensory evaluation. Another factor in this group is the force of penetration (F_{penetro}). Even though this variable is correlated to G' value we kept it for it represents the product behavior at large deformation. Moreover, it is the reference parameter to validate a fabrication in the Supplier Company.

The second HCA group includes seven factors: phase lags at 2 frequencies, slopes and yield stress. Two selected parameters from this group are phase angle at 10 Hz (63 rad/s, $\tan \delta_{10}$) and yield stress (σ_s). The $\tan \delta_{10}$ was highly correlated to all the parameters in this group ($\alpha = 0.9$) except σ_s . The σ_s was selected since it was less correlated to the other factors ($\alpha \cong 0.6$), and it allows us to complete the description of the rheological behavior of products in the non-linear region.

Finally, the last HCA group consists of one parameter: the strain corresponding to yield stress (γ_s). It is the only parameter with no correlation with other measured or calculated factors resulted from the same experiment.

The product map, Figure 50, shows that three products are discriminated from the rest, on the axis 1. Products P18 and P6 represent a higher elastic behavior and therefore were more firm than the rest of the products. The P11 product shows higher value for phase lag and therefore was more viscous than elastic. Three other products are discriminated on the axis 2: P4, P16 and P8. These products started to flow at higher deformation in comparison to the rest of products.

In conclusion, we selected 5 factors: 2 factors measured from small deformation in linear region (G'_{10} , $\tan \delta_{10}$) and 2 factors related to the non-linear region (γ_s , σ_s) and one factor in large deformation region (F_{penetro}).

Now that the rheological results are presented we firstly investigate the tack measurement and its results. Then, we discuss if this measurement brings additional information with regards to the rheological test.

5.2. Tack measurement

In this part, the result will be discussed according to the parameters extracted from Force-Distance curves and the supplementary parameters (adhesive surface “S_{adh}” and residue “Res”).

5.2.1. Force load (F_L) effect

Putting probe and product in contact using a predefined distance involves applying different levels of force load (F_L) on products according to their firmness. The F_L degree can enhance the bonding forces between the product and the probe and according to the rheological properties of the product influence the result (Hoseney & Smewing, 1999). A greater contact force will result in a greater bonding and therefore a greater adhesion.

The F_L variations over our product set was between 0.08–4.17 N. Therefore, the effect of F_L and products on the measured parameters was investigated by a two-way ANCOVA with interaction:

$$\text{Physical variables} = F_L + \text{Products} + F_L \times \text{Products} + \varepsilon$$

The result is shown in Table 23. It can be seen that all the variables have a significant effect for products discrimination. The product effect is always dominant than the F_L or the interaction effects with the exception of force after 1s of relaxation (F_{rel}).

Table 23: ANCOVA results for the force load (F_L) and the products effects with interaction.

Variables	P > F	F _L	Products	F _L × Products
F _{rel}	***	***	***	***
t _{mi-rel}	***	*	***	NS
d _{Fmax}	***	NS	***	*
F _{max}	***	NS	***	NS
E _{Fmax}	***	NS	***	**
E	***	*	***	NS
E _{Fmax} /E	***	*	***	NS
S _{adh}	***	NS	***	NS
Res	***	NS	***	NS

*P < 0.05, **P < 0.01, ***P < 0.001, NS: Non significant (P > 0.05)

The F_{rel} was strongly related to the F_L and its variation based on products textures (R²=0.96, Figure 50).

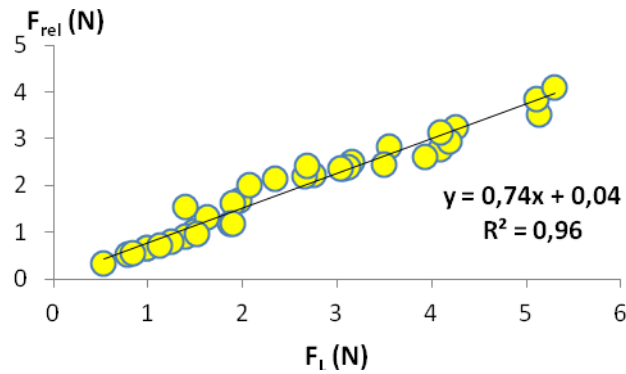


Figure 50: Force load (F_L) effect on the force of relaxation after 1s (F_{rel}) over entire product set

The effect of F_L and F_{rel} (the force before probe withdraw) can be therefore verified interchangeably on the measured parameters. This shows that most possibly 1s is not sufficient for investigating the products' relaxation. To conclude, the F_L (or F_{rel}) effect is negligible based on the dominant effect of products ($p < 0.001$).

5.2.2. Products' behaviors and failure modes

Analysis of the Force-Distance curves

Figure 52 illustrates a few examples of the resulting Force-Distance curves for three products containing the same texturing agents.

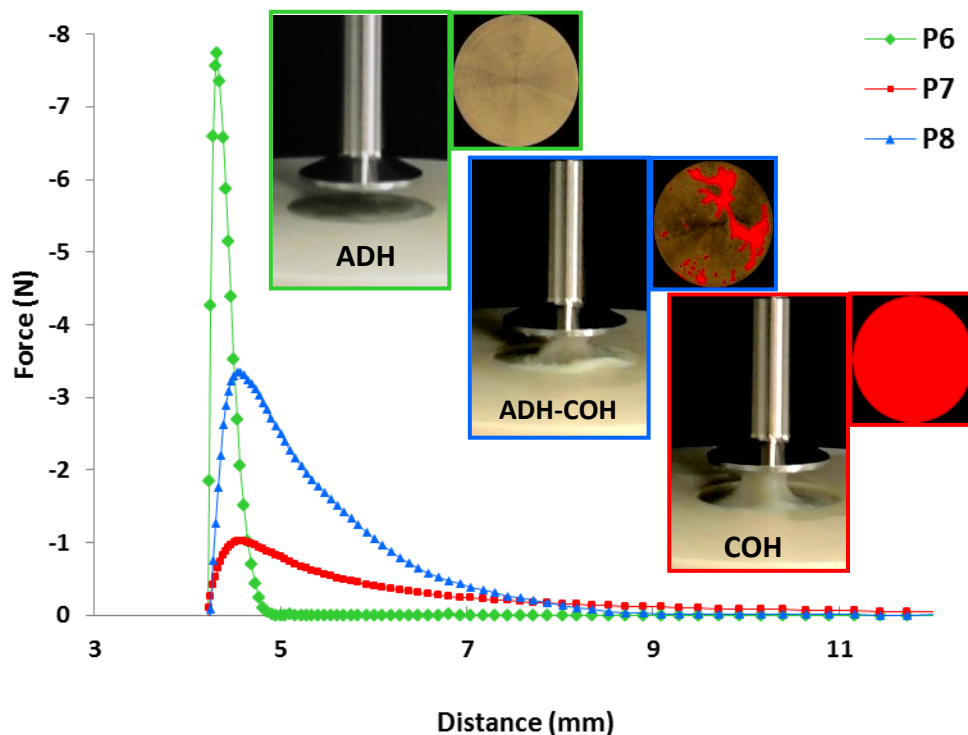


Figure 51: Example of Force-Distance profiles of three model products. The tensile force is plotted against the displacement distance, where the starting point was the thickness of the sample between the two plates. The tests were conducted at 1 mm/s and at room temperature ($25 \pm 1^\circ\text{C}$). ADH: adhesive failure, COH: cohesive failure, ADH-COH: adhesive-cohesive failure. The pictures are taken approximately after 5s of probe upward movements. The covered area of the probe with products is marked with red color.

In a typical Force-Distance curve, the force quickly reaches to its maximum and then drops to about zero once the separation is completed. It can be seen that the main differences between the three products in Figure 52 are the magnitudes of the tensile force and its decrease beyond its maximum. The force decrease for the product P6 from its maximum to the zero level is abrupt. However, for the two other products (P7, P8) not only the maximum of tensile force is lower but more importantly its drop is milder. The sharpest force decrease is related to the product that was additionally processed (P6) and the mildest force decrease is related to the product that was diluted (P7). Hence, it can be seen that the shape of the curves by itself gives interesting information concerning the products' behavior and their kinetic. The observation also showed that the debonding phase for product P6 was brutal. Product P8 was debonded sharply in some parts while in other parts the product was broken inside the material. Indeed, the debonding occurred both at the interfacial surface and in the bulk mass. The debonding of product P7, with the lowest level of concentration, was dramatically different. As the probe moved upward the product bulk flew toward the center. This movement was followed by the formation of one filament in the middle of the sample. The formed filament was stretching with the upward movement and became thinner. Finally, the break occurred inside the filament. Product P7 was the least structured and viscous in comparison to P6 and P8, Figure 52. Therefore, we can conclude that the mildest force decrease for P7 illustrates stretching of the filament during the detachment phase. This is related to structure of the product that is represented by $\tan \delta$, Figure 52.

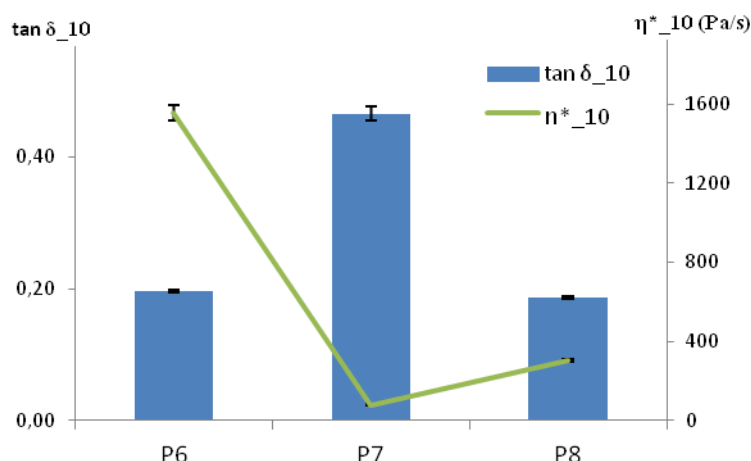


Figure 52: Phase angle ($\tan \delta_{10}$) and complex viscosity (η^*_{10}) at frequency of 10Hz of the three products.

Overall, the shape of the Force-Distance curves gives interesting information concerning the products' behavior during debonding phase. The differences in shape of the curves were related to products rheological properties, their interfacial bonding and the formulation factors.

Analysis of the contact surfaces and its effect

The adhesiveness of the products was evaluated visually by investigating the probe surface at the end of the test for all the trials. The probe surface after the tests revealed three different states for the three products: the probe surface was clean for P6, partially clean for P8 and totally covered with products for P7. It depicted an Adhesive, Adhesive-Cohesive and Cohesive failure respectively.

Besides the qualitative observation, quantification of the proper probe surface (S_{adh}) after debonding was done for all the trials, Figure 54.

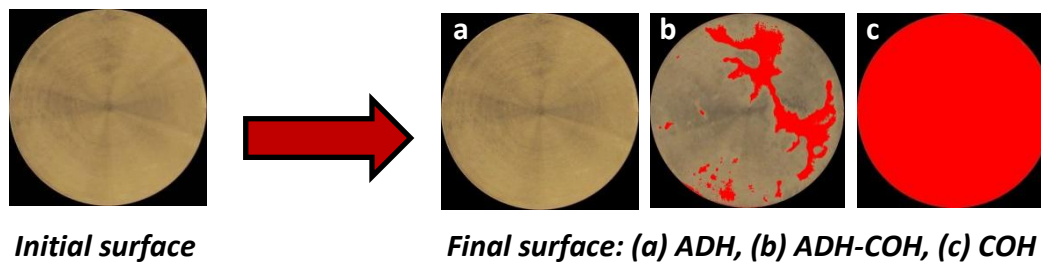


Figure 53: Change of contact surface during the debonding phase for (a) adhesive failure: ADH, (b) adhesive-cohesive failure: ADH-COH, cohesive failure: COH. The covered surface is marked with red color.

For quantification, the adhesive surface (S_{adh}) was defined as proportion of the proper area over total area of the probe after the separation. It was equal to “1” for products with Adhesive failure and “0” for products with Cohesive failure. The range of S_{adh} for products with Adhesive-Cohesive failure was 0.36 – 0.86, Figure 54.

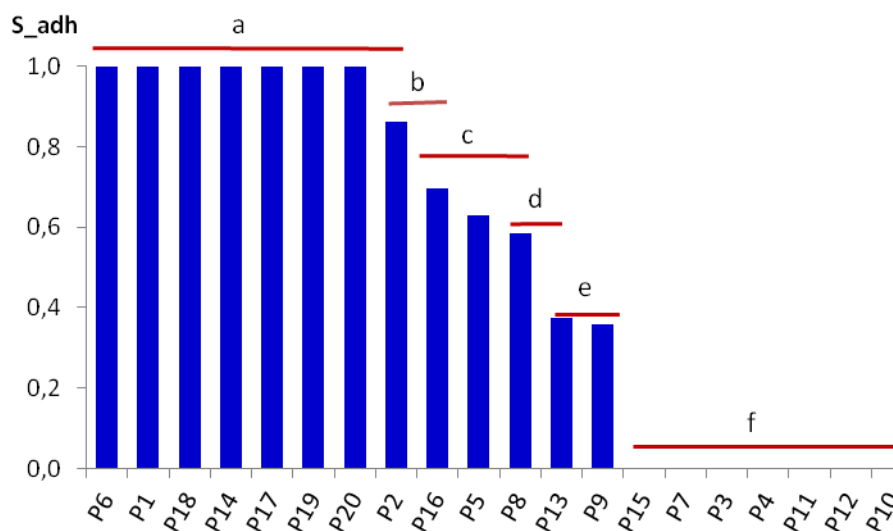


Figure 54: Adhesive surface variations (S_{adh}) between the products.

HCA was carried out after both qualitative and quantitative data and resulted in three main groups representing the three types of probe states at the end of the test. The HCA on the quantitative data (measure surface by image analysis) resulted in the same grouping of products as HCA on qualitative data with one exception (P2). This was because the covered surface of the probe for P2 was very small in comparison to the other products with Adhesive-Cohesive failure. Therefore, the classification after the qualitative data is presented (Figure 55) and will be taken into consideration for the further explanations.

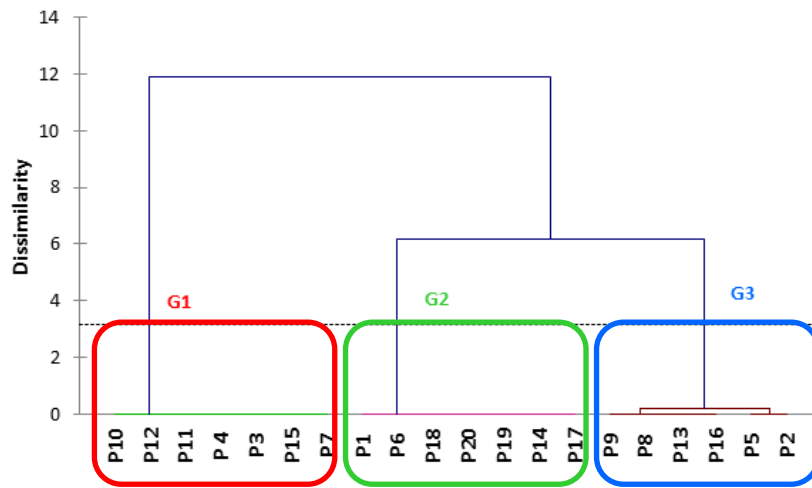


Figure 55: HCA result on qualitative data (observation). G1: Cohesive failure, G2: Adhesive failure and G3: Adhesive-Cohesive failure.

Group 1 (G1) contains the products for which the probe was totally covered and the detachment occurred truly inside a stretched filament of the product with one exception (P10). The failure is considered as being “Cohesive”. Group 2 (G2) contains the products for which the probe surface remained totally proper after the test. For this group the detachment occurred at the interface of probe-product and the failure is considered as being “Adhesive”. Group 3 (G3) contains the products for which some parts of the probe were covered by product while some other parts stayed clean after the separation. For this group the detachment occurred both at the interface of probe-product and within the product bulk. The failure is considered as being “Adhesive-Cohesive”.

In the literature, the work of separation is defined as the total energy of separation over the contact surface and is reported as a good indicator of adhesiveness only when an adhesive failure takes place. In this case, the work of adhesion or the total energy of separation could be indifferently used to compare products. However, for the product with Adhesive-Cohesive failure, the energy of separation could not be attributed simply to the work of adhesion as the surface where the adhesive phenomena occurred is not the total surface. In case of Cohesive failure the contact surface gets totally covered with product, Figure 54. Hence, we investigated the change of adhesive surface (S_{adh} : the clean area of the probe at the end of debonding phase) and its effect on the measured total energy (E) by a two-way ANCOVA with interaction:

$$E = S_{adh} + Product + S_{adh} \times Product + \varepsilon$$

The significance of the E for product discrimination was determined by $p < 0.05$. The results are shown in Table 24.

Table 24 : ANCOVA results for investigating the adhesive surface and the product effect on the measured total energy

Parameters	P > F	S_{adh}	Product	$S_{adh} \times Product$
E	***	****	****	NS

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$, NS: Non significance ($P > 0.05$)

The ANCOVA results on the entire set shows that both the S_{adh} and the product effect are very significant on measured total energy. Since the S_{adh} is equal to zero for products giving cohesive failure, in order to compare the adhesive property over the product range the energy of separation (E) is taken into account rather than the work of separation (W). In order to include the differences in state of the contact surface, the adhesive surface (S_{adh}) at the end of the test as well as the residue (the product mass on covered surface of the probe) are also taken into account. The range of residue for products with various levels of cohesive failure was 0.33-0.95 g/mm².

To sum up, the product in this work can be divided into three main groups according to their detachment behaviors and failure modes. The different failure modes are related not only to the balance between cohesive and adhesive energies but also the deformability of products. The products showing adhesive rupture were resistance to deformation and had cohesive forces that were more important than adhesive forces. The products with adhesive-cohesive rupture had two types of forces in competition with same importance. Finally, the products with cohesive failure showed an important degree of deformability (except P10). These products contracted by the probe movement and stretched during the separation phase. Additionally, the contact surface showed a significant effect on the total energy measured, hence, it has to be taken into account as an additional factor in comparing the total energies related to different failure types. The residue is another factor that helps to include the variations for products with different levels of cohesive failure.

5.2.3. Products discrimination through tack measurement

Studied parameters over the entire set

Table 25 shows the range of the eight discriminant factors from which 6 were extracted from Force-Distance curves and 2 were obtained after the probe state at the end of the test.

Table 25: Range of the tack tests parameters over product set.

Parameters	Min	Max	Max/Min	Unit
t_{mi-rel}	0.20	0.60	3.00	s
d_{Fmax}	0.08	0.44	5.50	mm
F_{max}	0.35	7.91	22.60	N
E_{Fmax}	0.04	0.93	23.20	J
E	0.23	10.03	43.60	J
E_{Fmax}/E	0.08	0.31	3.87	–
S_{adh}	0	1.00		–
Res	0	0.95		g/mm ²

Some factors such as time needed to reach half of relaxation (t_{mi-rel}) and distance corresponding to maximum force (d_{Fmax}) did not vary much between the different products. However, the range of variation for the maximum force (F_{max}) and the energy spent till the force maximal (E_{Fmax}) are greater. The important variation of F_{max} and E_{Fmax} can be related to the important differences in rheological properties between the products. Finally, the total energy (E) has the highest variation among the products.

It should be mentioned that the variation between the repetitions for a given product was important. The F_{max} variation was less than 10% for the majority of products. However, for 3 products (P14,

P18 and P19) the variation increased to 20% and 1 product (P3) had 50% of variation. Regarding the E, the variation was about 10% for half of the products; the variation increased to 20% for 8 products (P1, P6, P9, P14, P16, P18, P19, and P20). 2 products showed higher level of variations: 30% for P2 and 40% for P5. Based on our observations, these variations could be due to the differences in surface regularity. In fact, slight differences between the different implementations of a product can possibly impact the F_L effect. This can result in differences in actual contact. Another explanation is that during the product implementation some air holes may have been formed within the product bulk. This can modify the product resistance when putting the product-prob into contact and result in variations in measured parameters. Despite these variations at the individual level, ANOVA results showed that all the variables discriminate the products very significantly ($p < 0.001$).

To conclude, all the factors were significantly discriminative for product characterization. The F_{max} and the E variations are important at the individual product level. However, the variation between the products is more important than the variation within a product. Thus, E and F_{max} can be used for investigating adhesive properties of products.

Multidimensional study

A normed PCA was carried out on the average data of tack measurement over the entire product set. The first three axes explain 92% of the information (51, 31 and 10 % respectively). Further dimensions explained only a small proportion of variance ($< 5\%$). Based on the rule of eigenvalue value superior to 1, the first two axes with 82 % of the variance explained will be presented, Figure 57.

The factorial analysis made it possible to easily visualize the correlations among the various parameters. Axis 1 of the correlation circle opposes two variables (d_{Fmax} , Res) to a group of four variables (F_{max} , t_{mi-rel} , E_{Fmax}/E and S_{adh}). Axis 2 represents the total energy (E) and the energy until F_{max} (E_{Fmax}).

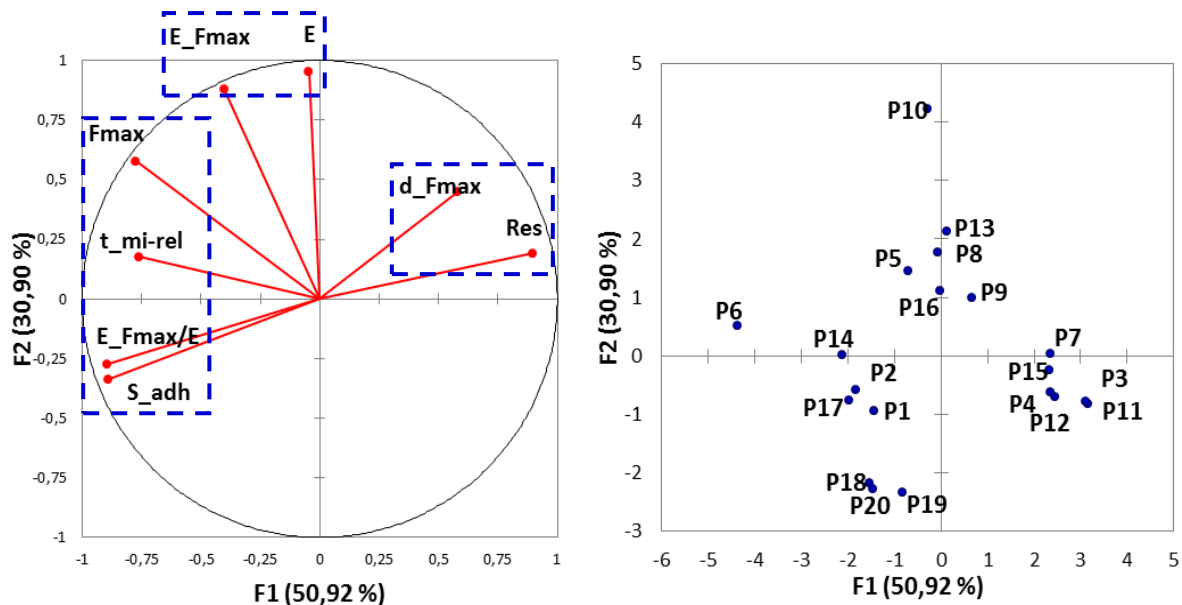


Figure 56: PCA results on the data of tack measurements. In left: the correlation circle for variables. In right: the products positioning on the first two components. The HCA results on the variable are presented on the correlation circle.

Running an HCA on the variables after the PCA components resulted in three groups of variables. These groups are also shown on the PCA plots in Figure 57. The variables belonging to the same group are correlated and bring the same information for the relative positioning of products. Among the correlated variables those that do not bring redundant information were chosen from each HCA group in order to describe the products range.

On axis 1, a group of HCA consists of four variables, among which S_{adh} and E_{Fmax}/E were highly correlated ($\alpha = 0.92$). In fact, the main variation of contact surface starts once the tensile force reaches its maximum (F_{max}) and when the probe-product start to detach from each other. So, it seems logical that the energy ratio (E_{Fmax}/E) gives an index of the change in the surface. Therefore, we decided to keep only the E_{Fmax}/E factor since it can be easily calculated from the Force-Distance curve. The two other variables in this group (t_{mi-rel} and F_{max}) were also significantly correlated ($\alpha = 0.74$). The time to reach half relaxation (t_{mi-rel}) and the maximum force (F_{max}) give information about products' elasticity. Moreover, t_{mi-rel} is not an index of adhesiveness and it represents the rheological property of product. Therefore, we only keep F_{max} . It had a higher contribution to this component to discriminate the products and is more often reported in literature for adhesiveness characterization. The second group on axis1 consists of two factors with a lower level of correlation ($\alpha = 0.46$): d_{max} and Res (product left-over on the probe). Therefore, both factors are kept as they showed lower correlation and they do not bring the same information.

Finally, the last HCA group includes two highly correlated variables ($\alpha = 0.83$) on the axis 2: total energy (E) and the energy expanded till maximum force (E_{Fmax}). We decided to keep E for it had more contribution to the second axis and it is the factor most often reported in the literature. Moreover, the effect of E_{Fmax} is already included in E_{Fmax}/E factor.

We can now interpret the differences between the products by means of the 5 selected variables from tack measurement, Figure 57.

Axis 1 best discriminates the product P6 as well as P14 and P17 on the left side versus a group of six products on the right side (P3, P4, P7, P11, P12, P15). Product P6 showed a higher F_{max} and E_{Fmax}/E than the rest of the products. This product showed a very abrupt adhesion rupture, did not deform and resulted to adhesive failure. On the other hand the group on the right side consists of the products that are discriminated from the rest by a lower E_{Fmax}/E and higher d_{Fmax} and Res values. These products, with lower concentrations, showed cohesive rupture and had deformed and stretched during the debonding phase. **Indeed, axis 1 opposes the products with adhesive rupture to products with cohesive rupture and represents the resistance of the products to deformability while debonding. The products with adhesive-cohesive rupture were situated between these two groups.**

Axis 2 opposes mainly the product P10 as well as P5, P8, P13 to P18, P19 and P20. The products on the top of axis 2 are best discriminated from the rest of the products by their higher total energy (E) values. The P10 product resulted to cohesive rupture presenting high adhesive (adhesiveness of the product to probe) and cohesive properties (cohesiveness of the mass over probe) whereas the rest gave an adhesive-cohesive failure. On the bottom of axis 2, a group containing three products discriminated by their lower total energy in comparison to the rest of products. These products showed an adhesive rupture. **Indeed, axis 2 opposes cohesive and adhesive-cohesive ruptures to**

adhesive products by total energy. It can be seen that the products are better distributed in the map resulting from the tack test compared to the map resulting from rheological test, Figure 50 vs. Figure 57 .

In conclusion, 5 variables of tack measurement were selected to discriminate the products: the maximum of tensile force (F_{max}), the total energy (E), the ratio of energies (E_{Fmax}/E), the distance corresponding to F_{max} (d_{Fmax}), and the residue of the product over covered surface of the probe (Res). We noticed that for our product range with important texture diversity the ratio of energies gave information on the type of failure and the resistance to deformability. It discriminates the three types of rupture while the total energy represents both adhesive and cohesive properties.

Focus on three main parameters representing different adhesion levels

Among the variables selected for tack measurement the F_{max} and E are mainly reported in literature and E_{Fmax}/E was found to be discriminating factor in our study. Figure 58 shows the results for these three parameters (F_{max} , E and E_{Fmax}/E) in logarithmic scale for a better visualization. The products are classified with respect to their failure modes in three different colors. Group (a) includes the products with cohesive failure (in red), group (b) includes the products with adhesive-cohesive failure (in blue) and group (c) includes the products with adhesive failure (in green).

Comparing the maximum tensile force (F_{max}) between the three groups (a, b and c) shows that the products with cohesive failure (a), in general, had lowest level of F_{max} in comparison to the products with complete or partially adhesive failures (b, c), except P10. However, the variation of F_{max} values between the products with adhesive-cohesive failure (b) is less important than for adhesive failure group (c).

The group with cohesive failure contains the products with a lower level of concentration (except P10). These products showed a contraction flow toward the center once the debonding phase started (except P10). In adhesiveness characterization of fluid food using the same method, Chen et al., (2007) explained that during the debonding phase, the probe upward movement results in a volume increase and a sharp pressure decrease within the material. Hence, the fluid is forced to flow toward the center to compensate this pressure drop. The tensile force magnitude depends on the speed of the contraction flow and the nature of the product. The higher F_{max} value of the P10 product in comparison to the other products with the same type of rupture can be explained by its rheological properties. P10 was the product with a higher concentration and it was more structured than the rest of the products in group “a” (higher G' and lower $\tan \delta$). Therefore, it is understandable that it resisted more to contraction flow giving a higher tensile force. The products in the two other groups (b and c) did not have this contraction flow and their higher level of F_{max} can be explained by their more structured texture that resist more to flow. However, investigating the FL degree of the products in the group “a” showed that the FL of P10 was about 10 times more important than the rest of the products within the same group (a). Hence, a question can be raised concerning the distinct characteristic of this product: Is the higher value of the F_{max} related to only the rheological characteristic or the FL magnitude or both? Did the failure mode of this product transit from a possible adhesive-cohesive failure to cohesive failure due to the magnitude FL?

Comparing the total energy of separation (E) between the three types of failure modes (a, b, c groups) shows that the variation of E values between the products of group “b” is less important

than the variations between the products of group “a and c”. Overall, the magnitudes of the separation energy for products with adhesive-cohesive failure were more important than the two other groups with a few exceptions such as P10.

In group with adhesive failure, the total energy varies more between the products. These products were resistance to deformation and had cohesive forces that were more important than adhesive forces. Therefore, a lower level of energy is needed to overcome adhesive bonds. The total energy for these products represents their adhesive property. Three products had the lowest total energy of separation, from which two of them were similar structured (P18 and P20, $\tan \delta=0.15$), whereas the third one was less structured (P19, $\tan \delta=0.23$). The total energy variations could be related to rheological differences and/or interfacial properties.

In the group with adhesive-cohesive failure, the adhesive and cohesive forces are in competition same importance. A partial separation has occurred within the product bulk. The competition between cohesive and adhesive properties of the products is related to both interfacial surfaces and rheological characteristics. Therefore, higher level of total energy can be explained by the fact that more energy is needed to overcome the adhesive bonds to partially separate the two surfaces. In this case, a part of total energy is dissipated to separate the product and the probe at the interface and represents the adhesive property. While some of the dissipated energy results in structure breaks within products mass bulk. Therefore, the total energy in this case integrates both adhesive and cohesive properties of products.

In the group with cohesive failure, the products showed an important degree of deformability (except P10). These products contracted by the probe movement, stretched during the separation phase and formed a filament that became thinner and thinner. The separation took place in the filament not because the adhesive forces increase the cohesive ones. This phenomenon is mainly related to high deformability of products which resulted in a low contact surface by filament formation.

In fact, the filament breaks are most possibly due to the fact that the applied stress over the contact area (filament thickness) had become very large. In this case, the total energy does not simply represent adhesive and/or cohesive property. It represents also the product deformability.

Finally, comparing the ratio of energies (E_{Fmax}/E) between the different types of failure mode shows that this factor is more stable between the products with cohesive failure. However, its variation for groups with some level of adhesive failures (b and c) is more important. Overall three levels of E_{Fmax}/E values can be observed for the three groups. The group with purely adhesive failure presents a higher level for this parameter. This can be explained by the highest resistance of the products in this group to deformation and their high cohesiveness. In contrast, the group with purely cohesive failure presents a lower level for this parameter.

To sum up, the group of products with cohesive failure is best discriminated from the two other groups by their lower level of Fmax values which is related to less structured characteristics of this group (diluted products, except P10). The group of products with adhesive-cohesive failure is best discriminated from the two other groups by their higher level of E values which is related to both adhesive and cohesive forces. Finally, the three groups are discriminated by E_Fmax/E values. **The total energy (E) related to different failure modes represent different phenomena involved in the separation phase. The results show that, for our product range, the E_Fmax/E factor allows discriminating the products with rich diversity of texture from pure adhesive to pure cohesive failures.**

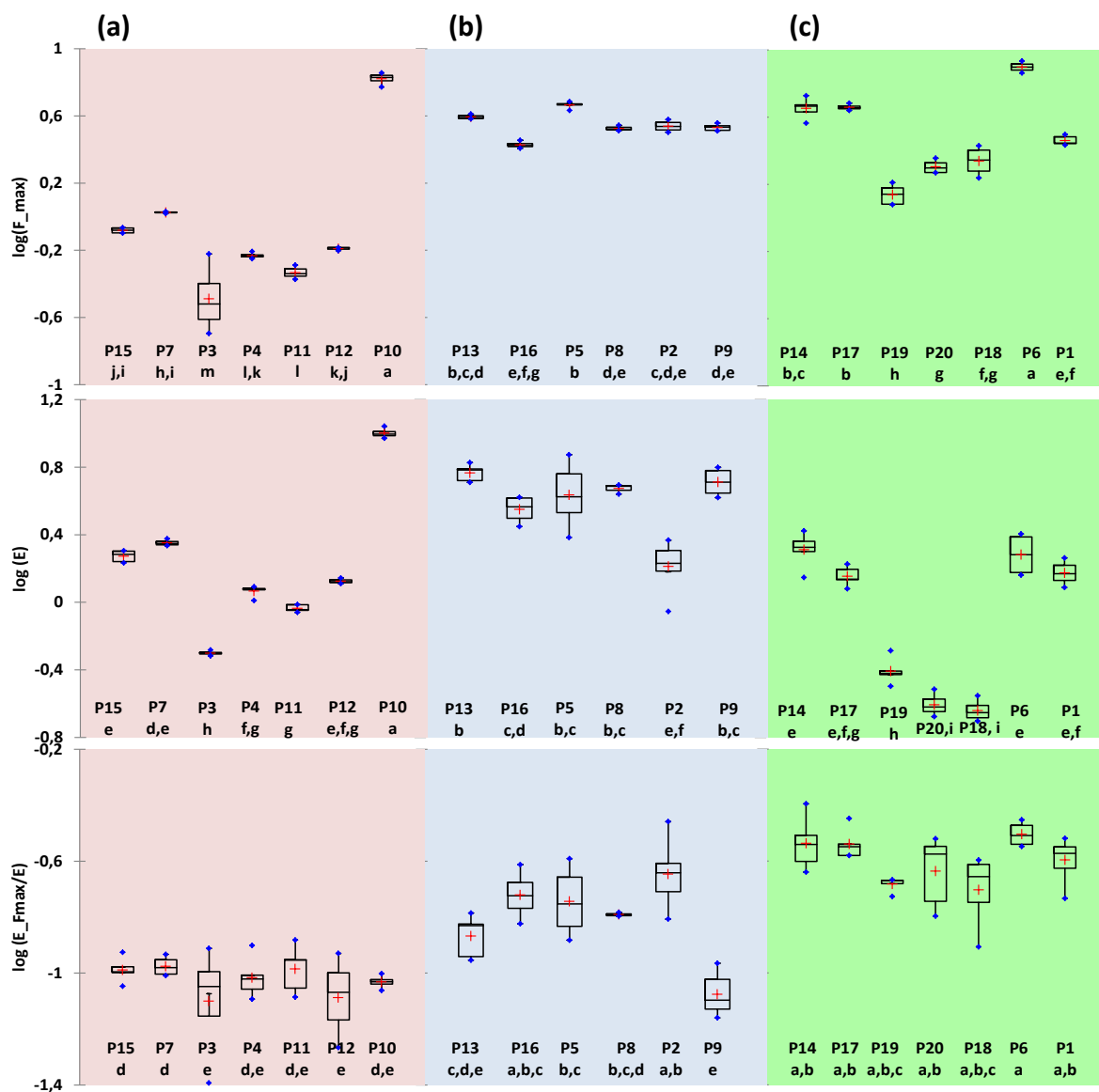


Figure 57: The box plot results for maximum tensile force (Fmax), the energy to maximum force (E_Fmax) and the total energy (E) based on failure modes: (a) Cohesive failure, (b) Adhesive-cohesive failure and (c) Adhesive failure.

In the next part, we are going to present the multidimensional study that was carried out on rheological and tack parameters in order to discriminate the products.

5.3. Products discrimination through both Instrumental approaches

5.3.1. Instrumental characterization of the entire set

The selected instrumental variables from the rheological and tack measurement are thus the following ones: 5 variables of tack measurement “d_Fmax, Fmax, E, E_Fmax/E and Res” and 5 variables of rheological measurement “G’_10, $\tan \delta_{10}$, γ_s , σ_s and F_penetro”.

The main objective in this section is to obtain a product map through the instrumental characterization of products and to investigate if the tack measurements bring additional information with regard to the rheological measurements. For this purpose, the existing relations between the 10 instrumental variables are investigated.

The instrumental product map was obtained by running a normed PCA on the reduced centered average data of the instrumental variables. The first five axes explain 94 % of the information (49, 17, 13, 9 and 6 % respectively). The further dimensions explained only a small proportion of variance (< 5%, Figure 58). Based on the rule of eigenvalue value superior to 1, the first three axes with 79 % of the variance will be presented.

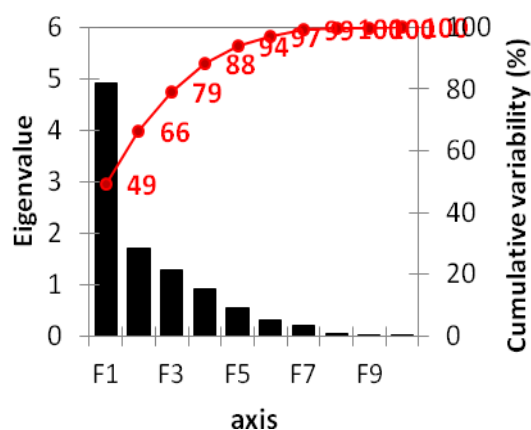


Figure 58: Distribution of the variance per dimension of PCA (Instrumental variables).

Axis 1 is mainly explained by rheological factors as well as tack parameters. It opposes the three rheological variables F_penetro, G’ and σ_s in addition to one tack factor (E_Fmax/E) versus phase lag ($\tan \delta$) and distance at Fmax (d_Fmax). Axis 2 is explained by 2 tack variables: total energy (E) and maximum force (Fmax). Finally, Axis 3 figured the minimum deformation that initiates the product movement (γ_s), Figure 60.

Axis 1 opposes a group of 5 products (P6, P14, P17, P18, P20) on the right side to a group of 6 products (P3, P7, P11, P12, P15) on the left side. Two products (P6 and P18) are best discriminated on the right side of this axis. The products on the right side were more structured and consistent (higher G’_10 and lower $\tan \delta_{10}$). They underwent a higher level of stress to initiate their deformation. In addition, the ratio of energies is also more important for these products. As explained before, the ratio of energies gives information on the debonding behavior of products and

is highly correlated to adhesive surface (S_{adh}). These products had adhesive failure. On the other hand, the products on the left side were less structured and had lower values for E_{Fmax}/E compared to the rest of products. They reached F_{max} at higher distance (d_{Fmax}). All of these products had cohesive failure. In fact, **axis 1 opposes the products with adhesive failure to products with cohesive failure based on rheological and tack parameters. It also gives information on products deformability according to the E_{Fmax}/E and d_{Fmax} factors.**

Axis 2 opposes four products (P5, P8, P10, P13) to one product (P19). Two products (P8 and P10) are best discriminated on this axis. These products are discriminated and opposed to P19 mainly by their higher E values. They gave an adhesive-cohesive failure (except P10) versus the product P19 that showed an adhesive failure. **In fact, the E factor discriminated the products with adhesive-cohesive failure (except P10) from the rest of the products. In our opinion, once the products do not give pure adhesives failures, the total energy integrates both adhesive and cohesive properties.** The E value can be translated to adhesive energy, for the part of the energy that was applied on the clean part of the probe surface in order to break probe-product adhesive bonds. Or, it can be interpreted as cohesive energy for the part of the energy that broke the cohesive bonds within the product bulk. In both, its high values reveal the competition between the cohesive and adhesive forces within products. The product P10 was the only product with high level of E that had cohesive failure. This product is discriminated on axis 2 having high level of F_{max} . As explained before, this product could potentially have given an adhesive-cohesive failure if it had undergone a lower level of force load.

An HCA was also carried after PCA to find groups of products. Three main groups resulted and are shown on the PCA plots, Figure 60. The groups are separated mainly along the first dimension. HCA resulted in the same groupings of products.

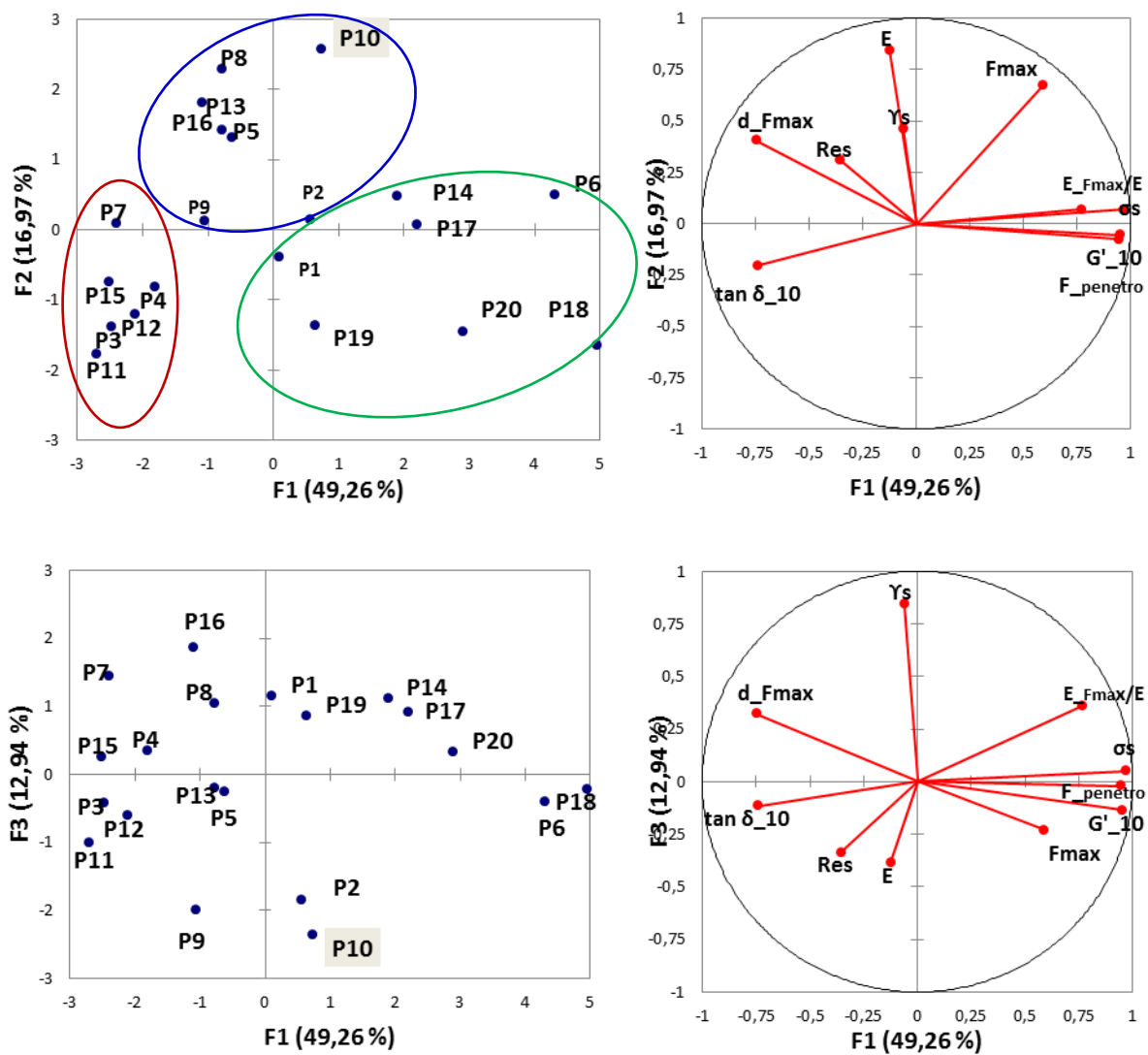


Figure 59: First three dimensions of PCA on the instrumental data. The ovals represent the group resulted from HCA.

Finally, axis 3 opposes P16 versus P9 based on their rheological behavior in the beginning of non-linear region. The P16 product deformed to a greater extent (higher γ_s) at the same stress that initiates the product movement compared to P9. Both of these products gave adhesive-cohesive failure.

In the previous section, we saw that the different failure modes represent the different products' behavior during the debonding phase. This, by itself, is affected by rheological properties of the products. On the other hand, the PCA results demonstrated that the first component represents 50% of information and discriminates the three groups of products with three types of failure modes. The two tack parameters that were contributed to this axe were significantly correlated to rheological factors: E_{Fmax}/E was correlated to σ_s ($\alpha = 0.73$) and d_{Fmax} was reversely-correlated to G'_{10} ($\alpha = -0.72$). In fact, γ_s was the only rheological parameter that was not well presented on the first two components. This brings a question if the different failure modes can be discriminated only by rheological factors.

Herein, the relationship between the different failure modes and rheological properties is discussed. Figure 61 illustrates the variables corresponding to the very beginning of the non-linear region: the minimum stress (σ_s, a) and the minimum strain (γ_s, b) at which the product starts to flow, with respect to products failure modes. These rheological variables are selected since they are related to the beginning of the nonlinear region and therefore are a better representative in regard with deformation that takes place in tack measurement and the sensory evaluation. Moreover, the yield stress was the variable more correlated to ratio of energies while the strain was not correlated to any factor.

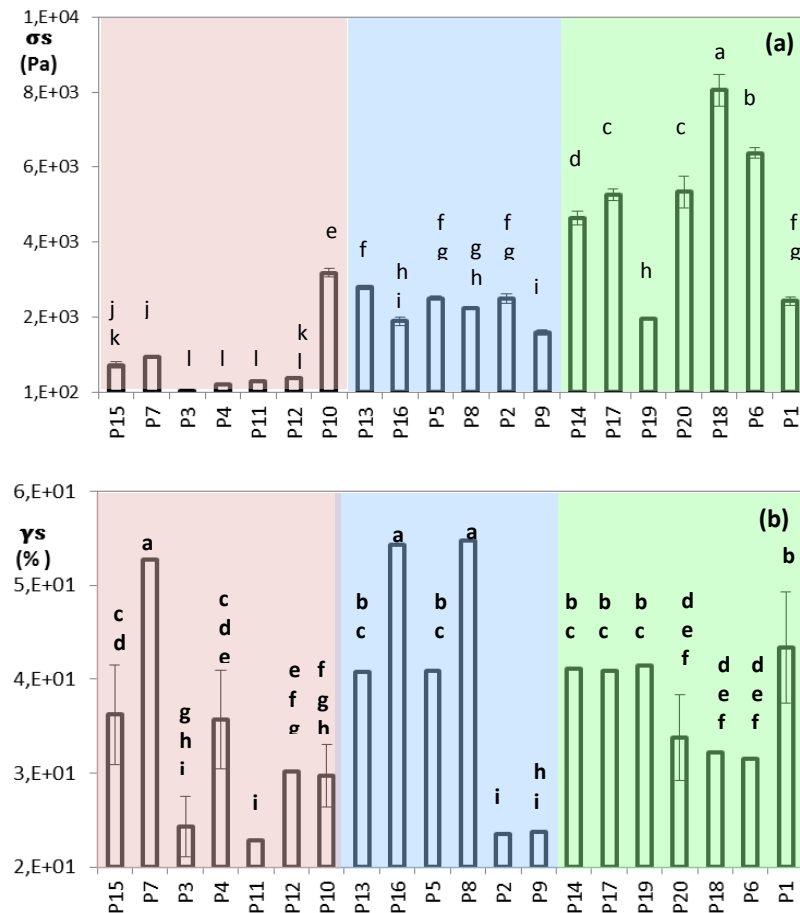


Figure 60: Stress (a) and strain (b) corresponding to yield stress. The different types of failure mode products in tack measurement are presented in different colors: Adhesive failure (in green), Adhesive-Cohesive failure (in blue), Cohesive failure (in red).

Concerning σ_s , the first point that can be seen is that the three different types of failure mode had in general three levels of σ_s , with some exceptions. Overall, the products with cohesive failure start to deform at lower stress except P10. The products with adhesive-cohesive failure had intermediate values for σ_s . Finally, the products with adhesive failure deformed at higher stresses with two exceptions (P1 and P19). Nevertheless, it can be seen that some products with similar yield stress resulted in different types of rupture, For instance, the product P1 versus P2, P5, P8 and P13 or the product P19 versus P8 and P16. In addition, P10 had a stress level close to those of products with adhesive-cohesive failure, while it featured to a cohesive rupture.

In an attempt to explain these differences, the γ_s values were investigated. The result shows no specific pattern with regard to the failure modes, Figure 61. It can be noted that some products with the same level of strain started to flow at different stress levels and result in different types of failure. For example products P7 versus P8 and P16. While other products with the same yield stress and strain resulted in different failure modes (P19 versus P5 and P13). **This also shows that the rheological properties of the product are not enough for investigating the adhesive properties and failure modes over the entire set.**

To sum up, combining the rheological with tack measurements improved the products distribution in the instrumental map. It showed that 80% of the information is explained on three dimensions. On the first dimension, the products were discriminated relative to both rheological and tack factors. The tack measurement brought new information on the second axis which was related only to the total energy of separation. Finally, the third axis was explained by strain at the beginning of the non-linear region.

Among the parameters resulting from the tack test, the ratio of energies (E_{Fmax}/E) discriminated the products with more texture diversity and different failure modes. This factor was correlated to yield stress (σ_s). Moreover, E_{Fmax}/E and d_{Fmax} gave information on products deformability which is related to product rheological characteristics. The total energy (E) brought further information and integrated both adhesive and cohesive properties. This brings an interest to study the sub-groups with products featuring the same mode of failure.

5.3.2. Instrumental characterization of the sub-sets

Characterizing the products by dynamic and tack methods gave appealing results rather the diverse product set. To provide a more stringent of the tack method utility, three sub-set of the product showing three types of failure mode were examined separately to investigate if this method permits to discriminate the products with less difference within each group. The objective of this part is to study the interest of tack measurements in addition to rheological tests for the characterization of three product sub-sets with distinct failure modes. Moreover, we wanted to investigate the tack parameters that allow discriminating the products based on their adhesion properties.

First, we investigate more precisely the effect of force load (F_L) on the parameters measured separately for each sub-set. Then, normed PCAs were run separately on tack and rheological parameters to select the efficient factors in the same way as for the entire set. Once the factors were pre-selected for each measurement, the third PCA was carried out. This aimed was to choose a limited number of parameters for discriminating the products. In this part only the result of PCA on selected factors (selected after preliminary PCA on tack and rheology variables) are presented. See annex for the results of preliminary PCAs on each measurement for each sub-set. Below, the results for each sub-set are discussed separately.

Adhesive sub-set

Seven products in the entire product set showed an adhesive failure in the tack measurements. As demonstrated in Figure 62, the F_L range varied from 1–4 N and was significantly different between

the products ($p < 0.0001$). Therefore, its effect on the measured parameters was studied first by a two way ANCOVA with interaction.

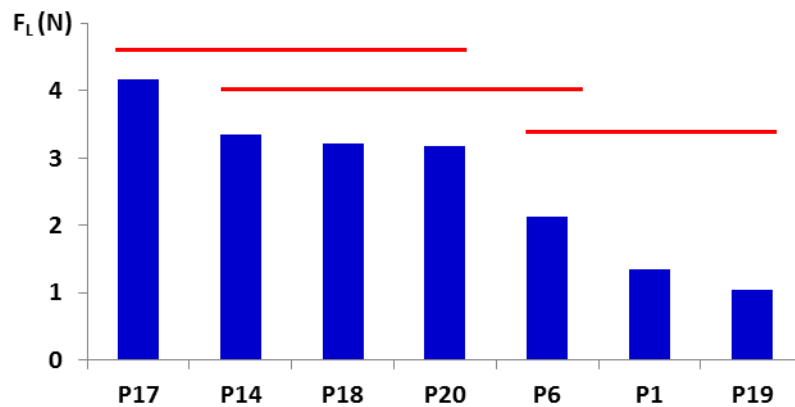


Figure 61: The average of force loads (F_L) for the products with Adhesive failure in tack measurement. ANOVA and Tukey pair-wise comparison, $P < 0.0001$.

Table 26 shows the results of the ANCOVA. It can be seen that the product effect is dominant for all the factors. This shows that even though the F_L range varies among the products, the differences among products are rather important. An interaction effect was identified for t_{mi-rel} showing that the F_L has an influence on the needed time to reach the half of force relaxation and this effect is not the same for all products.

Table 26: The result of 2-way ANCOVA with interaction on tack variables for Adhesive sub-set.

Variables	P > F	F_L	Products	$F_L \times \text{Products}$
t_{mi-rel}	**	NS	NS	*
d_{Fmax}	****	**	****	NS
F_{max}	****	NS	****	NS
E_{Fmax}	****	NS	****	NS
E	****	NS	****	NS
E_{Fmax}/E	**	*	**	NS

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS: Non significant ($P > 0.05$)

The preliminary PCAs on tack variables showed that the three factor of energy (E , E_{Fmax} and E_{Fmax}/E) were highly correlated. Among them, the factor E was selected since it is the most reported in the literature. Overall, three rheological parameters " G'_{10} , $\tan\delta_{10}$, γ_s " and three tack parameters " E , F_{max} and d_{Fmax} " were selected after the preliminary PCAs.

The instrumental product map was obtained by running a normed PCA on the standardized average data of the 6 selected instrumental variables for the characterization of the 7 products. A Varimax rotation was performed after the PCA to facilitate the interpretation of axes. Before the rotation, some variables were highly correlated to several dimensions. After the rotation, axes are mainly explained by a few variables with high loadings. The product map and the correlation circle are shown in Figure 63.

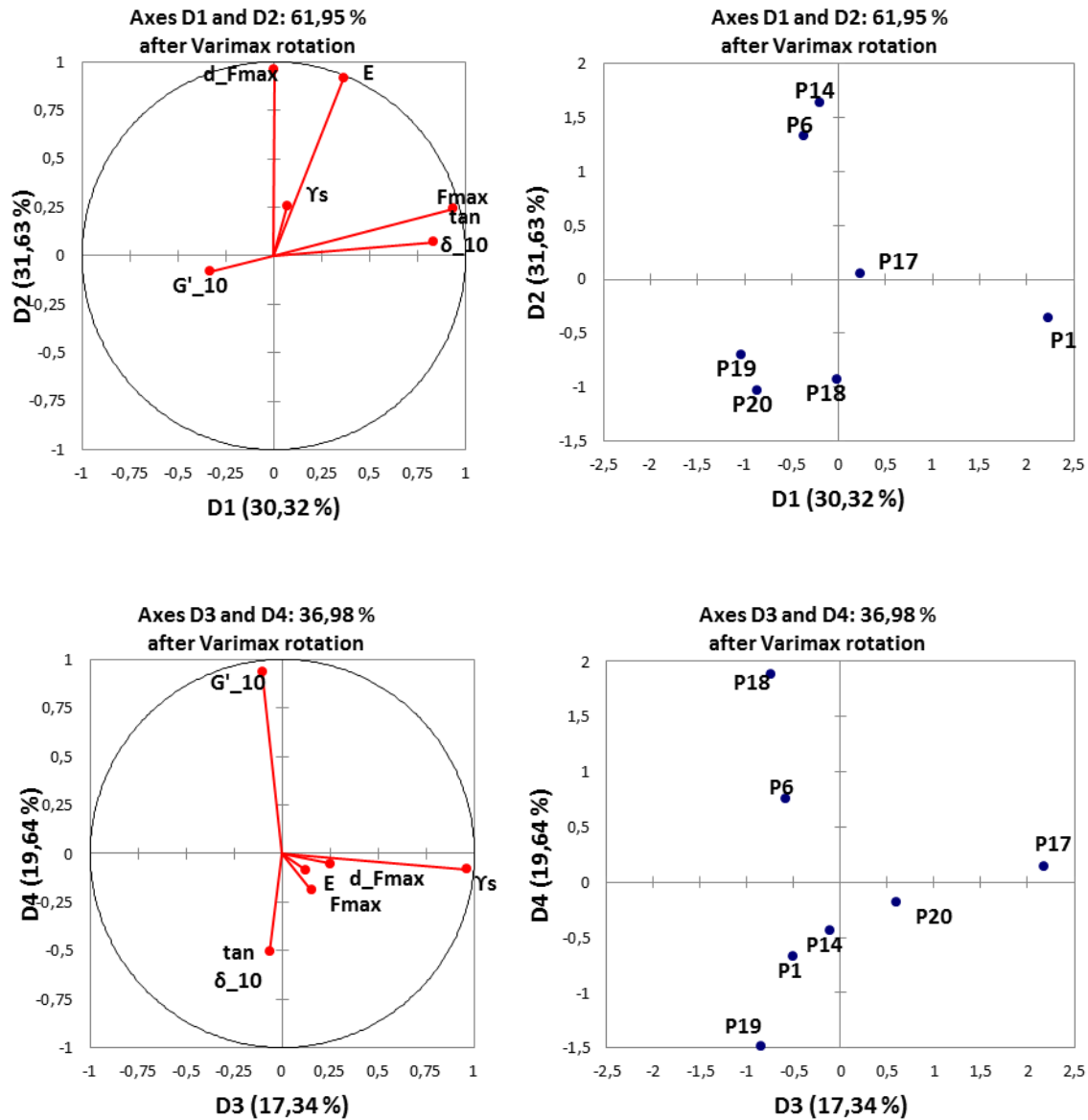


Figure 62: First forth dimensions of PCA for Adhesive sub-set.

The first four axes explain 99 % of the information (30, 32, 17 and 20 % respectively) after varimax. The further dimensions only explain a small proportion of variance (< 5%).

The correlation circle shows that the axis 1 is explained by rheological and tack parameters ($\tan\delta_{10}$, Fmax). The Fmax is correlated to some extent to $\tan\delta_{10}$ which seems logical for it is related to the

rheological characteristics. Axis 2 is explained only by tack parameters (E , d_{Fmax}). Axis 3 represents the deformation threshold (γ_s) and axis 4 is explained by elastic module (G'_{10}).

Axis 1 discriminated product P1 from the rest of the products. This product was less structured and had a higher tensile force than the rest of the products. Axis 2 opposes two products at the top (P6, P14) versus three products (P18, P19 and P20) at the bottom. P14 and P6 reached their maximum force at a higher distance and had higher total energy values. This shows that these products had a stronger bonding with the probe and therefore more energy was required to overcome the adhesive property of the products without breaking their structure. Axes 3 and 4 discriminated products based on rheological factors. Axis 3 discriminated P17 as being more deformable. Finally, axis 4 opposed P18 as being more consistent than P19.

To conclude, the F_L variation was significant between the products, however, products differences still dominated. The first two dimensions represent 62% of information and were explained mainly by tack parameters. Axis 3 and 4 represent 37% of information according to rheological factors. Thus, we can conclude that more information was brought by the tack test. The total energy (E) can be translated into adhesive properties for products with adhesive failure. Moreover, the preliminary PCA on tack variables showed that the E , E_{Fmax} and E_{Fmax}/E were highly correlated for these products.

Adhesive-Cohesive sub-set

Six products of the entire set showed an adhesive-cohesive failure in tack measurements. Figure 64 shows that the F_L values were not significantly different between the products in this sub-set. The F_L effect on the measured parameters was investigated by a two-way ANCOVA with interaction.

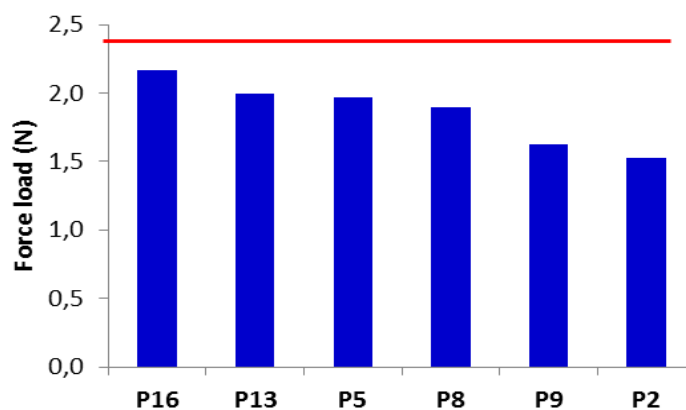


Figure 63: The average of force loads (F_L) for the products with Adhesive-Cohesive failure in tack measurement. ANOVA and Tukey pair-wise comparison, ($P < 0.0001$).

The ANCOVA results are shown in Figure 64. All the variables except t_{mi-rel} can significantly discriminate the products. The F_L effect is either not significant or negligible in comparison to product effects with the exception of d_{Fmax} .

Table 27: The result of 2-way ANCOVA with interaction on tack variables (Adhesive-Cohesive sub-set).

Variables	P > F	F _L	Products	F _L × Products
t _{mi-rel}	NS	NS	NS	NS
d _{Fmax}	****	****	****	NS
F _{max}	****	NS	****	NS
E _{Fmax}	****	**	****	NS
E	****	NS	****	NS
E _{Fmax} /E	**	NS	***	NS
S _{adh}	****	NS	****	NS
Res	**	NS	**	NS

*P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001, NS: Non significant (P > 0.05)

Furthermore, the effect of contact surface on the measured energy was studied. As explained before, the contact surface changes during the debonding phase for products with adhesive-cohesive failure. Therefore, the total energy to separate the surfaces is not a true index of product adhesive property by itself. The area of the probe that stays in contact with the product during the debonding phase has an impact on the measured energy and has to be taken into account for products comparisons. The effect of contact surface and the products on the measured energies (either total (E) or energy to maximum force (E_{Fmax})) is compared by a two-way ANCOVA, Figure 28. The results show that the product effect is dominant to surface until the F_{max}. This seems logical since the F_{max} is related to product rheological properties before any deformation or separation takes place. However, the surface effect becomes dominant after the F_{max} had reached and where the separation takes place.

Table 28: The result of 2-way ANCOVA with interaction to investigate the contact surface and products on energy of separation (Adhesive-Cohesive sub-set).

Variables	P > F	S _{adh}	Products	S _{adh} × Products
E _{Fmax}	****	*	***	NS
E	****	****	***	NS

*P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001, NS: Non significant (P > 0.05)

The adhesive surface (S_{adh}) was defined as the ratio between the clean parts of probe surface at the end of the test to the total surface. As demonstrated in Figure 64, E showed a significant linear decrease with an increase in S_{adh}. This linear decrease is understandable considering that when the product cohesiveness dominant over adhesiveness, less energy is needed to separate the probe from the product; hence, is the surface stays clean.

However, it seems complicated to separate the opposite forces from each other for the area of the probe that gets covered by products. Since the adhesion property is a combination of adhesive

property (the first layer of the product on the probe) and cohesive property (the mass or product left over on the probe). Moreover, part of the dissipated energy results in breaking the inner bonds of the product (cohesive bonds). Therefore, once the probe gets covered by product the energy gives information about adhesiveness and cohesiveness.

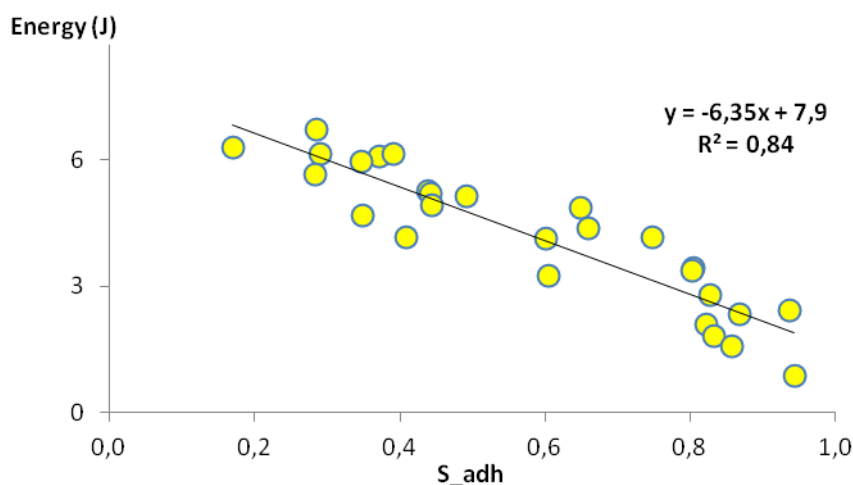


Figure 64: Effect of the surface in contact while debonding phase on the total energy to measure stickiness

The preliminary PCA on tack parameters showed that E_{Fmax}/E was highly correlated to S_{adh} and highly reverse-correlated to Res . Therefore, E_{Fmax}/E was selected since it is easier to obtain after the tack test. On the other hand, E_{Fmax}/E and E were also correlated. This seems logical because part of E_{Fmax}/E represents E value. Therefore, E_{Fmax}/E was kept since it includes some further information compared to E and was highly correlated to S_{adh} and Res . E_{Fmax} was selected to complete the E_{Fmax}/E factor. F_{max} was pre-selected since it has been reported in literature. The d_{Fmax} was the fourth chosen factor. In brief, from the preliminary PCA on tack data, four variables were selected first: d_{Fmax} , F_{max} , E_{Fmax} and E_{Fmax}/E . From the preliminary PCA on dynamic data, four variables were also chosen: G'_{10} , $\tan \delta_{10}$, σ_s and γ_s . Then, by running another PCA on the 8 pre-selected variables, 5 of them were kept for final characterization of the 6 products. After PCA on pre-selected factors, the **d_{Fmax} was eliminated since it was highly correlated to γ_s** . In addition to γ_s , G'_{10} and $\tan \delta_{10}$ were kept since they were not significantly correlated to any factor and had important contribution to component 1. From tack variables, E_{Fmax} and E_{Fmax}/E were kept to complete each other. E_{Fmax} was contributed to axis 1 while E_{Fmax}/E was mainly contributed to axis 3 and partially to axis 2.

A normed PCA was finally performed the selected variables after the preliminary PCAs for characterization of the products, Figure 66. **The 5 selected variables were: two variables from tack measurements (E_{Fmax} , E_{Fmax}/E) and three variables from rheological measurements (G'_{10} , $\tan \delta_{10}$, γ_s).**

The first three axes explain 97 % of the information (47, 38 and 11 % respectively). The further dimensions explained only a small proportion of variance (< 5%). Based on the rule of eigenvalue value superior to 1, the first two axes with 85.6 % of the variance is presented, Figure 66.

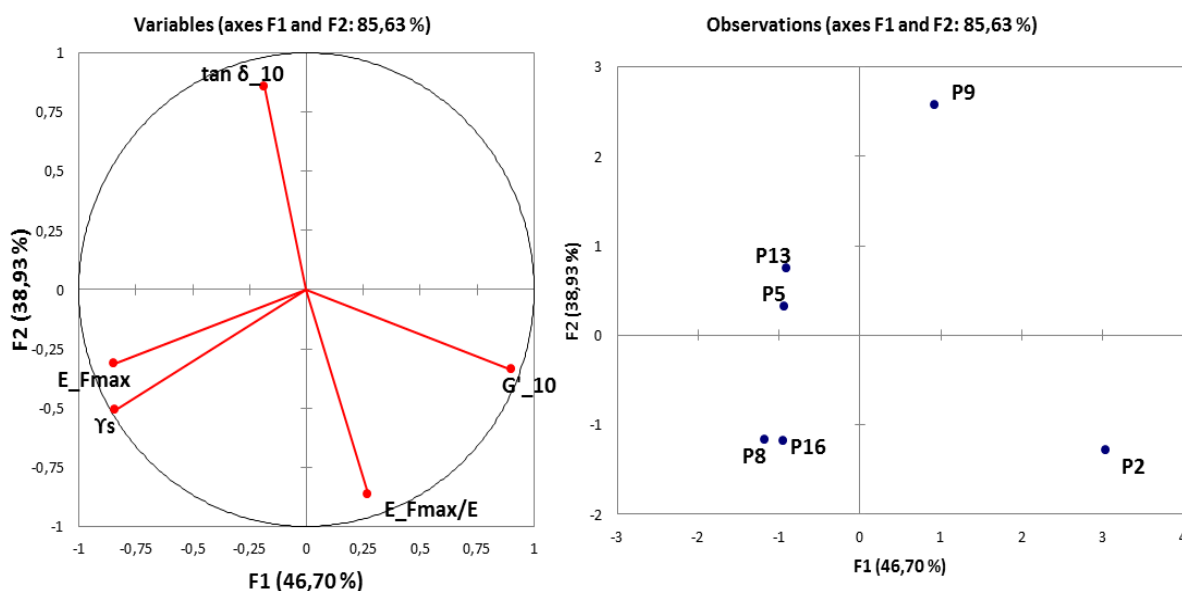


Figure 65: First two dimensions of PCA for Adhesive-Cohesive sub-set.

Axis 1 represents G'_10 versus γ_s and E_{Fmax} . Axis 2 represents $\tan \delta_{10}$ versus E_{Fmax}/E . It can be noted that both axes are explained by both rheological and tack variables. The rheological parameters representing the linear domain are opposed to the tack parameters. This could possibly be explained by the high level of competition between the adhesive and cohesive forces in products.

The first axis best discriminates P2 product and opposes it to P5 and P8. This product had higher G' value and was more consistent. It also had higher ratio of energies (E_{Fmax}/E) which shows that it rendered to adhesive-cohesive failure with adhesive failure being dominant. This shows that on one hand the product consistency and cohesiveness is more important and hence less E is needed for adhesive debonding. On the other hand, the majority of the dissipated energy broke the adhesive bonds between probe and product. Only a small part of the total energy broke the inner structure of product. The second axis best discriminates P9 and opposes it to P2, P8 and P16. This product had higher $\tan \delta$ value and therefore was less structured and more adhesive to the probe. In this case the adhesive and cohesive forces are in competition with the adhesive force being dominant. Hence, the majority of the dissipated total energy broke the structure within the product bulk rather than at the interface surface.

To conclude, the ratio of energies (E_{Fmax}/E) gives information on the dominance of adhesive failure, whereas the total energy (E) gives information on both adhesive and cohesive forces. The combination of rheological factors such as G' and $\tan \delta$ helps to interpret the dominance of these forces. However, completely separating the contribution of adhesive and cohesive energy in the energy of separation for these products is difficult.

Cohesive sub-set

Seven products from the entire set showed cohesive failure in tack measurements. In the same way as the other sub-sets we investigated first the effect of F_L on the measured parameters. As shown in Figure 66, F_L was significantly greater for the product P10. The F_L range for P10 was similar to the range for products with pure adhesive failures. All the products in this sub-set except P10 were

diluted products. Therefore, these products underwent less pressure while putting product-probe into contact compared to P10.

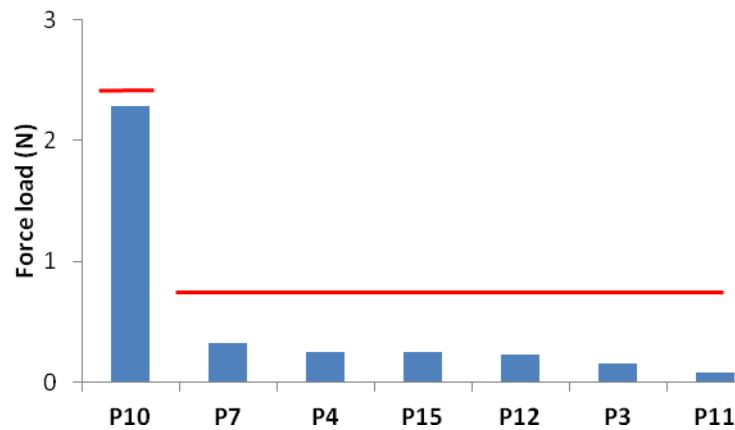


Figure 66: The average of force loads (F_L) for the products with Cohesive failure in tack measurement. ANOVA and Tukey pair-wise comparison, $P < 0,0001$.

To evaluate the importance of product and F_L effect a two-way ANCOVA with interaction was carried out. Below table shows the results.

Table 29: The result of 2-way ANCOVA with interaction on tack variables (Cohesive sub-set).

Variables	$P > F$	F_L	Products	$F_L \times \text{Products}$
t_mi-rel	****	****	****	NS
d_Fmax	***	NS	**	NS
Fmax	****	NS	****	NS
E_Fmax	****	NS	**	****
E	****	**	****	NS
E_Fmax/E	*	NS	*	*
Res	***	NS	****	NS

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$, NS: Non significant ($P > 0.05$)

It can be seen all the factors can discriminate the products significantly. The product effect was dominant except for one factor: t_mi-rel. P10 was more structured with higher degree of F_L and therefore had more time-elapse to reach the half relaxation. In addition, an interaction effect can be observed for the energy till the maximum of tensile force (E_Fmax). This shows that F_L has an influence on dissipated energy to reach the maximum force and this effect is not the same for all products.

The preliminary PCA on tack parameters showed that t_mi-rel, Fmax, E_Fmax and E were highly correlated. Among these variables, E was selected since it had slightly higher contribution to axis1. The other selected factors were E_Fmax/E, d_Fmax and Res (product left over). From the preliminary PCA on dynamic data, three variables were pre-chosen: G'_{10} , $\tan \delta_{10}$ and γ_s . Then, by

running another PCA on the 7 pre-selected variables, the **total energy (E) was eliminated since it was highly correlated to G'_{10}** and the rest were kept for final characterization.

A normed PCA was performed on the 6 selected variables for characterization of 7 products, Figure 68. **The 6 selected variables were: three variables from tack measurements (d_{Fmax} , E_{Fmax}/E , Res) and three variables of rheological measurements (G'_{10} , $\tan \delta_{10}$, γ_s).** The first four dimensions explain 96% of the information (42, 28, 16 and 9% respectively). Further dimensions explained only a small proportion of variance (< 5%). Based on the rule of eigenvalue value superior to 1, the first two axes with 70 % of the variance are represented, Figure 68. **There were no significant correlations among the selected variables.**

Axis 1 represents rheological characteristics of products and opposes G'_{10} versus $\tan \delta_{10}$. Axis 2 opposes deformation at the beginning of the non-linear domain (γ_s) and distance to reach Fmax (d_{Fmax}) versus products' left-over (Res). Even though based on the rule of eigenvalue value superior to 1 only the first two axes are presented, it is worth noting that axis 3 is explained by the ratio of energies (E_{Fmax}/E). It can be noted that these axes are mainly explained by factors related to structure and deformation of the products.

The first axis best discriminates P10 product and opposed it to P11. This product had higher G' and lower $\tan \delta$ values and was therefore more consistent and less structured than P11. These two products contained the same polysaccharide and were different in terms of concentration and additional processing. The second axis opposes P7 and P15 to P12. P7 and P15 were more deformable and reached their Fmax at higher distances, Figure 68. Whereas P12 reached Fmax at a lower distance and left more residue on the probe surface. P7 and P15 were less concentrated and they were squeezed under the force. They flow to the center and made one filament that became thinner as the test progressed until it broke. However, P12 were not squeezed by the F_L and it stretched less without making a long thin filament. The differences between these types of product at the time of rupture are shown in Figure 68. Finally, P3 is discriminated on axis 3 by its lower value for E_{Fmax}/E compared to the rest of the products. This product was the least concentrated product with high deformability. The dissipated total energies made the product deform; it broke the cohesive bonds since the contact surface decreased due to filament formation.

To conclude, the F_L squeezed the products of this group to some extent. The products with lower level of concentration flowed easily toward the center to avoid the pressure drop with the probe upward movement. The rupture either takes place within the stretched filament or right after the flow contraction. For this group the measured energy of separation cannot be easily interpreted. It can possibly represent product adhesiveness, cohesiveness as well as deformability. The (E_{Fmax}/E) gave information on products deformability.

In conclusion, instrumental characterization of product sub-sets shows that the same dynamic parameters (G' , $\tan \delta$ and γ_s) allow the characterization of the three sub-sets. The tack parameter that can be commonly used between the sub-sets is (E_{Fmax}/E). However, the total energy (E) brings different information depending on the sub-set. It represents adhesive properties for products with adhesive rupture. It integrates both adhesive and cohesive properties for products with adhesive-cohesive rupture. Finally, for products with cohesive rupture it integrates not only adhesive and cohesive properties, but also the deformation capacity of products.

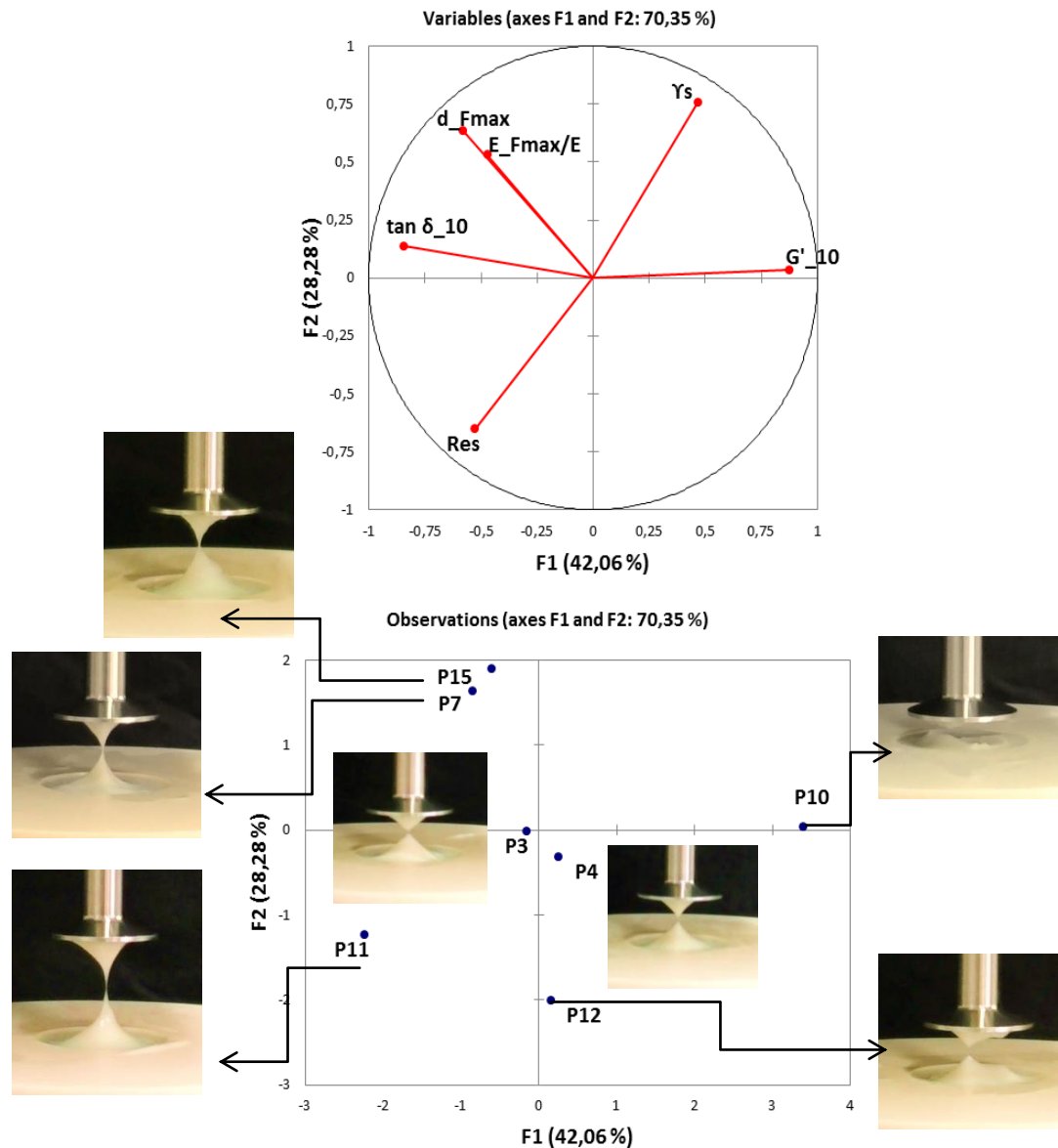


Figure 67: The first two dimensions of PCA for Cohesive sub-set. The figures show the products' behavior in debonding phase at their separation from probe.

5.4. Characterization of extruded products

In order to take different levels of product break down observed in sensory evaluations into account, the products were characterized at different physical states. Herein, we present the result of running dynamic and tack tests on products that were highly destructured through a pre-extrusion before their implementation.

The data analysis and the factor selection were carried out in the same way as for *Non-Extruded* products. The product maps were achieved first for each test separately and then it was achieved using the selected factors after both instrumental characterizations. However, since this experiment

aimed to study the effect of extrusion on textural properties of products we directly present the results in comparison with *Non-Extruded* products.

This step was meant to answer the following questions: *Do the different levels of applied force, the products undergo, have an influence on their overall positioning in the instrumental map? If so, do the textural changes are related to the change of rheological properties, adhesion properties or both?*

To answer these questions, the effect of extrusion for each product on each selected parameters was assessed by ANOVA. The Fisher test was used to calculate the minimum significant difference and a limit level of significance $p = 0.05$ was applied. Then, GPA was carried out on both data sets (*Extruded* vs *Non-Extruded* products) in order to compare product configurations. The results are presented below.

5.4.1. Extrusion effect

Table 30 shows the result of ANOVA for each parameter between *Extruded* and *Non-extruded* products.

Each column represents an instrumental factor. Each row represents the comparison results of *Non-extruded* versus *Extruded* products. The green color code shows a significant extrusion effect on a measured factor for a given product. The red color shows that the difference was not significant and the extrusion did not have influence on the corresponding factor. The white color shows the products for which the value of adhesive surface (S_{adh}) and residue on the probe (Res) was equal to zero.

Table 30: ANOVA results for extrusion effect on rheological and tack properties. Extruded products (-ext), $p < 0.05$.

Products	G' _10	tan δ _10	η^* _10	σ_s	γ_s	Fmax	E_Fmax	E	d_Fmax	t_mi-rel	S_adh	Residue
P1 vs. P1-ext	0,016	0,007	0,012	0,000	0,846	0,004	0,003	0,000	0,000	0,000	0,000	0,010
P2 vs. P2-ext	0,041	0,002	0,002	0,208	0,091	0,290	0,009	0,013	0,347	0,000	0,000	0,162
P3 vs. P3-ext	0,000	0,354	0,000	0,001	0,133	0,055	0,233	0,081	0,047	0,035		0,711
P4 vs. P4-ext	0,002	0,106	0,004	0,706	0,931	0,000	0,095	0,001	0,321	0,005		0,296
P5 vs. P5-ext	0,167	0,002	0,954	0,933	0,515	0,000	0,029	0,031	0,003	0,000	0,001	0,247
P6 vs. P6-ext	0,000	0,000	0,000	0,000	0,000	0,026	0,262	0,893	0,107	0,000		
P7 vs. P7-ext	0,001	0,003	0,027	0,962	0,797	0,000	0,425	0,040	0,018	0,000		0,003
P8 vs. P8-ext	0,003	0,969	0,035	0,010	0,538	0,001	0,005	0,471	0,070	0,000	0,001	0,038
P9 vs. P9-ext	0,000	0,028	0,154	0,000	0,107	0,000	0,177	0,375	0,000	0,000	0,002	0,663
P10 vs. P10-ext	0,000	0,006	0,012	0,000	0,176	0,021	0,183	0,018	0,233	0,000		0,859
P11 vs. P11-ext	0,173	0,231	0,719	0,010	0,000	0,007	0,026	0,004	0,460	0,000		0,066
P12 vs. P12-ext	0,855	0,025	0,054	0,557	0,000	0,843	0,283	0,423	0,057	0,082		0,001
P13 vs. P13-ext	0,000	0,000	0,000	0,000	0,000	0,001	0,089	0,089	0,036	0,000	0,040	0,767
P14 vs. P14-ext	0,001	0,000	0,000	0,000	0,016	0,414	0,067	0,417	0,177	0,000		
P15 vs. P15-ext	0,000	0,000	0,000	0,013	0,000	0,055	0,112	0,030	0,610	0,000		0,001
P16 vs. P16-ext	0,003	0,081	0,003	0,012	0,290	0,001	0,174	0,531	0,791	0,000	0,520	0,761
P17 vs. P17-ext	0,006	0,004	0,029	0,562	0,137	0,117	0,019	0,117	0,763	0,000	0,132	0,101
P18 vs. P18-ext	0,057	0,067	0,042	0,038	0,000	0,845	0,245	0,940	0,597	0,000		
P19 vs. P19-ext	0,000	0,000	0,000	0,000	0,000	0,651	0,001	0,001	0,000	0,000		
P20 vs. P20-ext	0,000	0,125	0,000	0,000	0,001	0,010	0,874	0,121	0,106	0,002		

The extrusion had a more important effect on rheological factors of products than on adhesive factors. In the first look it comes to attention that the first part of the table representing the rheological factors is, in general, greener. The only product for which the viscoelastic properties in

the linear region did not significantly change through extrusion is P11. However, a significant effect can be seen for the nonlinear region (yield stress).

Concerning the adhesive properties, extrusion resulted in a different failure mode for 6 products. The adhesive surface (S_{adh}) decreased in general for these products with one exception, Figure 68. Two *Non-Extruded* products (P17 and P1) became slightly more adhesive once they were extruded. The failure mode of these products had changed from adhesive to adhesive-cohesive. The failure modes of three products changed from adhesive-cohesive to completely cohesive (P5, P8 and P9). Finally, for one product the failure mode did not change but the adhesive surface increased and the product came less adhesive (P2), Figure 68. The only product for which the extrusion had modified the adhesive properties without changing its viscoelastic properties is P11. Otherwise, the extrusion either modified both properties together or only changed the viscoelastic properties.

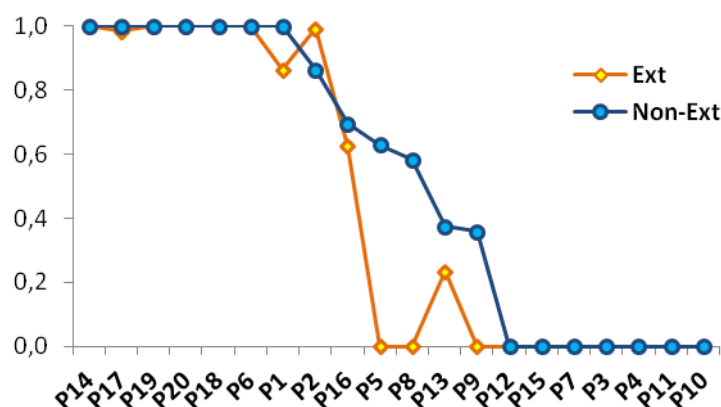


Figure 68: Adhesive surface (S_{adh}) after the debonding phase. $S_{adh} = 1$ for adhesive failure, $S_{adh} = 0$ for cohesive failure. Ext: *Extruded* products. Non-ext: *Non-extruded* products.

To sum up, extrusion significantly affected the viscoelasticity of all the products (except P11). This was accompanied by changes in adhesive properties for some products. The failure modes of six products (P1, P5, P8, P9 and P13) changed significantly. These products became more cohesive and left less adhesive surface. One product (P2) became less adhesive to the surface once it was extruded.

5.4.2. Products discrimination: Extruded versus Non-extruded

Now that the effects of extrusion on both rheological and adhesive properties have been investigated for each product we are interested in comparing the product map and the products positioning in relation to each other.

The ANOVA and PCA on *Non-extruded* products showed that the products can be best discriminated based on the G'_{10} , $\tan \delta_{10}$, γ_s , σ_s , $F_{penetro}$, F_{max} , d_{Fmax} , E , E_{Fmax}/E , Res factors. However, for *Extruded* products these factors were: G'_{10} , $\tan \delta_{10}$, γ_s , σ_s , η^*_{10} , F_{max} , d_{Fmax} , E , E_{Fmax}/E , t_{mi-rel} . It can be seen that the $F_{penetro}$ is replaced by complex viscosity η^*_{10} and Res is replaced by t_{mi-rel} for discriminating the *Extruded* products.

A GPA was then carried out on both data sets. The product configuration of *Non-extruded* products versus *Extruded* is depicted in Figure 70. The results show that the projections of configurations of *Extruded* and *Non-extruded* products coincide well on both axis 1 and 2 with a few exceptions.

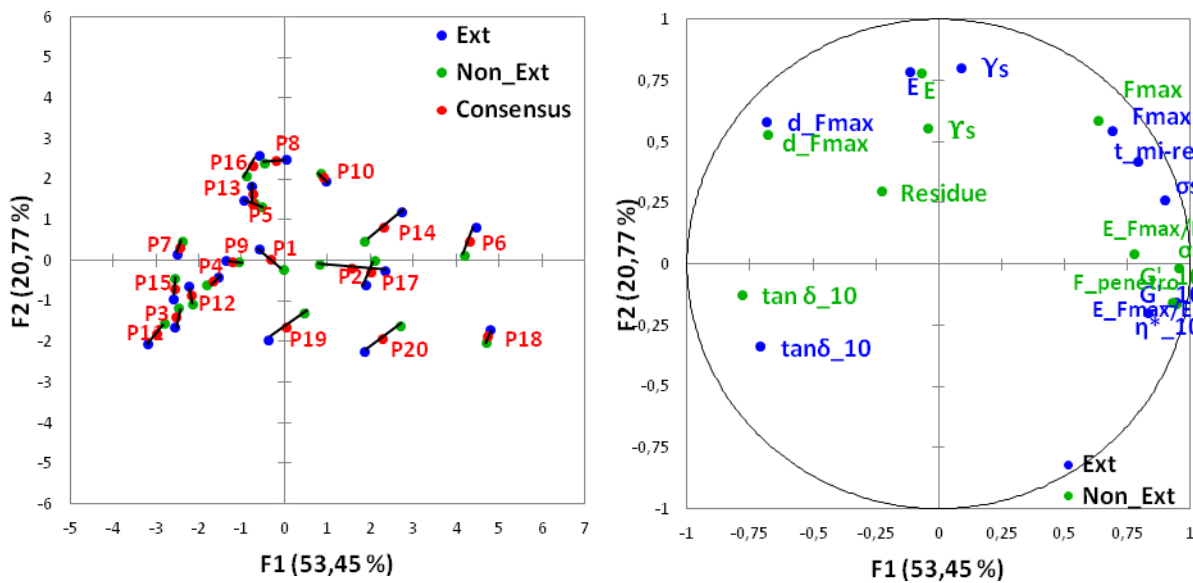


Figure 69: Results of the GPA comparing the product characterizations by instrumental methods at two physical states (*Non-extruded* versus *Extruded*). Representation superimposed the 20 consensual (●) products and partial products characterized at *Non-extruded* state (●) and *Extruded* state (●) on the first two components.

On axis 1, the projection of configurations of P2 was the main change. This product is better discriminated after extrusion on the axis 1 according to its rheological properties and its debonding behavior (adhesive failure). For 6 products (P1, P6, P14, P17, P19, P20) the projection changed slightly on both axis 1 and 2. Although, the rheological properties of these products changed, their failure modes stayed similar. The changes in adhesive properties of these products were basically related to maximum tensile force that is related to rheological characteristics. This shows that extrusion changed mainly the rheological properties rather than the adhesive properties of these products. The reason for differences on adhesive properties being less important could be explained by the fact the *Non-extruded* products were manipulated during the implementation whereas the dynamic characterization was performed on the products at-rest.

We can thus conclude that the products positioning coincide well before and after extrusion except for 7 products. The main differences were related to configurations of these 7 products (P1, P2, P6, P14, P17, P19, P20) that were mainly more consistent and structured. The rheological and adhesive characteristics of these products significantly changed after extrusion. This shows that the perception of these products can possibly change based on the way panelists evaluate the product. Overall, the results show that the differences between the products are more important than their structure changes under different level of deformations. Hence, in the rest of the study the map for *Non-extruded* products will be taken for instrumental characterization.

6. Conclusion

Rheological measurements in addition to tack measurements were selected and applied in order to characterize the products texture according to the sensory evaluation. The pertinent physical factors were identified for the entire set as well as the three distinct sub-sets after the tack test.

Ten parameters were identified based on the two methods for products discrimination over the entire set: " G'_{10} , $\tan \delta_{10}$, γ_s , σ_s and $F_{penetro}$ " from rheological tests and " d_{Fmax} , F_{max} , E , E_{Fmax}/E and Res " from the tack test. Among the identified variables, G'_{10} , $\tan \delta_{10}$, γ_s , σ_s and $F_{penetro}$ are the variables that were sought to characterize the 3 identified categories of terms "Firmness, Elasticity, Fluidity", Figure 70. Moreover, based on preliminary characterization of our products they can potentially explain the category "Spreadability". The parameters obtained through the tack test were sought to characterize the identified "Adhesive, Cohesive" categories. Moreover, based on the results and the correlation among the identified parameters after instrumental characterization, some tack factors can potentially characterize the "Spreadability, Fluidity and Firmness" categories. In the same way, some rheological factors give information on the "Adhesion" category.

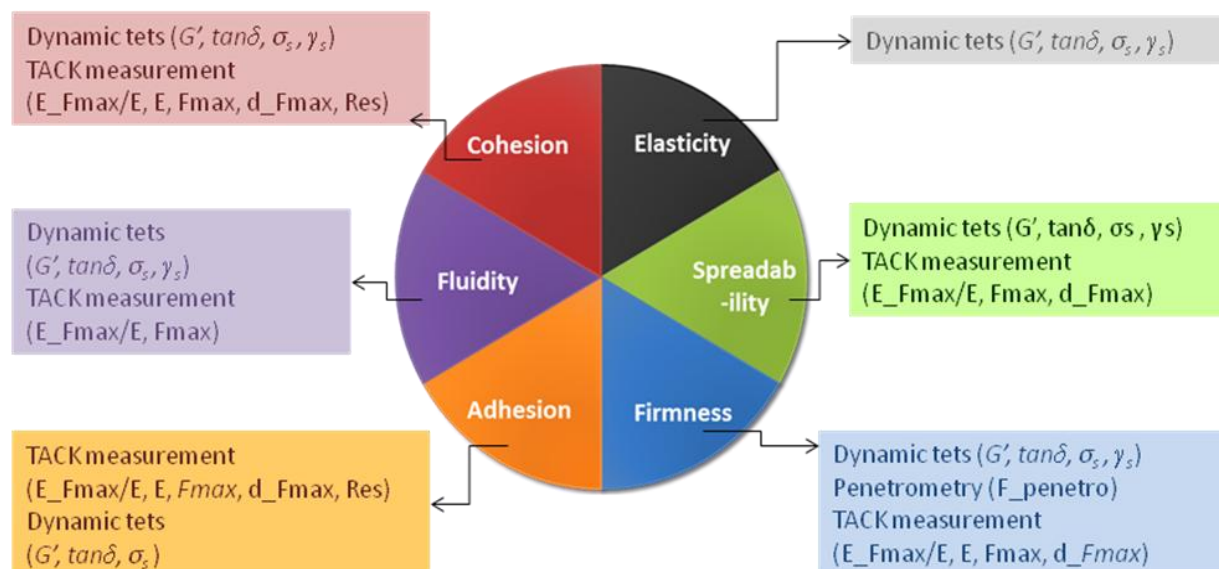


Figure 70: The identified parameters for characterization of the identified categories based on sensory results.

It is projected that combination of both rheological and tack techniques could provide richer information and improved the products distribution in instrumental map. The products with adhesive failure were opposed to products with cohesive failure based on their ratio of energies (E_{Fmax}/E) and distance at F_{max} (d_{Fmax}). These factors represent the deformability of the products and were highly correlated to rheological properties. The more consistent products resisted more to deformation and had a higher ratio of energies (adhesive failure). On the other hand, the total energy (E) brought further information for discrimination of the products with adhesive-cohesive failure. Hence, it takes both adhesive and cohesive properties into account. This factor was not associated to any rheological factors.

The characterization of sub-sets with different failure behaviors showed that the same rheological parameters can be used to discriminate the products in each sub-set (G' , $\tan \delta$ and γ_s). However, the best factors to discriminate the products after the tack test changed for each product subset. The total energy (E) is reported in literature as a factor of adhesiveness when a pure adhesive failure takes place. For our product set, the total energy represented the adhesive property for adhesive sub-set, the adhesive and cohesive properties for products with adhesive-cohesive rupture. However, for the cohesive sub-set it is not easy to fully explain this energy. It can include possibly both adhesive and cohesive properties as well as the deformation. **The total energy was not a common factor between the sub-sets for adhesive characterization. Instead, the ratio of energies (E_{Fmax}/E) seems to be a good factor when we have a product set with failure modes varying from adhesive to cohesive. This factor was in common among the sub-sets and over the entire set. This factor represents the product behavior during the debonding phase. It also brings information about failure mode as it was highly correlated to adhesive surface.**

Finally, comparing the characterization of the products with different physical states was done to take into account the differences that were observed in sensory evaluation of the products. The instrumental characterization of the *Non-extruded* versus *Extruded* products showed that:

Even though the products have been characterized differently, the products spaces stayed globally the same. Some slight differences were observed for 7 products related mainly to their initial properties. The similar positioning of the products before and after extrusion shows that the products differences dominate their structure changes under different levels of deformation.

In brief:

- The combination of both rheological and tack techniques provided richer information and improved the products distribution in instrumental map.
- The 10 identified parameters for product characterizations after the two methods were: " G'_{10} , $\tan \delta_{10}$, γ_s , σ_s and $F_{penetro}$, d_{Fmax} , F_{max} , E , E_{Fmax}/E and Res ".
- In our study, ratio of energies (E_{Fmax}/E) seems to be a good factor to characterize a product set with failure modes varying from adhesive to cohesive rather than the total energy (E). This factor was in common among the product subsets and over the entire set. It represents the product behavior during the debonding phase and gives information on the deformation capacity. It was also highly correlated to adhesive surface and hence is a good indicator of the failure modes.
- Comparing the characterization of the products with different physical states resulted in similar products spaces with some differences on the map for 7 products related mainly to their initial properties. Hence, in the rest of study we only consider the product map for *Non-extruded* products into account since it is easier and faster to obtain.

Part 6: Correlation study

In the present work, we aimed at characterizing textural properties of 20 model processed cheeses without tasting. The product sensory map was achieved based on key characteristics using the Flash Profile by two panels (consumers and experts). In order to find instrumental alternatives and obtain information correlated to the sensory evaluation of key characteristics, a series of instrumental tests were selected, based on the sensory results, and performed.

In this part, the relationships between sensory and instrumental data are sought in two ways: First, the link between the differentiating terms and the instrumental variables is studied by the calculation of Pearson's correlation coefficients. Two limit levels of significance $p \leq 0.05$ and $p \leq 0.01$ were used to study the correlation. Second, the sensory and instrumental maps are compared using Generalized Procrustes analysis (GPA).

Once the correlation between both measurements is studied, the possibility of predicting the key sensory perceptions through instrumental variables is investigated using the (multiple) linear regression.

Therefore, this part consists of 3 main sections: The results of correlation study for the consumer panel followed by the results for the expert panel and finally investigation of sensory predictions through instrumental factors.

1. Sensory-Instrumental correlation study

1.1. Relationship between sensory and instrumental data: consumers

In sensory analysis, as no common vocabulary was set, the semantic interpretation consisted in grouping the attributes that were used to differentiate the groups of products in a similar way by means of a cluster analysis. Table 31 summarizes the relationship between the sensory attributes, used at least by 10% of consumers in the same way, and the instrumental factors based on the Pearson's correlation coefficient.

Table 31: Pearsons' correlation coefficients between instrumental and sensory averaged data for group of terms after HCA on consumers' characterizations. (++) positive significant correlation at $p \leq 0.01$, (- -) negative significant correlation at $p \leq 0.01$. (+) positive significant correlation at $p \leq 0.05$, (-) negative significant correlation at $p \leq 0.05$.

Consumers' characterization: Key discriminating attributes			Rheological parameters					Tack parameters				
Segments (S)	Terms	Number of citation	Ys	σ_s	$\tan \delta_{10}$	G'_{10}	F_penetro	d_Fmax	Fmax	E	E_Fmax/E	Res
S1: Claire-Blanc (18 terms)	Claire Blanc	6		-		-	-		-			
S2: — (20 terms)												
S3: Brillant (26 terms)	Brillant	17		--	++	--	--		--		-	
S4: Tartinable-Collant-Crémeux (66 terms)	Tartinabilité	15		--	+	--	--	++	-		--	
	Collant	14		--	++	--	--	++	--		--	
	Crémeux	11		--	+	--	--	+	--		--	
S5: — (21 terms)												
S6: Jaune (27 terms)	Jaune	10										
S7: Dur-Compact (64 terms)	Dur	11		++	--	++	++	--	++		++	
	Compact	8		++	--	++	++	-	++		++	

It can be noted that in Table 31, the differentiating attributes related to the texture of the products (S4 and S7) are significantly correlated with both rheological and tack parameters. The “Segment 7” summarized by “Dur-Compact” is positively correlated to rheological factors (G'_{10} , F_{penetro} , σ_s) and tack factors (F_{max} , $E_{F_{\text{max}}}/E$). However, it is inversely-correlated to phase angle ($\tan \delta_{10}$) and the distance corresponding to the maximum tensile force ($d_{F_{\text{max}}}$). The result was opposite for the “Segment 4” that is summarized by “Tartinabilité–Collant–Crèmeux” notions.

This shows that the rheological properties and the tackiness properties related to the beginning of probe upward movement (F_{max} and $d_{F_{\text{max}}}$) are merged to some extent for characterizing the sensory perceptions of *Firmness*, *Spreadability*, *Creaminess* and *Stickiness*.

It can be noted that even if the dynamic rheological conditions (in small deformation) is far from what happens while handling the products, the dynamic factors are highly correlated to “Dur-Compact” and inversely-correlated to “Tartinabilité–Collant–Crèmeux” attributes.

This result is in good agreement with several studies that found correlation between the fundamental rheological properties and *Firmness* perception (Brighenti et al., 2008; Brown et al., 2003; Drake et al., 1999b,c; Rogers et al., 2009). Brighenti et al. (2008) in characterization of cream cheese reported a positive correlation between storage modulus (G') and the sensory perception “*Difficulty to spread*” and a negative correlation between (G') and sensory perception “*Stickiness*”. In a study on cheddar cheese, negative correlation was reported between the critical stress and strain and sensory *Adhesiveness*, (Rogers et al., 2009).

It can be noted that the visual perception “Brillant (shiny)” is highly correlated to instrumental variables. This correlation can be simply explained by the fact that in our product set, the majority of the products with lower level of concentrations were shiny. This characteristic was also highly correlated to *Creamy*, *Spreadable* and *Sticky* perceptions which can again explain the correlation reported. The light color “Clair” was also negatively correlated with instrumental factors. This could be due to the indirect correlation related to formulation and/or processing factors that leads to color variations rendering to these types of correlations. No correlation was found between the color-related terms like “Jaune, Blanc (Yellow, White)” and physical instrumental variables (S1 and S6, Table 31).

Another important point is that among the tack variables, the total energy of surfaces separation (E) that is reported in several studies as a good indicator of stickiness was not correlated to this perception **for our product set**. Previously, we explained that in the characterization of our product range with important texture variations, the total energy by itself is not sufficient for characterizing stickiness. Herein, we can note that *Stickiness* is related to the ratio of energies ($E_{F_{\text{max}}}/E$) rather than the total energy (E).

Furthermore, to assess the **correspondence between the sensory map and instrumental map**, a GPA was carried out on the both data sets.

The first three dimensions of GPA represent respectively 70%, 11% and 9% of the information, Figure 71.

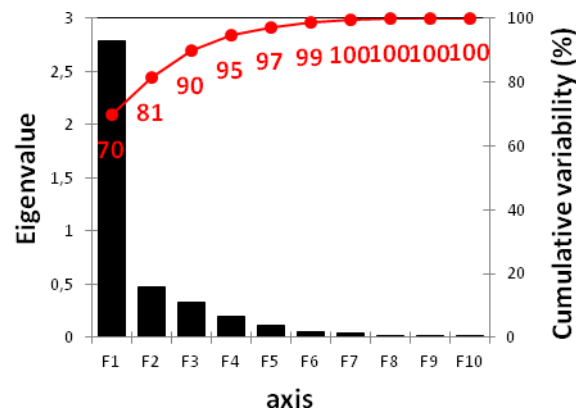


Figure 71: The cumulative variance for both sensory_instrumental approaches, GPA.

It can be seen that the product most similarly characterized through both approaches is P20, Figure 73. Six products (P6, P7, P10, P16, P18 and P19) are discriminated in the same way on the axis 1 by both characterizations, while their characterization on axis 2 differs. P10 and P18 are better discriminated on axis 2 by instrumental characterization rather than sensory perception. On the other hand, P4, P5 and P13 are discriminated similarly on axis 2 while their discrimination on axis 1 differs between sensory and instrumental analysis and they are better discriminated by sensory evaluation, Figure 73. Overall, the products configurations on the axis 1 coincide better than the axis 2.

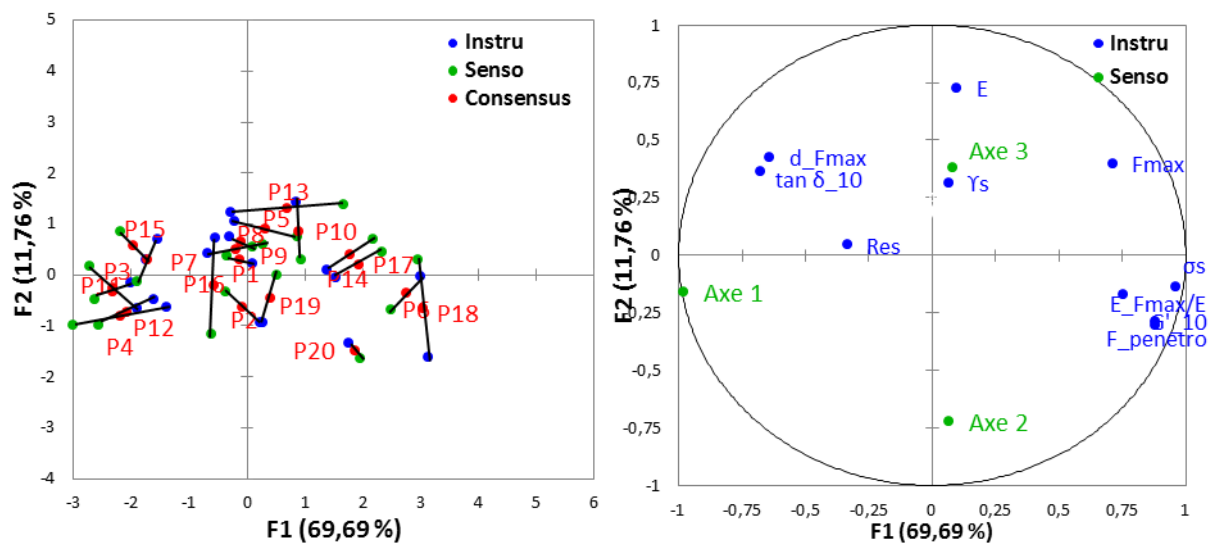


Figure 72: Results of the GPA plots (product map and attribute plot) of the instrumental and sensory data sets. Representation superimposed the 20 consensual (●) products and partial products characterized by the sensory (●) and by instrumental (●) on the first two components.

On the attribute biplot of the GPA, the “Axis 1” of the sensory evaluation that opposed the terms “Facile à Tartiner, Crémeux, Collant” (Segment 4, S4) to “Dur, Compact” (Segment 7, S7), is

positively correlated to ($\tan \delta$) and (d_{Fmax}). It is strongly inversely-correlated to yield stress (σ_s), storage modulus (G') and penetration force ($F_{penetro}$) as well as ratio of energies (E_{Fmax}/E) and F_{max} . The products that were more firm (higher G') and structured (lower $\tan \delta$) had higher tensile forces (F_{max}). These products were perceived as being harder, more compact, and less sticky, spreadable and creamy. Whereas the products that were more viscous and less structured, flow easier and therefore had lower tensile force. These products were perceived as being spreadable, sticky and creamy.

On the GPA, second component, “Axis 3” of the sensory characterization, representing 4.8% of sensory information, is positively correlated to F_{max} and E . However, the semantic interpretation of this sensory axis remained difficult. Sensory “Axis 2” is not significantly correlated to any instrumental factor. Finding no correlation for this sensory axis seems logical as the products were discriminated basically according to their visual characteristics (color-related terms) on “Axis 2” of sensory, whereas the instrumental variable on the second component of GPA was related to the mechanical properties of products (E). Assessing the correspondence between the instrumental and the sensory map based on **non-color-related terms** by GPA did not improve the correlation results and therefore the results are not presented. In fact, once the color-related terms were eliminated, the first axis represented 90% of information and the second axis only brought 6% of information. This can explain why eliminating the color-related terms did not improve the correspondence between the two maps, Figure 74. In addition, 2 instrumental variables (Res , γ_s) were not correlated to sensory attributes.

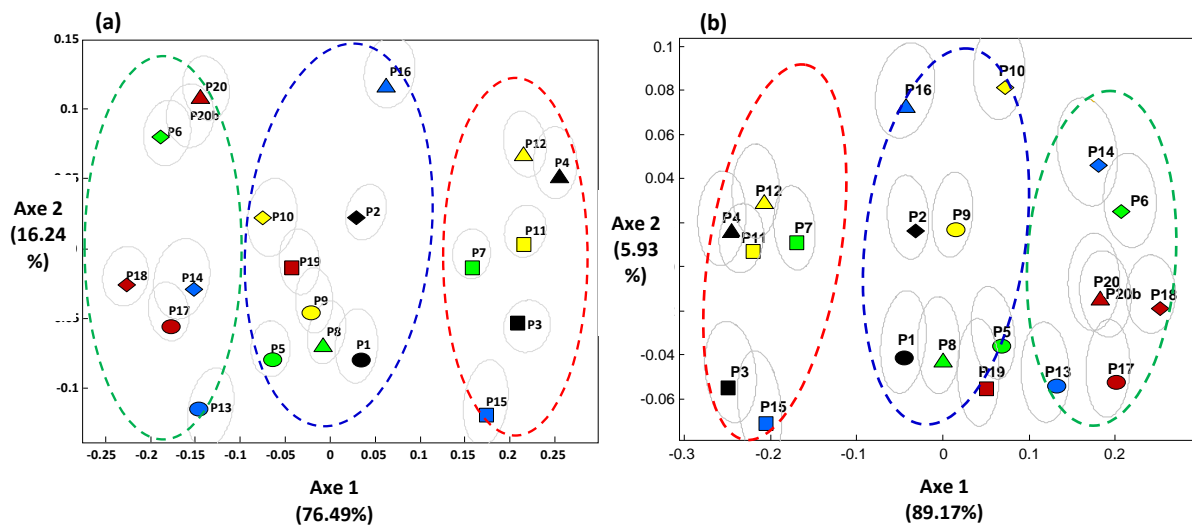


Figure 73: GPA result on all terms after consumers characterization (a). GPA result on non-color related terms after consumers' characterization (b).

1.2. Relationship between sensory and instrumental data: experts

The correlation between the experts sensory attributes after HCA and instrumental parameters were investigated using the Pearson's correlation in the same way as for the consumers (terms cited by at least 2 experts). Table 32 shows the summary of the results.

Table 32: Pearsons' correlation coefficients between instrumental and sensory averaged data for group of terms after HCA on experts' characterizations. (++) positive significant correlation at $p \leq 0.01$, (- -) negative significant correlation at $p \leq 0.01$. (+) positive significant correlation at $p \leq 0.05$, (-) negative significant correlation at $p \leq 0.05$.

Experts' characterization: Key discriminating attributes		Number of citation	Rheological parameters					Tack parameters				
Segments (all terms)	Terms		Ys	σ_s	$\tan \delta_{10}$	G'_{10}	F_penetro	d_Fmax	Fmax	E	E_Fmax/E	Res
S1: — (3 terms)												
S2: — (4 terms)	collant	1		+					++	++		
S3: — (3 terms)	collant	1	-									
S4: Tartinabilité (13 terms)	tartinable	5		--	++	--	--	++	--		--	
	brillant	3		--	++	--	--	++			-	
	collant	1		--		--	--		--		--	+
S5: — (4 terms)	Jaune	2										
	collant	1										
S6: Tranchable-Dur (14 terms)	dur	4		++	--	++	++	-			+	
	tranchable	3		++	--	++	++	--	++		++	
	ferme	3		++	--	++	++	--	++		++	
	facile d'etalement	2										
S7: Gélifié (7 terms)	Gélifié	2										

As it can be seen in the Table 32, the correlations are in good agreement with consumers' results for the same sensory attributes related to firmness and spreadability perceptions. The 4 experts had used the term “Collant (sticky)” as a key attribute. However, they did not use it in the same way and therefore no correlation was found for this term after experts' evaluation and instrumental variable. The individual evaluation of experts showed that only one expert used this term in a similar way as consumers. **The term “Gélifié” was only applied as a key attribute by experts, and no correlation was found between this perception and instrumental variable.**

The **correspondence between the experts' sensory map and the instrumental map** was also assessed by running a GPA on both data sets. The first three dimensions of GPA represent respectively 68%, 12% and 8% of the information, Figure 75.

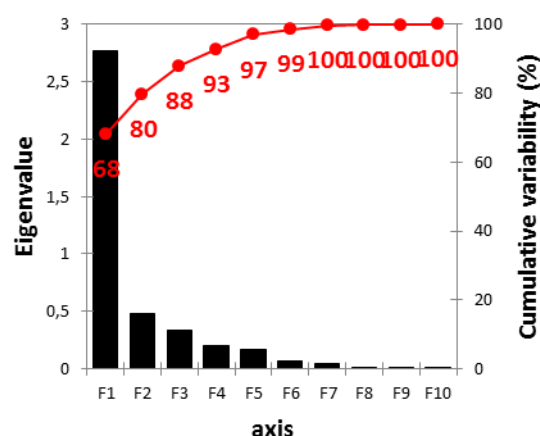


Figure 74: The cumulative variance for both sensory-instrumental approaches, GPA.

Figure 76 depicts the result of GPA on the two data sets. The global results stay similar to the one observed for the consumers. The positioning of two products (P4 and P13) is more different on axis 1, whereas five products (P8, P10, P14, P18 and P19) are more differently positioned on the axis 2, Figure 76.

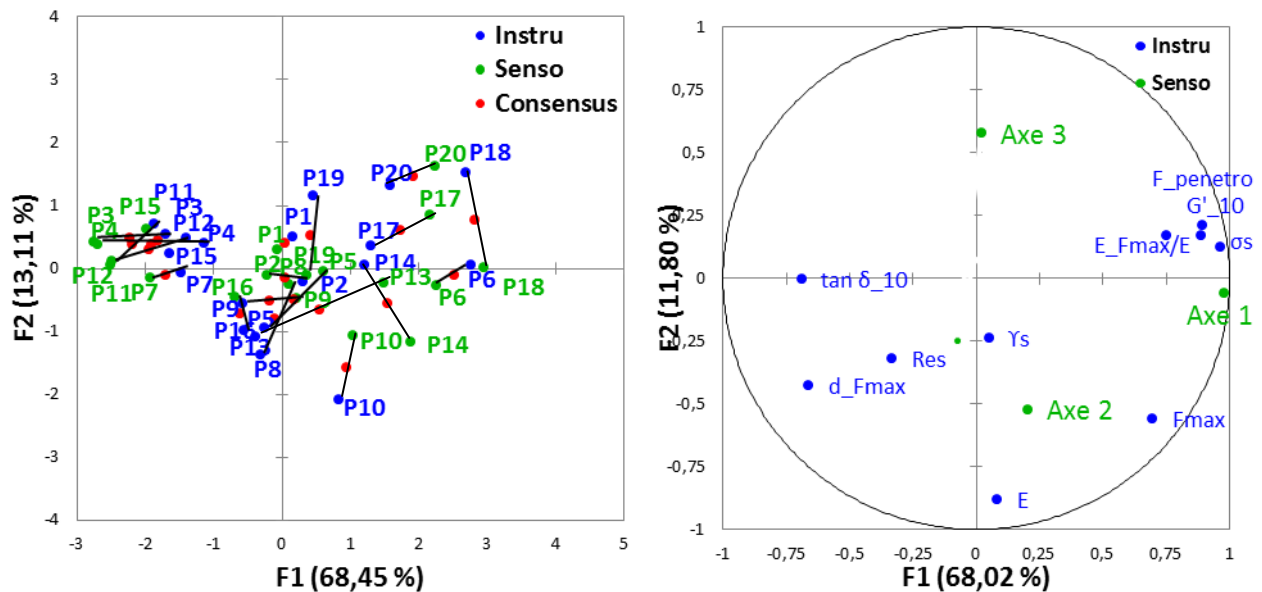


Figure 75: Result of GPA plots (product map and attribute plot) of the instrumental and sensory data sets. Representation superimposed the 20 consensual (●) products and partial products characterized by the sensory (●) and by instrumental (●) on the first two components.

On the first GPA component, “Axis 1” of the sensory evaluation that opposed the notion “Tartinable” (Segment 4, S4) to “Tranchable-Dur” (Segment 6, S6), is strongly correlated with the penetration force ($F_{penetro}$), ratio of energies (E_{Fmax}/E , F_{max}) and reverse-correlated to ($\tan \delta$) and (d_{Fmax}).

On the second GPA component, “Axis 2” of the sensory evaluation representing the attribute “Gélifié” was not significantly correlated to instrumental variables. Finally, “Axis 3” of sensory evaluation that presented only 5% of sensory information is correlated to instrumental variable (E). However, the interpretation of sensory “Axis 3” remained difficult. In the same way as for consumers, the instrumental variables (Res , Y_s) were not correlated to sensory attributes.

To sum up, for our product set, the correlation results of both consumers and experts showed that:

- On the 1st GPA axis, four rheological parameters (G' , $\tan \delta$, σ_s , F_{penetro}) and three tack parameters (E_{Fmax}/E , F_{max} , d_{Fmax}) are merged to some extent for characterizing sensory perceptions of “Axis 1” related to *Firmness* and *Spreadability* of the products. These factors were also related to for sensory perceptions of *Creaminess* and *Stickiness* for consumers.
- On the 2nd GPA axis, no correlation was found between the sensory perception of “Axis 2” and any instrumental variable for any of the panel. This sensory axis was related to visual characteristics for consumers and “Gélifié” characteristic for experts.
- Nevertheless, the 2nd GPA axis correlates the sensory “Axis 3” to the total energy (E). However, this sensory axis represented only a small percentage of information and remained difficult to interpret.

Hence, we can conclude that, the texture characterization of consumers was explained by only one axis which was highly correlated to rheological and tack factors. The consumer characterization was slightly different from experts’ characterization on the second axis which was relative to products texture for experts. However, no correlation was found between the extra characteristic “Gélifié” given by experts and instrumental factors. Hence, the products characterization directly through consumers would be sufficient and can be explained by identified instrumental factors.

2. Sensory prediction through instrumental characterization

One of the aims of this study was to predict sensory perceptions in general and especially the complex and multidimensional sensory ones such as “Collant”, through instrumental variables.

Multiple linear regression is used for prediction of sensory data. This technique attempts to model the relationship between two or more explanatory variables (X) and a response variable (Y) by fitting a linear equation to observed data.

Every value of the independent variable x is associated with a value of the dependent variable y . The population regression line for p explanatory variables (X) is defined to be:

$$Y = a + b_1X_1 + b_2X_2 + \dots + b_kX_k + e$$

Where Y is the dependent variable, X_1 , X_2 , X_k are the independent variables, a is the constant and b_1 , b_2 , b_k are the partial coefficients of regression, and e is the error. The coefficient of correlation is a measure of association enter X and Y , it varies between 1 (for a perfect positive correlation) and -1 (for a perfect negative correlation). The coefficient is equal to 0 when there is no linear relation between X and Y .

The sensory characterization showed that the first sensory axis represented the main information relative to texture differences perceived by consumers. Therefore, the prediction ability for this axis (Sensory “Axis 1” after consumers’ characterization) through the instrumental variables was

investigated. The most influential instrumental variables were also identified and their correlation with this the sensory “Axis 1” were evaluated.

Using the multiple linear regression method enabled establishing relations between the Sensory “Axis 1” and instrumental parameters.

$$\text{Sensory "Axis 1"} = f(\text{Instrumental parameters})$$

$$\text{Instrumental parameters} = G', \tan \delta, \gamma_s, \sigma_s, F_{\text{penetro}}, d_{\text{Fmax}}, F_{\text{max}}, E, E_{\text{Fmax}}/E, \text{Res}$$

Multiple linear regression yields a model to predict the sensory perception of consumers related to textural differences from the instrumental parameters. The model was determined by considering the data for all the model products. The first predictive model, including all 10 instrumental variables, gave a good adjustment ($R^2 = 0.90$) and p-value < 0.001. Table 33 summarizes the result for each independent factor.

Table 33: Coefficients of the general model Instrumental-Sensory for Sensory “Axis 1” (Consumers).

	A	σ_s	γ_s	G'_{10}	$\tan \delta_{10}$	F_{penetro}	d_{Fmax}	F_{max}	E	E_{Fmax}/E	Res
Coefficients	0,01	-0,25	0,00	0,13	0,01	0,01	0,04	0,03	-0,06	-0,02	-0,01
Standard error	0,01	0,08	0,02	0,08	0,02	0,07	0,02	0,04	0,04	0,05	0,02
Pr > F	0,53	0,01	0,89	0,13	0,67	0,91	0,10	0,55	0,15	0,67	0,72

It can be seen that several parameters did not have a significant effect on the model. Therefore, the model is simplified by removing the least significant factors one by one by through a backward elimination.

Table 34 shows the results for the main 4 instrumental factors that had significant effect in predicting the sensory “Axis 1”. The simplified predictive model presents a good adjustment ($R^2 = 0.93$) and a p-value less than 0.0001.

Table 34: Coefficients of the simplified model Instrumental-Sensory for Sensory “Axis 1” (Consumers).

Source	A	d_{Fmax}	E	G'_{10}	σ_s
Coefficients	0,01	0,04	-0,04	0,13	-0,243
Standard error	0,01	0,01	0,01	0,03	0,030
Pr > F	0,443	0,019	0,001	0,001	< 0,0001

One of the main results of Table 34 is that “Yield stress” is the most significant factor for predicting the sensory “Axis 1” and the model is mainly explained by this factor. Hence, a simple linear regression was carried out by taking only this factor into account.

The result show that the sensory “Axis 1” can be significantly modeled by “Yield stress (σ_s)” is the most important factor to the prediction ($R^2=0.82$, Figure 76).

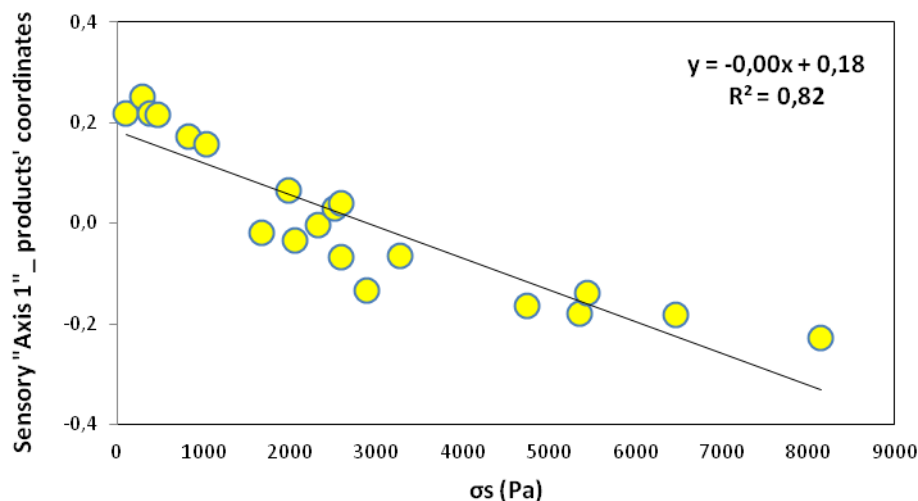


Figure 76: Yield stress versus sensory "Axis 1" based on consumer evaluations.

In brief: the sensory "Axis 1" is largely explained by rheological properties and the contribution of tack properties is less important. For this product range, performing the dynamic test using vane geometry gives important information on the main perceivable textural differences among products for consumers.

2.1. Sensory prediction of consumers perception relative to "Collant (Stickiness)"

Sensory evaluation of our product set by a consumer panel showed that the term "Collant" was most frequently cited by consumers for individual characterization of products. Also, it was the most cited texture-related key attribute for comparison of the products. As no common vocabulary was set, the definition of this term for each consumer is not evident. However, the HCA results showed that perception of "Collant" was relative to sensory "Axis 1" for consumers.

The correlation study showed that the consumers' averaged perception of "Collant" is inversely-correlated only to "E_Fmax/E, Fmax" and "d_Fmax" factors of tack measurements ($r = -0.74, -0.61, -0.64$). In addition, no clear correlation was found between the (E) and this perception. This result is not in agreement with the definition of stickiness which is defined as the energy of separating two contacting surfaces (Gay, 2002). Therefore, this raises a question: whether it is always appropriate to use the total energy of separation to evaluate sensory stickiness.

Nevertheless, the "Collant" perception and the rheological parameters showed a stronger correlation. The highest correlation was related to yield stress ($r = -0.93$). Figure 77 shows the relationship between the consumers' averaged data relative to "Collant" perception and "Yield stress".

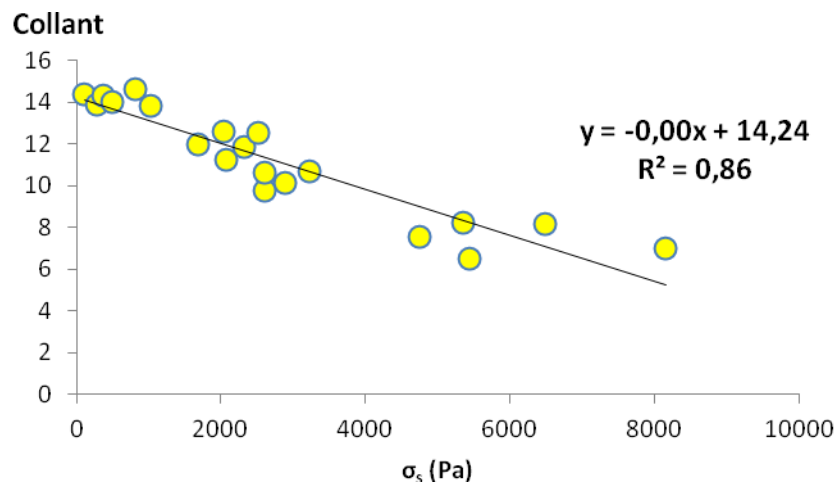


Figure 77: “Collant” perception (average ranking) in function of yield stress (σ_s), by consumers.

As demonstrated in Figure 77, “Collant” perception showed significant linear decrease with the increase of σ_s . This linear decrease shows that the products that flow easily are perceived as being more “Collant” by evaluation of consumers and the products that are more firm and resist to flow are perceived as less “Collant” for our product set.

This result was then investigated at individual level to see if this is applicable to the diversity of perception. Figure 78 shows the prediction of stickiness perception of each consumer as a function of yield stress.

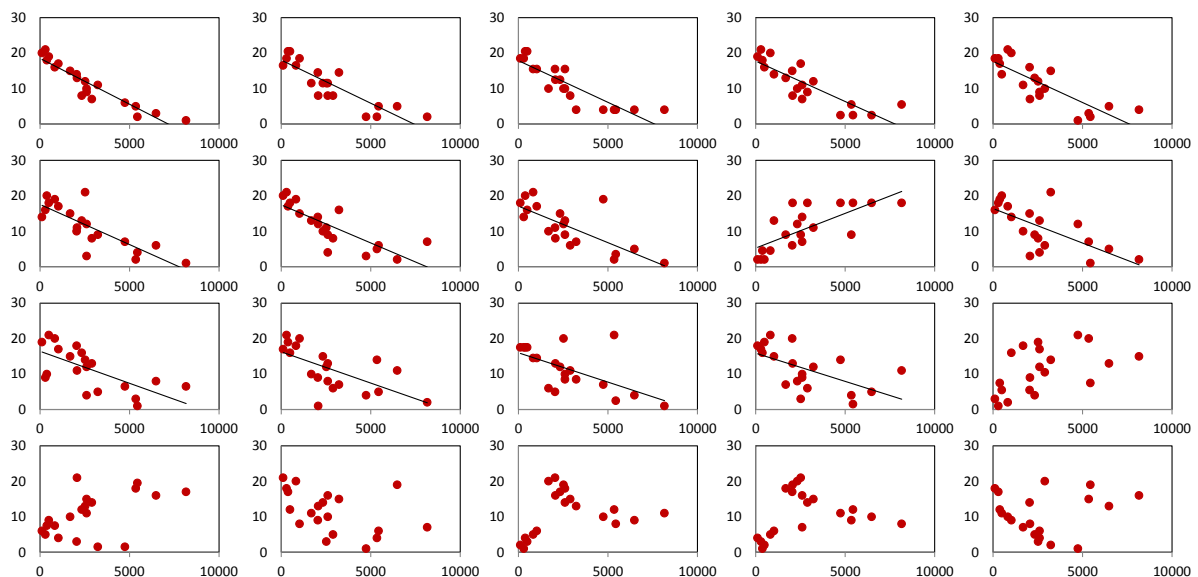


Figure 78: “Collant” perception in function of yield stress (σ_s) of each consumer.

The individual prediction shows that there is a linear relation between the yield stress and “Collant” perception of 2/3 of the consumers. However, for six consumers no relationship is identifiable. Therefore, “ σ_s ” is a good factor at average level and for the majority of the consumers

who used “Collant” as a key factor for comparing products. However, for 1/3 of consumers this correlation does not apply, Figure 78. This once again, shows evidence of the diversity of the perception and the importance of its investigation.

From a sensory point of view, in classical methods, “Collant” has been mainly considered as the required force to remove food adhering to a surface (Szczenial, 1963), or the tendency of food to adhere to the surfaces of contact (Jowit, 1974). While, from a physical point of view, “Collant” is generally defined as the adhesion force when two surfaces are in contact or the work of separation of the surfaces. However, there is no general consensus to be taken into account for the parameters and the forces which are involved in the notion of stickiness. For our product set, “Collant” can be characterized by the resistance of the product to flow for majority of the consumer who cited this term for their evaluation, whatever were their definitions for stickiness.

To sum up, the product characterization by consumers gave one main texture-related axis for product discrimination. This sensory axis was relative to “Dur, Compact, Tartinable, Collant, Crémeux”. Overall, the rheological properties (yield stress, storage module) are good indicators for the prediction of the main consumer perception of texture differences between the products.

In addition, the prediction of individual perception relative to “Collant” attribute also showed that yield stress can predict this attribute for the majority of the consumers.

Part 7: Conclusion and perspective

The objectives of this work were:

- **Characterize the texture of model processed cheese products** using a sensory **approach grasping diversity** in terms of product, evaluation procedure, perception and description. Additionally, the diversity in expertise on product evaluations was also investigated by using 2 panels for sensory evaluations (consumers & experts).
- **Selection of efficient instrumental methodologies and conditions to characterize the identified perceptions.** Then, running the instrumental characterization of products using the selected methods and conditions.
- Predict the identified sensory perceptions, in particular the multidimensional ones, by instrumental factors.

A set of model processed cheese (without fat) with various textures were fabricated according to an experimental design and provided by the Supplier Company as a support for this study. The preliminary study on texture perception of products, using three-step sorting, led to the same groupings of products by In-hand and In-mouth evaluations. Hence, for this product set, texture sensory characterization was simplified to visual and In-hand evaluations to eliminate the possible bias related to the taste of the products.

In the sensory part of the study, the combined approach of free comment method following a Flash Profile method was applied using consumer and expert panels. This approach enabled us to investigate the diversity in terms of methodologies (one panelist–one product interaction as well as one panelist–several products interactions), conditions, evaluation procedures, descriptions as well as the level of expertise.

Concerning the products discriminations, 4 product maps after both sensory approaches by the two panels (2 from consumer panel and 2 from expert panel) were obtained. **Important differences were observed between the product maps from consumers and experts using the free comment method.** However, the resulting sensory maps after Flash Profile were very similar between the two panels. Moreover, comparing the sensory maps from both approaches (monadic versus comparative) showed that the resulting maps from Flash Profile were close to the consumers' map from the free comment method. In fact, the free comment approach revealed the important differences of perceptions between consumers and experts in monadic characterization that were related to prior expertise. This could be explained by the different evaluation methods since memory is not involved in the same manner. This shows that the effect of prior expertise on product characterization could be more pronounced in monadic characterization of products. This could be related to the fact that the expert panel gave very detailed characteristics of each product that are probably not relevant to consumers. **On the contrary, in the comparative study as the expert panel focused on important discriminative characteristics, which were more similar to those characteristics relevant to consumers, the resulting product maps were very similar.** This shows that working with experienced panelists could lead to a risk of losing part of the information related to consumers' perceptions especially through a monadic characterization.

Concerning the explicative attributes, free comments with a frequency-based method provided us with a glossary of consumer terms and very detailed consumer-derived descriptions of each product.

This approach put in evidence the differences of terminology and products characterizations related to differences between two panel's expertise. **The free comment method revealed that the experts cited a greater number of terms than consumers with more consistently. However, some frequently applied terms by experts were never cited by consumers.** This can be explained by two reasons: either the experts evaluated characteristics that were not relevant to consumers or they used more technical attributes that are not applied or known by consumers. Also, the free comment approach revealed differences in applying similar term relative to "Compact" perception between the two panels. This term was used more freely by consumers to characterize 12 products while experts used this term more specifically for 2 products.

The free comment approach is a good method to investigate the differences of terminology between the consumers and experienced panelists. On the other hand, using Flash Profile revealed interesting extra information on the characteristic that can become important based on the differences in methodology (monadic versus comparative approach). Additionally, some differences in terms of explicative terms of sensorial maps between the two panels were identified. For example, the first axis in sensory characterization after Flash Profile was relative to attribute "Collant" for the consumers. However, the experts did not use this term in a similar way for products evaluations.

Furthermore, including the diversity of personal choices in testing conditions revealed that despite the large variation between the testing conditions among assessors, the differences are product-dependent rather than panelist-dependent. In fact, the differences between the products were predominant over the differences in evaluation conditions.

Hence, we can conclude that if the objective is to maintain product positioning based on consumers' perceptions and descriptions, we can obtain quickly a solid positioning of products based on the characteristics that are relevant and important for consumers through Flash profile. However, if the objective is to study the consumers' terminology and the characteristics perceivable to them for products discrimination, the combined method (monadic + comparative) gives a rich insight of the characteristics that are relevant and/or important as well as the characteristics that can become important depends on the way they approach the products. **This approach allowed us to achieve our first objective which was characterizing the products through a sensory methodology that includes diversity.**

Another originality of this study consisted in basing the instrumental evaluations on the sensory results. Therefore, sensory description and observations were taken into account to govern the choice of the method and conditions for instrumental characterizations. Investigating the explicative terms for product discrimination resulted in 6 different categories representing the different physical behavior of products. Two approaches were selected for instrumental characterizations: rheological methods for general characterization and tack method for adhesive characterization of products since the stickiness characteristics was important for products discrimination. The main advantage of this strategy was to bring together the free descriptions to physical factors that possibly would be efficient to predict the corresponding sensorial perceptions. Moreover, it helped us to identify the conditions for product implementation and instrumental tests closer to sensorial conditions. For example, based on sensory observations, we decided to evaluate the products at two different physical states (*Non-Extruded* and *Extruded* products). Through this strategy two instrumental methods were carried out: the rheological and tack measurements.

Ten physical variables were identified for products discrimination over the entire set: “G’₁₀, tan δ_{10} , γ_s , σ_s and F_{penetro}” from rheological tests and “d_{Fmax}, F_{max}, E, E_{Fmax}/E and Res” from tack test. The instrumental characterization of products based on the selected factors indicated that **the combination of both rheological and tack techniques could provide richer information and improve the products’ distribution on the instrumental map. The tack test brought an extra dimension for product discrimination that was not correlated to any rheological factors related to total energy (E).**

Applying the tack method using a predefined distance made it possible to apply this methodology over a product range with important textural diversity (solid, semi-solid and liquid). Among the tack factors, ratio of energies (E_{Fmax}/E) and distance at F_{max} (d-F_{max}) represented the deformability of the products and were highly correlated to rheological properties. These factors opposed the products with adhesive failure to products with cohesive failure. On the other hand, the total energy (E) brought further information on another component and discriminated mainly the products with adhesive-cohesive failure. The total energy of separation is reported in literature as a factor of adhesiveness. However, for our product set with important texture diversity, it took both adhesive and cohesive properties into account. Hence, for our product set, **the ratio of energies (E_{Fmax}/E) seems to be a better factor for characterization of products ranging from adhesive to cohesive failures.**

On the other hand, comparing the characterization of products at different physical states was done to take the differences that were observed in sensory evaluation of products into account. **The similar configurations of the products before and after extrusion showed that the product differences dominated their structure changes under different level of deformations at instrumental level.**

The results showed that combining the two instrumental methods, based on the sensory results, made it possible to achieve a new instrumental dimension for product characterization related to tack measurement. In addition, it improved the product positioning on instrumental map compared to the resulting map after each method. Hence, our strategy made it possible to achieve our second objective which was improving the instrumental characterization based on the sensory evaluation results.

The correlation study between the sensory and instrumental characterizations highlighted that:

There were significant relationships between the sensory terms relative to “Dur, Compact, Tranchable, Collant, Tartinable, Crémeux”, explaining the product maps, and the instrumental variables. The rheological properties and the tackiness properties were combined to some extent for characterization of these identified sensory perceptions related to texture. The correlation results for consumers and experts were in good agreement for the same sensory attributes relative to *firmness* and *spreadability* perceptions. However, the term “Gélifié” that was only applied by expert panel and explained the second sensory component of their sensory map (Flash Profile) was not correlated to any instrumental variables. On the other hand, the *stickiness* perception of consumers was related to both rheological and tack parameters. However, the experts did not use this term in the same way, and therefore no correlation with instrumental variables was found for the term “Collant”.

The prediction study showed that combining the tack and rheological factors gave more precise model for predicting the consumers’ perception. However, rheological measurement can be

sufficient to predict in general the sensory “Axis 1”. In fact, even though the tack test was applied to characterize the perceptions relative to *stickiness* and brought interesting information on instrumental characterization of products, the textural differences of products is highly influenced by their rheological properties. Yield stress can largely predict the sensory “Axis 1” as well as *stickiness*.

The results show that, for our product set, dynamic characterization of products using vane geometry made it possible to easily characterize the products. The yield stress obtained from viscoelastic measurements is a good factor for predicting consumers’ perceptions in general as well as for the complex perceptions relative to *stickiness*. This factor predicted *stickiness* perception of the majority of the consumers who evaluated the product based on this character. However, it is worth noting that this perception for one third of the consumers stayed unpredictable. This shows the variety of perceptions that could be related to differences in definition or perception of this characteristic. **In conclusion, we reached our goal to predict the main texture-related sensory data through instrumental characterization. Furthermore, we partially achieved to predict the complex perceptions such as stickiness by an instrumental factor for the majority of consumers who applied this term in their evaluations.**

Finally, our strategy to start the product characterization from sensory evaluation and determining the efficient instrumental methodologies and conditions based on the sensory results led to improving the instrumental product map and obtaining further information regarding the factors that can possibly vary among the products. This result can ultimately help the formulators/developers to better master the product fabrication. However, the prediction study showed that the main differences among the products can be easily explained by running the rheological test at small deformation upto the non-linear region. Moreover, the rheological characterization at small deformation using vane geometry makes it possible to evaluate a range of products with important textural differences.

In terms of perspectives and in the continuity of this work, a number of points remain to further investigate:

- Evaluate the products stickiness using a greater number of consumers in order to validate the result.
- Validate this approach on another product range -commercial products- close to the supplied product range and study the in-mouth characterization of products. The in-mouth sensory characterization is essential for commercial products and allows avoiding the problems of model products regarding their taste.
- Apply the approach on a range of product with less difference. This with the aim of investigating if the consumers can discriminate between the products with the less varied textures?
- In terms of sensory characterization, it seems interesting to investigate terms such as “Compact” that were used differently between both panels.
- It would be relevant to fabricate a range of products by working on ingredient and/or process variables in order to obtain products with more variations in terms of total separation energy (E: represented on second instrumental axis) values. Then, they could be characterized through sensory evaluation to investigate if any differences would be perceivable and could be described.

- It would be interesting to validate this approach for other product sets or commercial products, presenting possibly less important sensory differences than in our study. This approach could also be used for other sensory modalities (texture in mouth, taste, smell).

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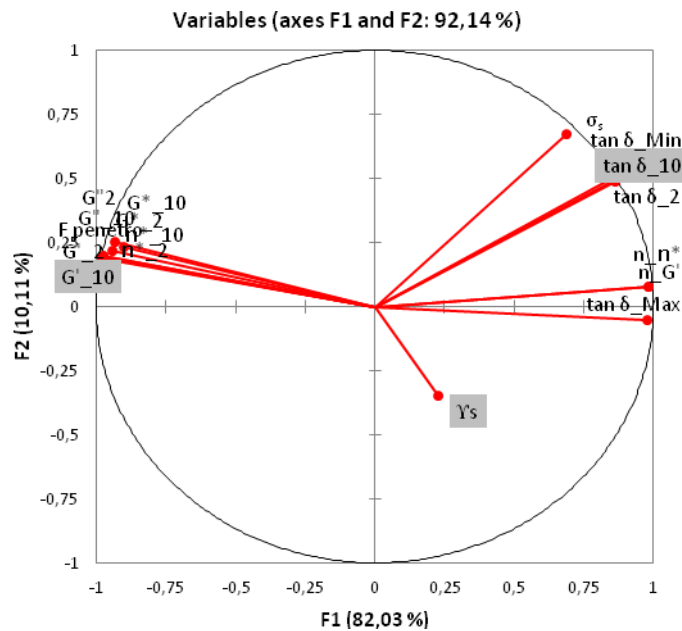
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Appendices

In this part the preliminary PCAs for selection of the rheological and tack parameters for characterization of the three identified sub-sets after tack test are presented. The highlighted factors in correlation circle are pre-selected.

Appendix 1: Preliminary PCA on rheological factors on Adhesive sub-set

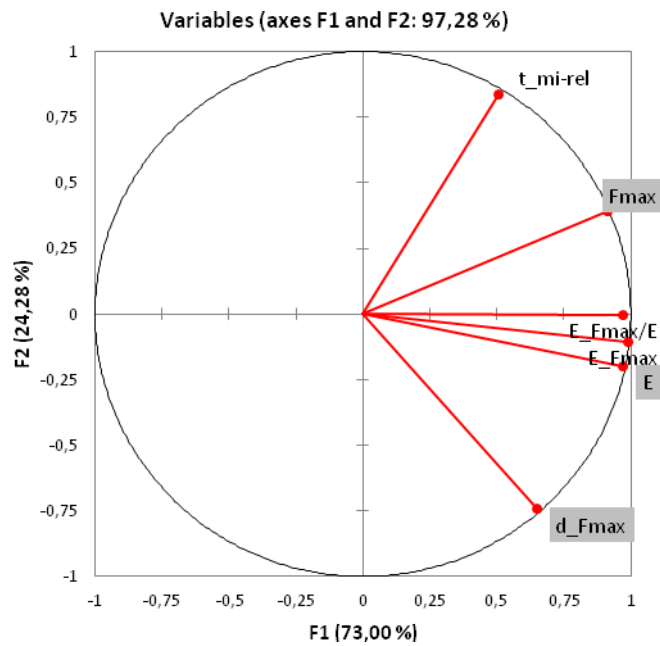


Correlation matrix (Pearson (n)):

Variables	σ_s	Y_s	G'_{10}	$\tan \delta_{10}$	$\tan \delta_{Max}$	η^*_{2}	$\tan \delta_{2}$	G''_2	G''_{10}	$n_{G'}$	$\tan \delta_{Min}$	G'_2	n_{η^*}	η^*_{10}	G^*_{2}	G^*_{10}	F penetro
σ_s	1,00																
Y_s	0,10	1,00															
G'_{10}	-0,53	-0,22	1,00														
$\tan \delta_{10}$	0,91	0,05	-0,75	1,00													
$\tan \delta_{Max}$	0,66	0,36	-0,95	0,81	1,00												
η^*_{2}	-0,53	-0,23	1,00	-0,75	-0,95	1,00											
$\tan \delta_{2}$	0,92	0,02	-0,74	1,00	0,81	-0,75	1,00										
G''_2	-0,49	-0,11	0,98	-0,68	-0,91	0,97	-0,69	1,00									
G''_{10}	-0,45	-0,05	0,94	-0,63	-0,87	0,93	-0,64	0,99	1,00								
$n_{G'}$	0,74	0,31	-0,93	0,89	0,99	-0,93	0,89	-0,88	-0,84	1,00							
$\tan \delta_{Min}$	0,92	0,01	-0,75	0,99	0,82	-0,75	1,00	-0,70	-0,66	0,89	1,00						
G'_2	-0,54	-0,24	1,00	-0,76	-0,95	1,00	-0,75	0,97	0,93	-0,93	-0,75	1,00					
n_{η^*}	0,74	0,31	-0,93	0,89	0,99	-0,93	0,89	-0,88	-0,83	1,00	0,89	-0,93	1,00				
η^*_{10}	-0,53	-0,22	1,00	-0,75	-0,95	1,00	-0,74	0,98	0,94	-0,93	-0,75	1,00	-0,93	1,00			
G^*_{2}	-0,53	-0,23	1,00	-0,75	-0,95	1,00	-0,75	0,97	0,93	-0,93	-0,75	1,00	-0,93	1,00	1,00		
G^*_{10}	-0,53	-0,22	1,00	-0,75	-0,95	1,00	-0,74	0,98	0,94	-0,93	-0,75	1,00	-0,93	1,00	1,00	1,00	
F penetro	-0,45	-0,36	0,96	-0,71	-0,92	0,96	-0,69	0,88	0,82	-0,91	-0,69	0,97	-0,91	0,96	0,96	0,96	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 2: Preliminary PCA on tack factors on Adhesive sub-set

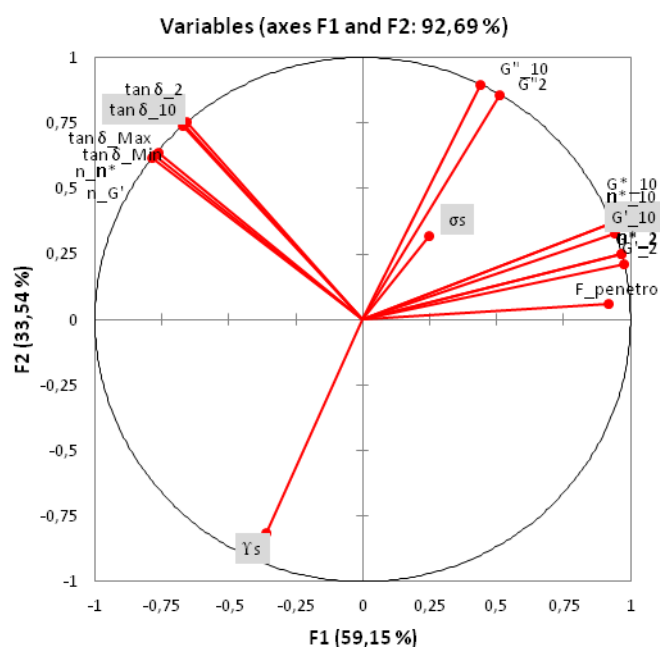


Correlation matrix (Pearson (n)):

Variables	d_Fmax	Fmax	E_Fmax	E	E_Fmax/E	t_mi-rel
d_Fmax	1,00					
Fmax	0,29	1,00				
E_Fmax	0,72	0,86	1,00			
E	0,78	0,80	0,99	1,00		
E_Fmax/E	0,62	0,90	0,94	0,92	1,00	
t_mi-rel	-0,26	0,77	0,42	0,34	0,46	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 3: Preliminary PCA on rheological factors on Adhesive-Cohesive sub-set

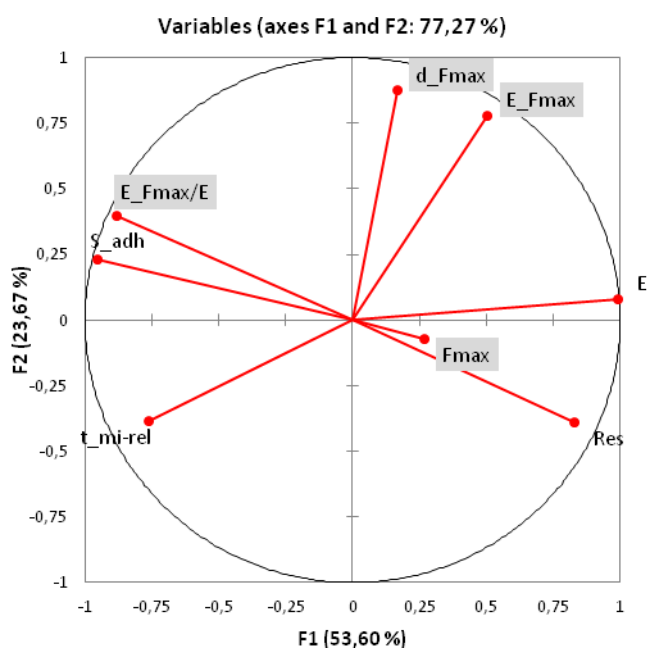


Correlation matrix (Pearson (n)):

Variables	σ_s	γ_s	G'_{10}	$\tan \delta_{10}$	$\tan \delta_{Max}$	η^*_2	$\tan \delta_2$	G''_2	G''_{10}	$n_{\eta'}$	$\tan \delta_{Min}$	G'_2	n_{η^*}	η^*_{10}	G^*_{10}	G^*_{10}	$F_{penetro}$
σ_s	1,00																
γ_s	0,06	1,00															
G'_{10}	0,31	-0,62	1,00														
$\tan \delta_{10}$	0,07	-0,36	-0,38	1,00													
$\tan \delta_{Max}$	0,11	-0,20	-0,51	0,98	1,00												
η^*_2	0,29	-0,56	1,00	-0,46	-0,58	1,00											
$\tan \delta_2$	0,11	-0,34	-0,39	1,00	0,99	-0,47	1,00										
G''_2	0,39	-0,88	0,76	0,30	0,16	0,71	0,29	1,00									
G''_{10}	0,36	-0,90	0,71	0,37	0,23	0,65	0,37	1,00	1,00								
Pente G'	0,06	-0,20	-0,53	0,98	1,00	-0,60	0,99	0,14	0,22	1,00							
$\tan \delta_{Min}$	0,08	-0,38	-0,37	1,00	0,98	-0,45	1,00	0,31	0,39	0,98	1,00						
G'_2	0,28	-0,54	0,99	-0,49	-0,61	1,00	-0,50	0,68	0,62	-0,63	-0,48	1,00					
Pente η^*	0,03	-0,20	-0,54	0,98	1,00	-0,61	0,99	0,13	0,21	1,00	0,98	-0,64	1,00				
η^*_{10}	0,32	-0,65	1,00	-0,35	-0,48	0,99	-0,35	0,79	0,74	-0,49	-0,33	0,99	-0,50	1,00			
G^*_{10}	0,29	-0,56	1,00	-0,46	-0,58	1,00	-0,47	0,71	0,65	-0,60	-0,45	1,00	-0,61	0,99	1,00		
G^*_{10}	0,32	-0,65	1,00	-0,35	-0,48	0,99	-0,35	0,79	0,74	-0,49	-0,33	0,99	-0,50	1,00	0,99	1,00	
$F_{penetro}$	0,55	-0,24	0,87	-0,57	-0,62	0,89	-0,56	0,51	0,44	-0,66	-0,56	0,89	-0,67	0,86	0,89	0,86	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 4: Preliminary PCA on tack factors on Adhesive-Cohesive sub-set

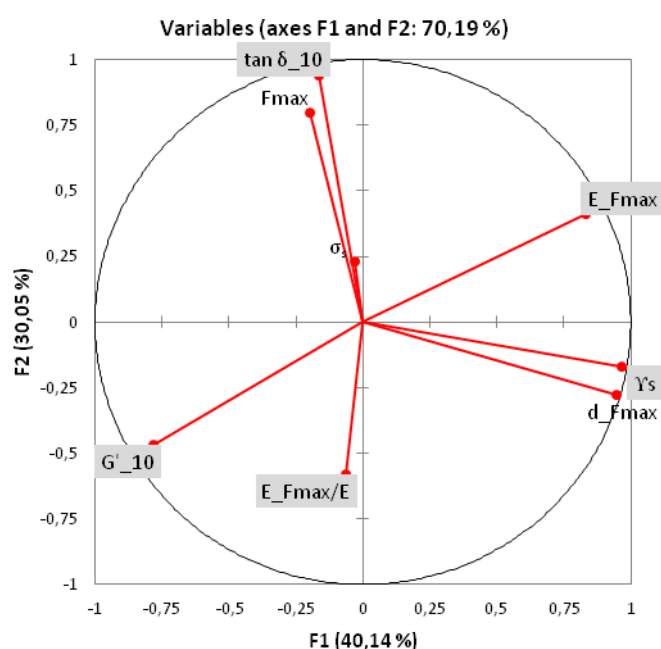


Correlation matrix (Pearson (n)):

Variables	d_Fmax	Fmax	E_Fmax	E	E_Fmax/E	Res	t_mi-rel	S_adh
d_Fmax	1,00							
Fmax	-0,44	1,00						
E_Fmax	0,66	0,35	1,00					
E	0,21	0,33	0,60	1,00				
E_Fmax/E	0,10	-0,03	-0,05	-0,82	1,00			
Res	-0,08	0,05	0,13	0,78	-0,91	1,00		
t_mi-rel	-0,37	-0,26	-0,59	-0,76	0,54	-0,32	1,00	
S_adh	0,01	-0,19	-0,28	-0,93	0,95	-0,87	0,62	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 5: Preliminary PCA to reduce rheological & tack factors for Adhesive-Cohesive sub-set

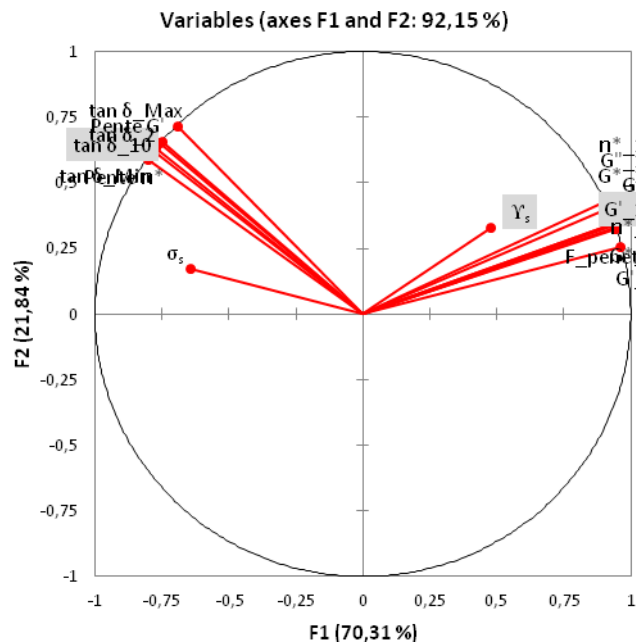


Correlation matrix (Pearson (n)):

Variables	d_Fmax	Fmax	E_Fmax	E_Fmax/E	σ_s	G'_10	$\tan \delta_{10}$	Ys
d_Fmax	1,00							
Fmax	-0,44	1,00						
E_Fmax	0,66	0,35	1,00					
E_Fmax/E	0,10	-0,03	-0,05	1,00				
σ_s	-0,08	0,60	0,42	0,44	1,00			
G'_10	-0,61	-0,05	-0,70	0,55	0,31	1,00		
$\tan \delta_{10}$	-0,38	0,67	0,17	-0,60	0,07	-0,38	1,00	
Ys	0,95	-0,22	0,80	0,15	0,06	-0,62	-0,36	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 6: Preliminary PCA on rheological factors on Cohesive sub-set

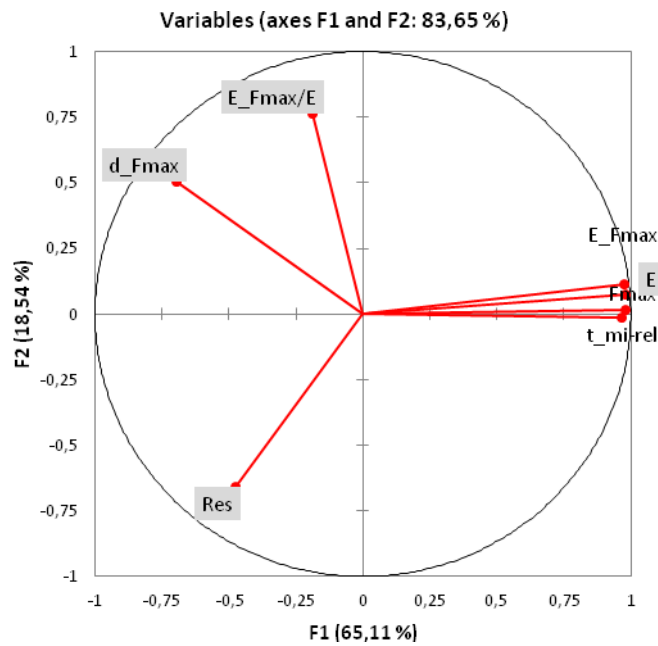


Correlation matrix (Pearson (n)):

Variables	σ_s	Y_s	G'_{10}	$\tan \delta_{10}$	$\tan \delta_{Max}$	η^*_{2}	$\tan \delta_{2}$	G''_{2}	G''_{10}	$n_{G'}$	$\tan \delta_{Min}$	G'_{2}	n_{η^*}	η^*_{10}	G^*_{2}	G^*_{10}	$F_{penetro}$
σ_s	1,00																
Y_s	-0,82	1,00															
G'_{10}	-0,49	0,49	1,00														
$\tan \delta_{10}$	0,63	-0,23	-0,55	1,00													
$\tan \delta_{Max}$	0,54	-0,05	-0,41	0,97	1,00												
η^*_{2}	-0,49	0,49	1,00	-0,56	-0,42	1,00											
$\tan \delta_{2}$	0,61	-0,18	-0,52	1,00	0,98	-0,53	1,00										
G''_{2}	-0,46	0,51	1,00	-0,49	-0,35	1,00	-0,46	1,00									
G''_{10}	-0,45	0,50	0,99	-0,47	-0,32	0,99	-0,44	1,00	1,00								
$Pente G'$	0,54	-0,08	-0,49	0,98	1,00	-0,49	0,99	-0,42	-0,40	1,00							
$\tan \delta_{Min}$	0,57	-0,12	-0,51	0,99	0,99	-0,52	1,00	-0,45	-0,43	1,00	1,00						
G'_{2}	-0,49	0,49	1,00	-0,56	-0,43	1,00	-0,53	1,00	0,99	-0,50	-0,53	1,00					
$Pente \eta^*$	0,56	-0,11	-0,49	0,99	0,99	-0,50	0,99	-0,43	-0,41	1,00	1,00	-0,51	1,00				
η^*_{10}	-0,48	0,49	1,00	-0,54	-0,41	1,00	-0,51	1,00	1,00	-0,48	-0,51	1,00	-0,49	1,00			
G^*_{2}	-0,49	0,49	1,00	-0,56	-0,42	1,00	-0,53	1,00	0,99	-0,49	-0,52	1,00	-0,50	1,00	1,00		
G^*_{10}	-0,48	0,49	1,00	-0,54	-0,41	1,00	-0,51	1,00	1,00	-0,48	-0,51	1,00	-0,49	1,00	1,00	1,00	
$F_{penetro}$	-0,49	0,46	0,99	-0,63	-0,49	0,99	-0,59	0,98	0,98	-0,56	-0,59	0,99	-0,57	0,99	0,99	0,99	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 7: Preliminary PCA on tack factors on Cohesive sub-set

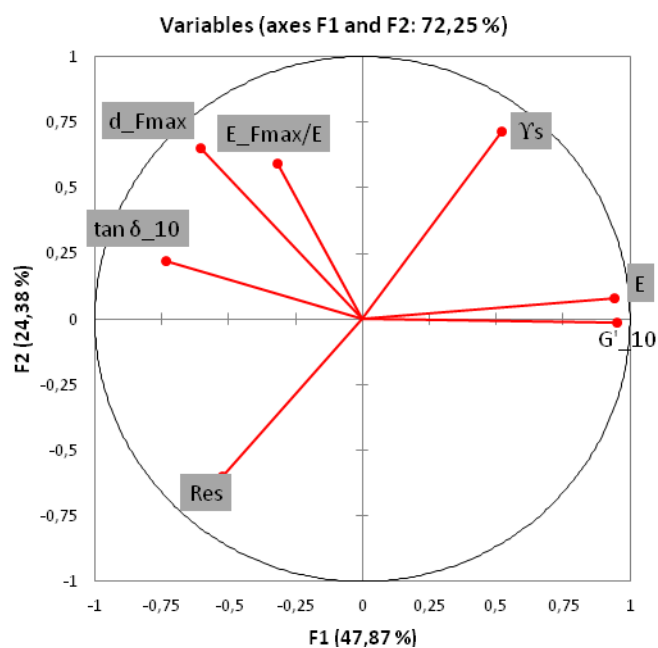


Correlation matrix (Pearson (n)):

Variables	d_Fmax	Fmax	E_Fmax	E	E_Fmax/E	Res	t_mi-rel
d_Fmax	1,00						
Fmax	-0,64	1,00					
E_Fmax	-0,61	0,99	1,00				
E	-0,63	1,00	1,00	1,00			
E_Fmax/E	0,30	-0,12	-0,03	-0,07	1,00		
Res	-0,05	-0,38	-0,44	-0,43	-0,12	1,00	
t_mi-rel	-0,61	0,92	0,91	0,92	-0,32	-0,55	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Appendix 8: Preliminary PCA to reduce rheological & tack factors for Cohesive sub-set



Correlation matrix (Pearson (n)):

Variables	d_Fmax	E_Fmax/E	Res	Ys	G'_10	tan δ_10	E
d_Fmax	1,00						
E_Fmax/E	0,30	1,00					
Res	-0,05	-0,12	1,00				
Ys	0,29	0,03	-0,53	1,00			
G'_10	-0,67	-0,15	-0,35	0,49	1,00		
tan δ_10	0,37	0,58	0,40	-0,23	-0,55	1,00	
E	-0,63	-0,07	-0,43	0,53	0,99	-0,51	1,00

Values in bold are different from 0 with a significance level $\alpha=0,05$

Résumé en Français

La texture est une propriété sensorielle majeure des aliments qui détermine leur qualité globale pour les consommateurs. La production des produits de qualité qui respectent les attentes des consommateurs est cruciale pour des industries souhaitant rester compétitives sur le marché. Par conséquent, les développeurs doivent maîtriser au mieux l'effet de la formulation et/ou du procédé sur les caractéristiques perçues pour fabriquer des produits satisfaisants qui anticipent les perceptions des consommateurs. C'est pourquoi la pression industrielle pour comprendre comment les consommateurs perçoivent et décrivent les caractéristiques des produits a augmenté devenant aujourd'hui un enjeu majeur.

Les propriétés sensorielles de texture sont traditionnellement caractérisées par des méthodes descriptives. Dans ces méthodes, un groupe de panélistes est entraîné afin que tous utilisent le même vocabulaire et les mêmes procédures d'évaluation pour décrire et évaluer l'intensité de leurs sensations. Pour minimiser la subjectivité des panélistes, la priorité est donnée à l'entraînement et à l'utilisation de références. Les panélistes sont considérés comme "des machines" et les évaluations comme étant "objectives et analytiques". Toutefois, afin de répondre au besoin industriel décrit plus haut de prévoir les perceptions des consommateurs, les panélistes devraient bien plutôt, ou également, être vus comme des personnes, comme des consommateurs plutôt que "des machines" analytiques. Le jury entraîné fournit un profil de produit détaillé utilisable pour le formulateur. Cependant, la perception et la description des panélistes entraînés peuvent différer de celle des consommateurs. Ceci est probablement dû à l'utilisation d'une méthode extrêmement contrôlée dans le premier cas. Un entraînement trop intensif pourrait probablement conduire à la perte d'une partie de l'information liée aux spécificités de produit ou à une perception différente ou nuancée d'une minorité des panélistes. Ainsi, la question du niveau d'adéquation des méthodes utilisées pour prévoir la perception des consommateurs peut être posée. Ceci peut être particulièrement important pour les perceptions qui impliquent une certaine complexité, une réalité multidimensionnelle, et/ou plus de variations interindividuelles comme le « collant » par exemple que nous allons rencontrer dans ce qui va faire l'objet de notre travail. Des approches sensorielles descriptives par des consommateurs se sont montrées comparables à celles de panélistes entraînés pour ce qui est de la discrimination de produits. Cependant, l'univers sémantique est plus varié pour ce qui est de la description des produits, même s'il est parfois moins

précis. En revanche, le manque d'informations quant à la définition et la procédure d'évaluation dans des approches moins contrôlées rend l'interprétation plus difficile. Dans ce contexte, la question est comment pouvons-nous impliquer les consommateurs dans une approche descriptive tout en fournissant un meilleur compromis entre la condition contrôlée et l'inclusion d'une diversité en matière de mode de perception ? Comment obtenir plus d'information par l'inclusion de plus de diversité et maintenir en même temps un contrôle adéquat ?

Bien que l'évaluation sensorielle soit la méthode principale pour déterminer la perception de la texture, des méthodes instrumentales sont également utiles pour décrire les produits et comprendre pourquoi les différences de texture existent. Le lien entre les propriétés mécaniques ou de structure et de surface des produits et la perception sensorielle de la texture permettrait au formulateur de conduire un design de texture raisonné pour satisfaire les consommateurs.

Dans les études passées, les mesures rhéologiques ont largement été utilisées en parallèle des mesures descriptives classiques pour prédire les descripteurs sensoriels par des facteurs physiques. Cette double approche a permis de prédire certaines propriétés sensorielles de texture des aliments principalement liées à la fermeté du produit. Cependant, les perceptions multidimensionnelles liées tant à la texture de produit qu'à des propriétés de surface, comme le collant, sont moins ou mal prédites par des méthodes rhéologiques. Par conséquent, une autre question se pose : est-ce que des approches sensorielles de description libre apporteraient de nouvelles informations quant à la physique de l'évaluation du produit, ce qui pourrait probablement aider à orienter et améliorer le choix des mesures instrumentales et des paramètres de ces méthodes afin mieux prédire les perceptions complexes, comme le collant par exemple ?

Afin d'avancer sur ces problématiques et pour répondre à un besoin industriel dans le domaine de la maîtrise de la texture de produits laitiers, nous avons conduit une étude sur un espace produits proches de produit réels. La texture d'un ensemble de 20 fromages fondus modèles a été caractérisée par des approches sensorielles et instrumentales. La gamme définie des produits modèles présentant une grande variété de texture a été préparée chez l'industriel. Les produits couvraient la diversité du marché quant à la texture de produits de type fromage fondu, variant de cuillérable à tartinable. De plus, l'espace de produit avait l'avantage de permettre l'identification de l'effet de plusieurs facteurs de

fabrication (ingrédients et procédé) sur la perception finale. Il est donc possible pour l'industriel, à l'issue du travail, d'examiner les données sensorielles et instrumentales en lien avec la formulation et le procédé. Ainsi, au plan des applications, une des retombées pour le développeur est bien d'améliorer sa connaissance du produit et des leviers d'actions en lien avec la perception par le consommateur, dans une approche de rétro-ingénierie.

Trois objectifs principaux ont guidé notre travail:

1. Décrire un ensemble de fromages fondus modèles en utilisant une approche individuelle qui prend en compte la diversité en termes de perception, de manipulation et de description.
2. Établir les évaluations instrumentales sur la base des résultats sensoriels. Ceci en utilisant l'étape sensorielle pour obtenir plus d'information sur les procédures d'évaluation afin de mieux déterminer les méthodologies instrumentales pertinentes et les conditions de leur mise en œuvre pour caractériser les perceptions identifiées.
3. Étudier la possibilité de prédire la perception sensorielle de la texture des fromages fondus, en particulier des caractéristiques particulières, multidimensionnelles, comme le collant par exemple, par des facteurs instrumentaux.

Évaluations sensorielles :

Dans notre travail expérimental, nous avons décidé de commencer tout d'abord par l'évaluation sensorielle. Ainsi, deux caractérisations sensorielles principales ont été effectuées :

Une pré-étude avait pour but de vérifier au niveau sensoriel la diversité de texture des produits fabriqués. Cette étape devait permettre d'identifier rapidement les caractéristiques globales de texture des produits fournis et leurs variations au niveau sensoriel. Donc, une méthode à base de similitude a été utilisée pour obtenir une description rapide et globale de l'ensemble de l'espace produit. Une méthode de tri en trois étapes (visuel, à la main et en bouche) a été appliquée pour décrire les variations de texture au niveau sensoriel.

L'analyse multidimensionnelle du positionnement des produits (MDS) a été conduite pour traiter les données à un niveau agrégé. Ainsi, la configuration MDS de chaque étape a été saisie par Classification Ascendante Hiérarchique (CAH) avec le critère de Ward. L'analyse CAH a abouti à 3 groupes principaux constitués de 5 sous-groupes dans chacune des trois étapes. Aucun produit n'a constitué un groupe à lui seul. La comparaison des résultats a montré que les évaluations manuelle et en bouche ont conduit à des regroupements identiques des produits, les positionnements étant également proches. Cependant, les groupes résultants de l'évaluation visuelle étaient différents en terme de proximité des groupes aussi bien que de produits. Les résultats montrent que les groupes de produits ont été liés aux variables de formulation.

Le tri en trois étapes a ainsi permis d'étudier la perception de la texture à ces différentes étapes de consommation du produit. De manière générale, le plan expérimental basé sur la formulation a fourni une bonne gamme de produits modèles avec des propriétés de texture variées au niveau sensoriel. Il a aussi montré que les évaluations manuelle et en bouche aboutissent à des regroupements semblables des produits. Seules les évaluations visuelles et manuelles ont été retenues pour décrire les textures des produits modèles pour le reste de l'étude.

La deuxième étude a concerné la caractérisation de produits par une approche individuelle fournissant un bon équilibre entre l'inclusion de la diversité et le contrôle de l'évaluation. Des facteurs divers comme la façon d'approcher du produit par le panéliste, la condition du test, la procédure d'évaluation et le niveau d'expertise peuvent affecter la perception et la

description. Donc, le but principal dans cette partie était de caractériser la texture de la gamme de fromages fondus modèles en utilisant une méthodologie sensorielle qui prenne en considération la diversité des panélistes en termes de perception, de manipulation et de description. Ceci de façon à obtenir plus d'informations quant aux évaluations des produits. Une méthode combinée a donc été appliquée : premièrement, une phase de description libre pour examiner l'interaction entre "un panéliste - un produit". Elle permet de fournir la terminologie générée par un ensemble de consommateurs et un profil sensoriel très détaillé de chaque produit. Ensuite, un Profil Flash a été conduit. Le profil Flash a permis d'impliquer les consommateurs dans une approche descriptive plus synthétique et d'étudier les interactions entre "un panéliste - un ensemble de produits". Les produits ont pu être distingués en se basant sur les caractéristiques clés importantes pour les panélistes. Pour améliorer la méthodologie pour prendre en compte la diversité d'évaluation, des divers moyens ont été proposés aux panélistes (du pain et des couverts de nature différentes). Ainsi, en plus de la procédure d'évaluation, les conditions d'évaluation différaient selon le choix individuel. Les données ont été relevées pour chaque panéliste et chaque produit. Les panélistes ont également été observés au cours de l'évaluation de quelques produits pour obtenir des informations supplémentaires concernant la façon de manipuler et d'évaluer les produits. Enfin, pour examiner l'effet de l'expertise antérieure des panélistes, l'ensemble des phases décrites ci-dessus a été réalisée d'une part par un groupe de 60 consommateurs et d'autre part par 10 experts évaluant les mêmes produits suivant les mêmes propositions de conditions d'évaluation.

Une analyse de la fréquence de citation des mots a été utilisée pour traiter les données de description libre.

L'Analyse Procrustéenne Généralisée (la GPA), a été utilisé pour traiter les données de Profil de Flash. Le tableaux croisee dynamique a été utilisée pour synthétiser les données supplémentaires brutes rassemblées quant aux conditions d'évaluation lors de la caractérisation individuelle de produits.

La caractérisation sensorielle de chaque produit par les consommateurs en commentaires libres nous a permis d'identifier les 9 termes le plus fréquemment cités parmi 550 termes différents utilisés pour caractériser l'ensemble des produits :

"Collant", "Brillant", "Jaune", "Lisse", "Compact", "Dur,"Étalable ", " Crèmeux ", " Facile Tartiner ". De plus nous avons obtenu des images sensorielles très détaillées pour chaque produit directement par les termes utilisés des consommateurs.

La caractérisation comparative issue du Profil Flash a révélé la caractéristique "granuleux" devenue importante lorsque les consommateurs ont évalué tous les produits simultanément. La caractéristique "Collant" a été le terme le plus cité par les consommateurs pour la caractérisation individuelle des produits aussi bien que pour la comparaison entre les produits.

Le traitement par GPA sur les données individuelles de Profil Flash nous a permis d'obtenir une carte sensorielle moyenne. Les deux premières dimensions de GPA permettent d'expliquer 93 % de l'information totale. Après la GPA, deux analyses de CAH ont été exécutées: une sur les coordonnées de configuration des produits pour évaluer les proximités sensorielles entre ceux-ci et donner une idée de leurs discriminations. Une autre CAH a été effectuée sur les coordonnées des termes descriptifs pour identifier les groupes de termes semblables.

Le CAH sur les termes a abouti à 7 groupes principaux. Deux groupes représentent les différences de texture principales qui peuvent être récapitulées comme "Dur-compact" et " Facile à tartiner-Collant-Crèmeux". Trois autres groupes identifient les termes visuels et peuvent être récapitulés comme "Couleur Claire, Brillance, Jaune". Les autres groupes sont restés difficiles à interpréter. Le CAH sur les produits a abouti à trois groupes principaux principalement séparés le long de la première dimension de GPA (des notes moyennes). Cet axe oppose un groupe de produits décrits comme "Dur, Compact" à un groupe de produits décrits comme "Collant, Tartinable, Crèmeux". Le deuxième axe oppose deux produits (P13 contre P16) basé sur l'aspect visuel lié à la couleur et à la transparence : aspect visuel "Couleur-Claire" contre aspect visuel "Couleur Jaune". Cela montre que pour des consommateurs, une seule dimension concernant purement la texture se dégage. Cette dimension représente la majeure partie des informations (90 %) sur les produits et les distingue selon leurs différences de texture de "Dur, compact" à "Facile à tartiner, Collant, Crèmeux", Figure 1, 2.

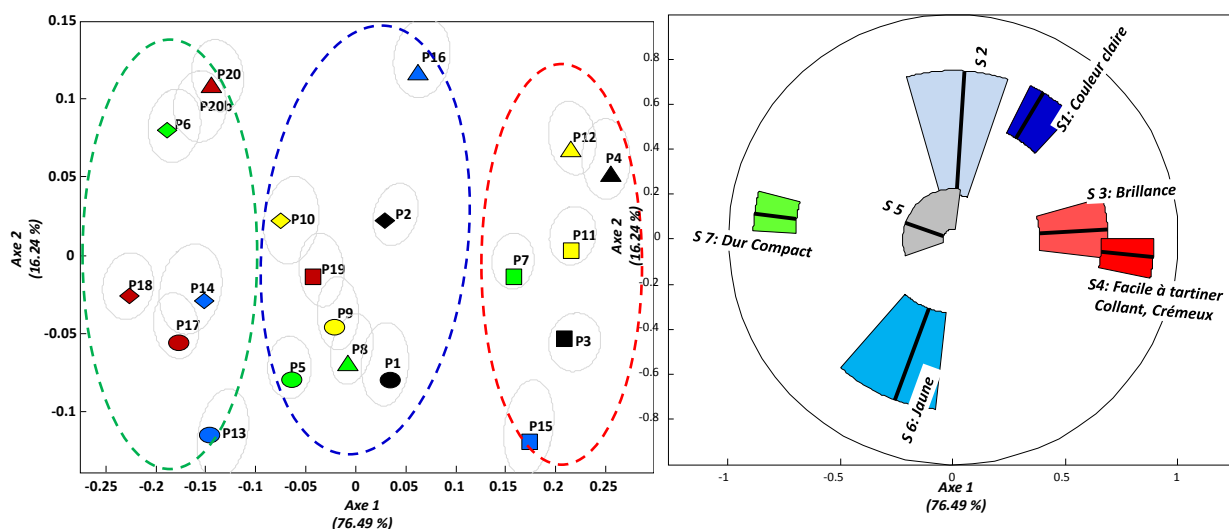


Figure 1: Représentation des deux premières dimensions de GPA (carte de produit et CONPLOT) issues du Profil Flash sur l'ensemble des termes utilisés par les consommateurs).

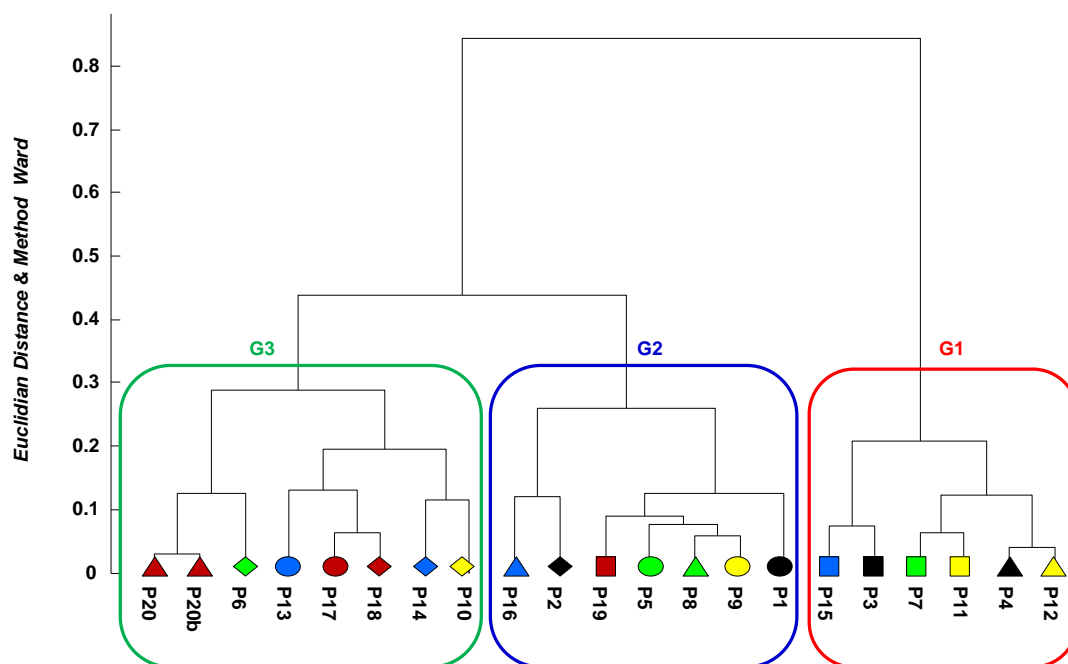


Figure 2: Regroupement des produits par Dendrogramme obtenu par CAH sur les produits après GPA menée sur la description par les 60 consommateurs. Trois groupes de produits se dégagent G1, G2 et G3.

L'approche combinée de deux méthodologies avec deux différents types de verbalisation (Description libre suivi par Profil Flash) a permis d'identifier des spécificités dans la façon de

répondre des deux panels. La description libre a montré les similitudes et les différences entre les terminologies des deux panels. Elle a montré que les experts produisent en moyenne plus de termes que les consommateurs. Cependant, certains de leurs termes sont spécifiques et n'ont jamais été cités par les consommateurs. Les cartes sensorielles obtenues après le Profil Flash étaient très semblables pour les deux panels.

En ce qui concerne la condition d'évaluation, les deux panels ont montré une tendance à changer leur type de pain ou des couverts pendant le test ou même pour un produit. Cependant, l'adaptation était dépendante des panelistes mais pas de produit.

Vers l'évaluation instrumentale :

Le deuxième objectif était d'établir une évaluation instrumentale des produits sur la base des résultats sensoriels pour ainsi mieux déterminer des méthodes et conditions pertinentes de caractérisation en regard des perceptions identifiées. Nous avons donc utilisé les descriptions et observations des mesures sensorielles pour choisir des méthodes instrumentales appropriées. Sur cette base, des méthodes rhéologiques classiques (mesures de propriétés viscoélastiques et pénétrométrie) et une mesure de tack adaptée ont été utilisées pour la caractérisation des produits. De plus, les produits ont été caractérisés dans deux états physiques (sans ou après un traitement mécanique important).

Évaluation Instrumentale :

Pour la caractérisation instrumentale, la méthode de tack adaptée et la rhéologie aux petites déformations avec une géométrie à ailette ont permis de caractériser l'ensemble des produits présentant pourtant une diversité importante de texture (solide, semi-solide, liquide). Les mesures rhéologiques ont montré que les produits modèles présentent une grande variation en termes de module conservatif et complexe, avec des propriétés qui dépendent peu de la fréquence. Une ACP sur les données moyennes a abouti à une carte de produits pour laquelle les trois premiers axes expliquent 96 % des informations (76, 14 et 5 % respectivement).

La méthode de tack a montré que les produits peuvent être divisés en trois groupes principaux selon leurs comportements lors du détachement selon les modes de rupture. Ainsi, les modes de rupture différents observés sont, liés non seulement à l'équilibre entre les énergies cohésives et adhésives, mais aussi à la déformabilité des produits. Les produits montrant la rupture adhésive sont résistants à la déformation et présentent des forces cohésives plus importantes que les forces adhésives. Les produits présentant une rupture adhésive-cohésive mettent en jeu deux types de forces en concurrence de même importance. Finalement, les produits qui présentent une rupture cohésive montrent un degré important de déformabilité (sauf pour un produit). Ces produits se contractent lors du mouvement du mobile et se tendent pendant la phase de séparation. Par ailleurs, la surface de contact joue un effet significatif relativement à l'énergie totale mesurée. Ce paramètre doit être pris en compte comme un facteur supplémentaire dans la comparaison des énergies totales liées aux types de rupture différents. La mesure des résidus de produit sur le mobile (surface couverte) après l'arrachement est un autre facteur qui a été retenu pour inclure les variations entre produits présentant des niveaux différents de rupture cohésive. L'ACP en données moyenne a abouti à une carte des produits pour laquelle les trois premiers axes expliquent 92 % des informations (51, 31 et 10 % respectivement).

Finalement, les résultats d'ACP sur les données moyennes centrées réduites des variables instrumentales choisies ont montré que la combinaison des deux méthodes (rhéologie classique et tack) améliore la représentation de l'espace produits et qu'elle apporte de nouveaux axes de description, Figure 3. Cette description montre que l'on explique 80 % des informations sur trois dimensions. Sur la première dimension, les produits présentant une rupture adhésive sont opposés aux produits avec rupture cohésive et sont distingués tant quant aux caractéristiques de tack que quant aux paramètres rhéologiques. La mesure de tack apporte de nouvelles informations sur le deuxième axe qui est seulement lié à l'énergie totale de séparation. Les produits avec rupture adhésive-cohésive (sauf un produit) se distinguent du reste des produits sur cet axe. Finalement, le paramètre déformation au seuil de rupture (estimé à partir des mesures de propriétés viscoélastiques au début du domaine non-linéaire) explique le troisième axe, avec la distinction et l'opposition deux produits (P16 contre P9).

Parmi les paramètres résultant du test de tack, le ratio d'énergies (E_{Fmax}/E) permet de distinguer les produits présentant une diversité des modes de rupture. Ce facteur était

corrélé au seuil de contrainte (σ). L'énergie totale (E) apporte une information complémentaire et intègre tant les ruptures adhésives que cohésives.

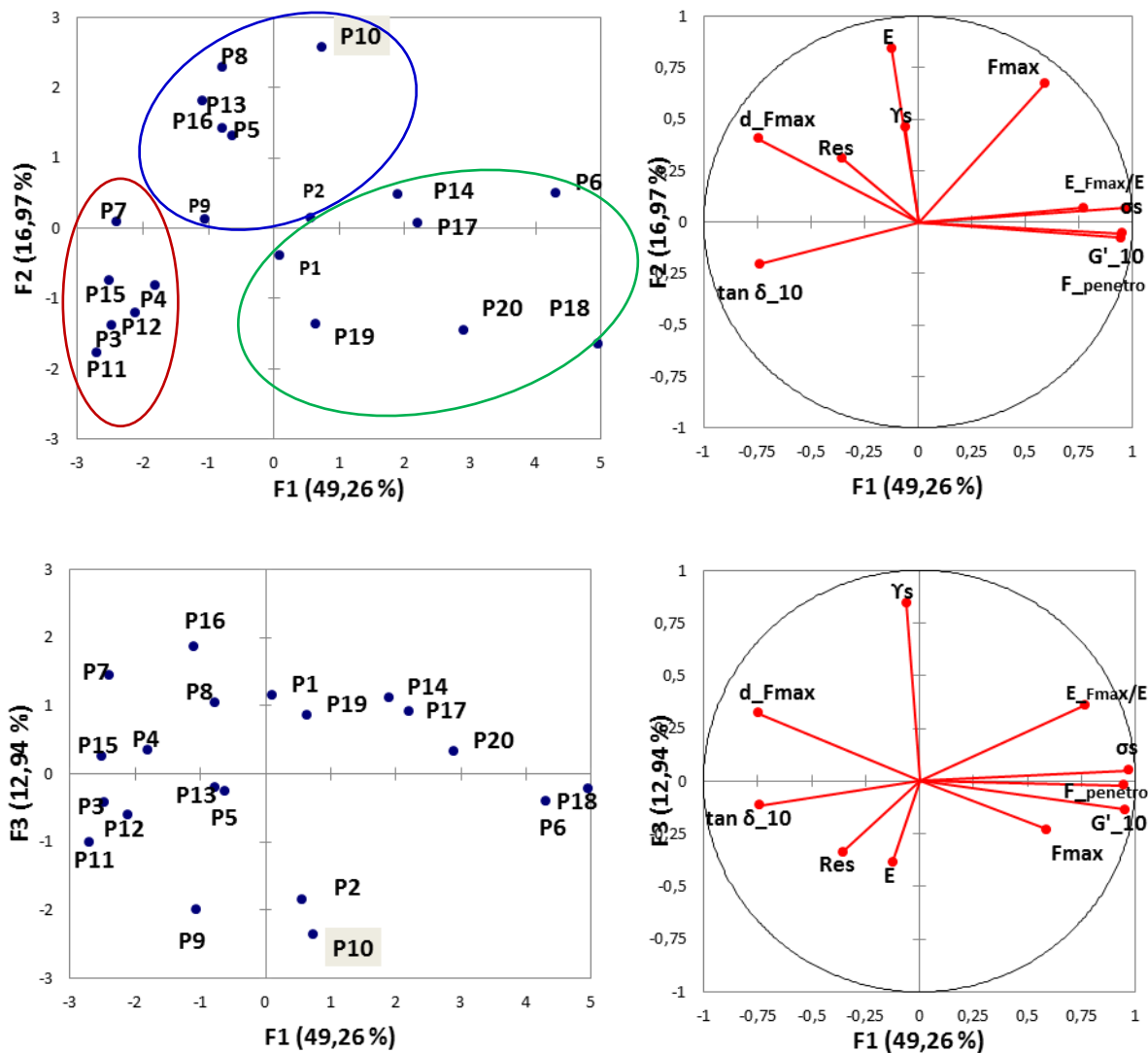


Figure 3: Représentation des trois premières dimensions de l'ACP sur les données instrumentales. Les ovales représentent les groupes obtenus par CAH.

La caractérisation instrumentale sur des produits traités mécaniquement n'a pas amené à une configuration sensiblement différente des produits.

Étude de Corrélation :

Dans cette partie la possibilité de corrélérer les deux ensembles de données et la possibilité de prévoir les données sensorielles par des variables instrumentales sont discutées. Pour évaluer la correspondance entre la carte sensorielle et la carte instrumentale, une GPA (sur les notes moyennes) a été effectuée sur les deux ensembles de données. Les trois premières dimensions de GPA représentent respectivement 70 %, 11 % et 9 % des informations.

Comme indiqué dans la Figure 4, le produit le plus proche caractérisé selon les deux approches est P20. Six produits (P6, P7, P10, P16, P18 et P19) sont distingués de la même façon sur l'axe 1 par les deux caractérisations, tandis que leur caractérisation sur l'axe 2 diffère. P10 et P18 sont mieux distingués sur l'axe 2 par la caractérisation instrumentale plutôt que la perception sensorielle. D'autre part, P4, P5 et P13 sont distingués de la même façon sur l'axe 2 tandis que leur discrimination sur l'axe 1 diffère entre l'analyse sensorielle et instrumentale et ils sont mieux distingués par l'évaluation sensorielle. En général les configurations de produits sur l'axe 1 coïncident mieux que selon l'axe 2.

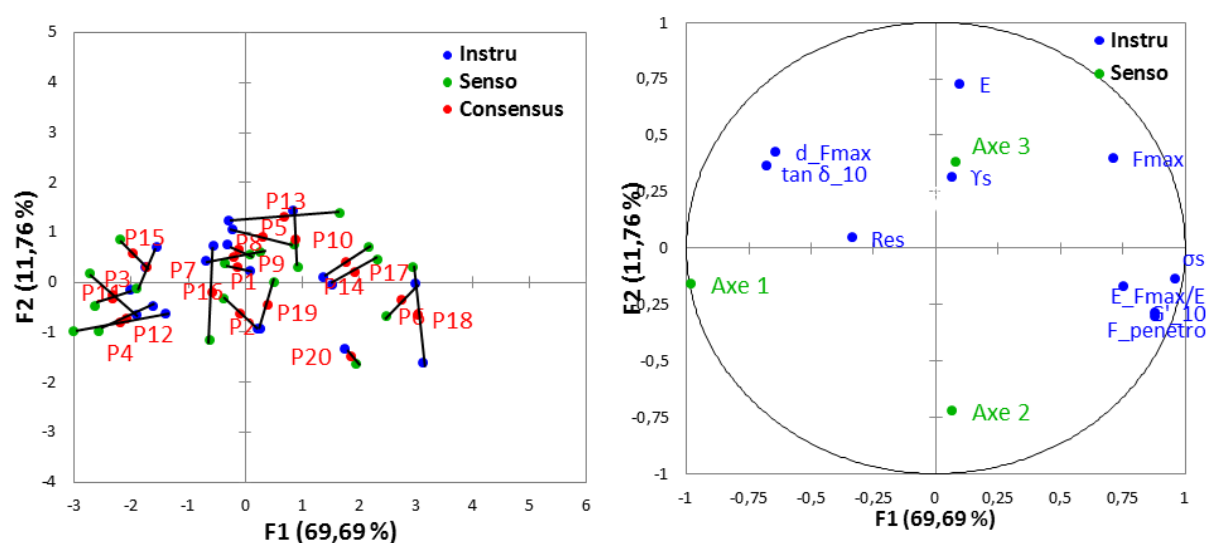


Figure 4: Résultats de GPA (carte de produit et d'attributs) des ensembles de données instrumentales et sensorielles : représentation superposées selon les deux premières composantes des produits caractérisés par le sensoriel (●) et par instrumental (●) et présentation du point consensuel (●).

Sur le bi-plot d'attributs du GPA, "Axe 1" de l'évaluation sensorielle qui oppose les termes "Facile à Tartiner, Crémeux, Collant" à "Dur, Compact", est positivement corrélés au ($\tan \delta$) et (d_{Fmax}). Il est fortement inversement corrélé au seuil de contrainte (σ_s), au module conservatif (G') et à la force de pénétration ($F_{penetro}$) aussi bien qu'au ratio d'énergies

(E_{Fmax}/E) et F_{max} . Les produits qui sont les plus fermes (G' plus important) et les plus structurés ($\tan \delta$ moins important) ont des forces maximum au test de tack plus élevées (F_{max}). Ces produits ont été perçus comme étant plus durs, plus compacts et moins collants, étalables et crémeux. Tandis que les produits qui sont plus visqueux et moins structurés, coulent plus facilement et présentent donc la force maximale (F_{max}) la moins importante. Ces produits ont été perçus comme étant étalables, collants et crémeux.

Prédiction les perceptions sensorielle par caractérisation instrumentale :

Un des buts de cette étude était de prévoir le positionnement sensoriel de produits (la carte de produit) et plus particulièrement la perception spécifique de certains attributs comme "Collant", à partir des mesures instrumentales. La régression linéaire multiple a été utilisée pour la prédiction des données sensorielles. Cette technique essaye de modéliser la relation entre deux ou plusieurs variables explicatives (X) et une variable de réponse (Y) en adaptant une équation linéaire aux données observées.

La caractérisation sensorielle a montré que le premier axe sensoriel représente les informations principales quant aux différences de texture perçues par des consommateurs. La capacité de prédiction pour cet axe ("Axe 1" sensoriel après la caractérisation des consommateurs) par les variables instrumentales a donc été examinée. Les variables instrumentales les plus influentes ont été identifiées et leur corrélation avec "Axe 1" sensoriel a été évaluée.

L'utilisation de la méthode de régression linéaire multiple a permis d'établir des relations entre "Axe 1" sensoriel et des paramètres instrumentaux :

$$\text{"Axe 1" sensoriel} = f(\text{paramètres Instrumentaux})$$

$$\text{Paramètres instrumentaux} = f(G', \tan \delta, \gamma_s, \sigma_s, F_{\text{penetro}}, d_{F_{\text{max}}}, F_{\text{max}}, E, E_{F_{\text{max}}}/E, \text{Res})$$

Le modèle a été déterminé en considérant les données pour tous les produits modèles. Le premier modèle prédictif, comprenant l'ensemble des 10 variables instrumentales, a donné un bon ajustement ($R^2 = 0.90$) avec la p-valeur de 0.001. Toutefois, ce modèle a été simplifié en enlevant les facteurs les moins significatifs un par un par élimination successive.

Le tableau 1 montre les résultats pour les 4 facteurs instrumentaux principaux qui présentent un effet significatif dans la prévision de "Axe 1" sensoriel. Le modèle prédictif simplifié présente un bon ajustement ($R^2 = 0.93$) et une p-valeur de moins de 0.0001.

Table 135: Les coefficients du modèle simplifié Instrumental-sensoriel pour "Axe 1" Sensoriel (Consommateurs).

Source	A	d_Fmax	E	G'_10	σ_s
Coefficients	0,01	0,04	-0,04	0,13	-0,243
Standard error	0,01	0,01	0,01	0,03	0,030
Pr > F	0,443	0,019	0,001	0,001	< 0,0001

Un des résultats principaux du tableau 1 est que le "seuil de contrainte" est le facteur le plus significatif pour prévoir l' "Axe 1" sensoriel et ce facteur explique principalement le modèle. Une régression linéaire simple a donc été effectuée en prenant seulement ce facteur en considération.

Les résultats montrent que "Axe 1" sensoriel peut être significativement modélisé par le "seuil de contrainte (σ_s)" ($R^2 = 0.82$, Figure 5).

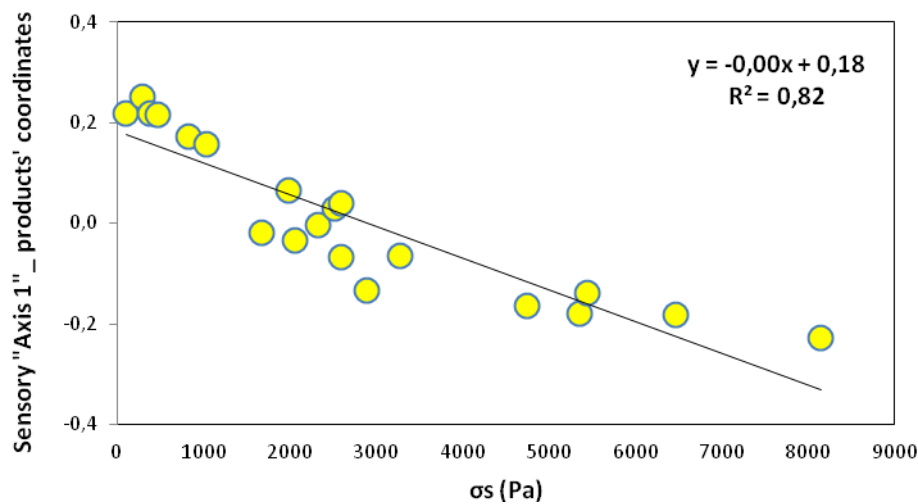


Figure 5: Représentation de “Axis 1” sensoriel basé sur évaluations des consommateurs en fonction du seuil de contrainte.

En bref, Une prédiction plutôt satisfaisante de la perception des produits par le jury de consommateurs est obtenue à partir des mesures de propriétés viscoélastiques en dynamique (module conservatif et seuil de contrainte) et des paramètres issus du test de tack (énergie totale et distance à la force maximale).

De plus, la perception sensorielle du terme «collant » est bien prédite par le paramètre instrumental seuil de contrainte pour la majorité de consommateurs qui ont utilisé ce terme dans leurs évaluations. Le Figure 6 montre la relation entre les données moyennées des consommateurs quant à la perception du paramètre "Collant" et les valeurs du "seuil de contrainte".

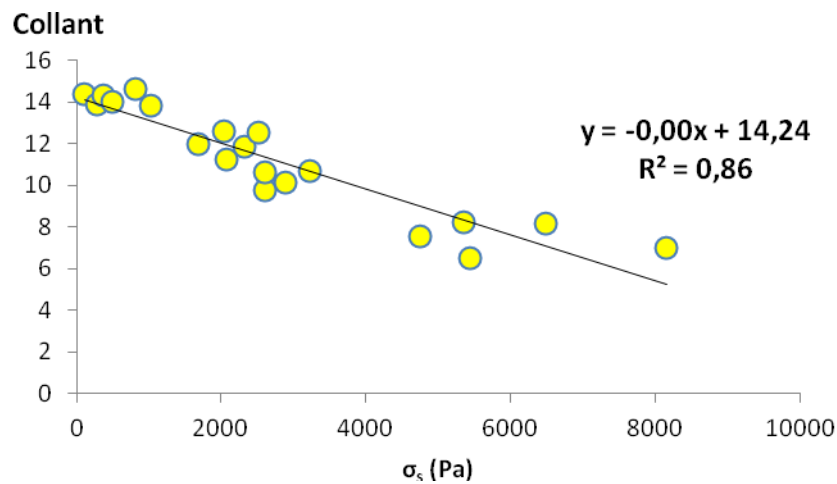


Figure 6: Perception du terme “Collant” par les consommateurs (en classement moyen) en fonction du seuil de contrainte (σ_s).

Comme démontré dans la Figure 6, la perception "Collant" montre une diminution linéaire significative avec l'augmentation de σ_s . Cette diminution linéaire indique que les produits dont l'écoulement est plus facile à engager (seuil plus faible) sont perçus comme étant plus "Collants" par les consommateurs et qu'à l'inverse les produits qui sont plus fermes et résistent à s'écouler sont perçus comme moins "Collants", ceci pour notre ensemble de produits.

Une analyse de ce résultat au niveau individuel a montré que le seuil de contrainte peut prédire cet attribut "Collant" pour la majorité des consommateurs, mais que par contre ceci n'est pas du tout vérifié pour d'autres, ce qui illustre bien les différences d'expression des perceptions interindividuelles même si celles-ci font référence à un même terme.

Abstract

In our study the texture of a set of model processed cheeses is characterized through both sensory and instrumental approaches. Three objectives guided our work. The first was using an individual approach that takes the diversity in terms of perception, manipulation and description into account for sensory characterization of products. Furthermore, to study the effect of prior expertise, two panels evaluated the products: consumer and expert panel. A combined approach with two different methodologies and verbalization (Free comment followed by Flash Profile) made it possible to identify specificities in the answer behavior between the two panels. Free comment showed the similarity and differences between the terminologies of two panels. It showed that experts generate more terms in average than consumers. However, some of their terms are specific and never was cited to consumers. Flash profile showed that there are some characteristics that become important once the assessors evaluate the products simultaneously. The result showed important differences between the resulted product maps from consumers and experts after free comment method. However, the resulted sensory maps after the Flash Profile were very similar for both panels and were close to the sensory map obtained for consumer panel after free comment. Some specific attributes were frequently cited for products evaluations in two applied methods, such as “Collant (Stickiness)”.

The second objective was to establish the instrumental characterization on the basis of sensory results in order to better determine some efficient methodologies and conditions to characterize the identified perceptions. We thus used sensory descriptions and observations to choose appropriate instrumental methods. On this basis, classic rheological methods (measurement of the viscoelastic properties and penetrometry) and adapted tack method were used for product characterization. Furthermore, the products were characterized at two physical states (without or after a mechanical treatment). The adapted tack method and the rheology at small deformation with vane geometry permitted to characterize the products set with important texture diversity (solid, semi-solid, liquid). The results showed that the combination of two methods improves the product map and brings new axes of description. The instrumental characterization of mechanically treated products did not lead to a rather different products configuration.

The third objective was to predict the sensory positioning of products (product map) as well as the specific multidimensional perception “Collant (Stickiness)”, by instrumental measurements. A rather satisfactory prediction of consumer perception of texture was obtained through viscoelastic measurements (storage module and yield stress) and parameters stemming from tack measurement (total energy and distance at maximum tensile force). Furthermore, the sensory perceptions relative to “Collant (Stickiness)” is well predicted by the instrumental parameter “yield stress” for the majority of the consumers who applied this term in their evaluations.

Key words: *processed-cheese, sensory perceptions, texture, free methods, rheology, tack, stickiness, prediction.*

Résumé

Notre travail a porté sur la caractérisation instrumentale et sensorielle de la texture d'une gamme de produits modèles de types fromages fondus. Trois objectifs ont guidé cette thèse. Le premier objectif était d'utiliser une approche individuelle qui prenne en compte la diversité de perception, de manipulation et de description des panélistes pour la caractérisation sensorielle. De plus, pour étudier l'effet d'expertise préalable, deux panels ont évalué les produits : des consommateurs et des experts. Une approche combinée de deux méthodologies différentes avec deux différents types de verbalisation (Description libre suivi par un Profil Flash) a permis d'identifier des spécificités dans la façon de répondre des deux panels. La description libre a montré les similitudes et les différences entre les terminologies des deux panels. Elle a montré que les experts produisent en moyenne plus de termes que les consommateurs. Cependant, certains de leurs termes sont spécifiques et n'ont jamais été cités par les consommateurs. Le Profil Flash a montré qu'il y a quelques caractéristiques qui deviennent importantes lorsque les panélistes évaluent l'ensemble des produits simultanément. Le résultat a montré des différences importantes entre les cartes produites des consommateurs et des experts issues de la méthode de Description libre. Cependant, les cartes sensorielles obtenues après le Profil Flash étaient très semblables pour les deux panels et proche de la carte obtenue pour le jury de consommateurs avec la méthode de Description libre. Quelques attributs spécifiques ont été fréquemment cités pour des évaluations de produits par les deux méthodes appliquées, comme le terme "Collant".

Le deuxième objectif était d'établir une évaluation instrumentale des produits sur la base des résultats sensoriels pour ainsi mieux déterminer des méthodes et conditions pertinentes de caractérisation en regard des perceptions identifiées. Nous avons donc utilisé les descriptions et observations de mesures sensorielles pour choisir des méthodes instrumentales appropriées. Sur cette base, des méthodes rhéologiques classiques (mesures de propriétés viscoélastiques et pénétrométrie) et une mesure de tack adaptée ont été utilisées pour la caractérisation des produits. De plus, les produits ont été caractérisés dans deux états physiques (sans ou après un traitement mécanique important). La méthode de tack adaptée et la rhéologie aux petites déformations avec une géométrie à ailette ont permis de caractériser l'ensemble des produits présentant pourtant une diversité importante de texture (solide, semi-solide, liquide). Les résultats ont montré que la combinaison des deux méthodes améliore la représentation de l'espace produits et qu'elle apporte de nouveaux axes de description. La caractérisation instrumentale sur des produits traités mécaniquement n'a pas amené à une configuration sensiblement différente des produits.

Le troisième objectif était de prévoir le positionnement sensoriel de produits (la carte de produit) et plus particulièrement la perception spécifique de certains attributs comme "Collant", à partir des mesures instrumentales. Une prédiction plutôt satisfaisante de la perception des produits par le jury de consommateurs est obtenue à partir des mesures de propriétés viscoélastiques en dynamique (module conservatif et seuil de contrainte) et des paramètres issus du test de tack (énergie totale et distance à la force maximale). De plus, la perception sensorielle du terme «collant» est bien prédite par le paramètre instrumental seuil de contrainte pour la majorité de consommateurs qui ont utilisé ce terme dans leurs évaluations.

Mots clés : *fromages fondus, perception sensorielle, texture, méthode de description libre, rhéologie, tack, collant, prédiction.*