CHEWING SIMULATION, A WAY TO UNDERSTAND THE RELATIONSHIPS BETWEEN MASTICATION, FOOD BREAKDOWN AND FLAVOUR RELEASE

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Abstract

Understanding in-mouth mechanisms is necessary to understand flavour release and perception phenomena. To overcome the limitations of in-vivo flavour release measurements, we developed a chewing simulator that faithfully reproduced many mouth functions. Using brittle foods, we showed that in-vitro food breakdown was very comparable to that obtained in-vivo. We also studied on model cheeses in-vitro flavour release by connecting on-line the chewing simulator to APCI-MS. Preliminary results are discussed.

Introduction

Mastication is a complex process involving many mouth functions [1]. The main consequences of this process are the food matrix breakdown and impregnation of food by saliva. This allows flavour compounds to be released in the mouth before reaching olfactory and taste receptors, inducing perception. During chewing and swallowing, flavour release is dependent upon food composition and texture, saliva and mastication parameters as well as the nature of the flavour compounds [2, 3]. It is an important issue in food science that has been extensively studied in-vivo these last years, using direct on-line analyses by connecting the subject’s nose to an Atmospheric Pressure Chemical Ionization Mass Spectrometer (APCI-MS) [4]. This device also enables real-time monitoring of several aroma compounds released during chewing. Although temporal in-vivo studies enable the direct release-perception tests, numerous limitations are observed, such as major inter-individual differences and moderate intra-individual reproducibility. In addition, the food sample must be acceptable to panellists and only a limited number of samples can be evaluated daily. The use of a chewing simulator to perform in-vitro temporal analyses could overcome these difficulties. However, the functionalities of the existing devices already are low.

The aim of the present study was to develop a system reproducing as faithfully as possible the main phenomena occurring in mouth during eating such as compression and shearing forces and introduction of saliva, while allowing fluid sampling during the chewing time. We also present the first results obtained in-vitro on food breakdown and flavour release.
Experimental

**Chewing simulator.** The system is made of a mechanical part, an electronic control box and a computer to monitor and tune each parameter. It is fully detailed in reference [5].

**Breakdown of hard and brittle food.** Four volunteers were asked to eat three peanuts and, after 4 and 8 chews, to spit the sample which was rinsed and dried. For in-vitro measurements, the same procedure in terms of number of peanuts and chew cycles was applied. Different procedures were studied, varying in terms of the maximum bite force or the shearing angle value. Three replicates were performed for each procedure. The degree of fragmentation of both in-vivo and in-vitro chewed samples was studied by measuring the weight of masticated peanuts that could pass through both 4 mm and 2 mm aperture size sieves. Weight percentages were calculated for the 3 size fractions (> 4 mm, 4-2 mm, < 2mm).

**Breakdown of airy and brittle food.** The in-vivo and in-vitro experimentations are precisely described in [6]. Two cornflakes types, coded B (more cohesive and sticky) and K (more brittle and crackly), were used. One panellist was asked to eat 2 g of each product. Electromyography recording was done simultaneously. The bolus was collected after 3, 5, 7, 10, 15 chew cycles and just before swallowing and dried. Particle characteristics were determined by image analysis. Analogue experiments were made using the chewing simulator.

**In-vitro flavour release.** This experiment was carried out on flavoured lipoproteic matrices made by action of rennet on a mixture of milk powder, milk fat to which volatile compounds had been added (Figure 1), NaCl (1 %) and water (water/milk powder: 2.55). Bite force (250 and 350 N), salivary flow rate (1 and 3 mL/min) and ratio fat/proteins (0.5 and 1) were the considered variables. Shear angle remained constant at 3°. Artificial saliva was used [7] without alpha-amylase. Three replicates were considered for each variable. The chewing simulator was connected to an APCI-MS (mass spectrometer equipped with atmospheric pressure chemical ionisation source) apparatus. Air flow rate due to the venturi effect was 30 mL/min. The APCI-MS conditions were similar to that given in reference [8].

Results and Discussion

**Breakdown of hard and brittle food under mastication conditions.** High in-vivo interindividual variability in masticatory performance was observed at 4 and 8 bites for the 4 panellists (10). At a fixed number of peanuts and bites, the same particle distribution was approximately reproduced in-vitro by varying the biting force. Biting force and shearing angle were the parameters, which most affected the degree of peanut breakdown. Changes in the saliva flow rate did not modify the degree of peanut breakdown probably because of product hardness and high fat content. In order to study the effect of bite force and shearing angle on the degree of breakdown, differences in the particle size distribution of fragmented peanuts obtained after 4 and 8 chews were studied. As expected, an increase in both shearing angle and bite force resulted in an increase in the degree of peanut breakdown with a significant interaction between the two factors. In general, the effect of bite force on particle size distribution was greater when no shearing was applied rather than when shearing angles of 3° and 6° were applied.

**Breakdown of airy and brittle food in mastication conditions.** The objective was to relate human mastication to food texture of brittle products in order to model fracture
mechanisms [6]. In-vivo, despite a high variability, the rate of average particle area significantly decreased for B whereas it was not significantly changed for K during chewing. In the case of product B, electromyography data depicted a large increase of the chewing force during the 5 first cycles. A cohesive bolus was obtained after 7 chewing cycles for B whereas it was observed later (after 10 chewing cycles) for K. These results suggested that the transition between the fragmentation and agglomeration mechanisms operated at different characteristic times depending on the nature of the airy product.

In-vitro, using the chewing simulator, the force increased continuously during the first cycle due to the reaction force exerted by the products when the mobile jaw of the system moved forward. Major fracturing events were observed between 200 N and 300N.

Product B exhibited a higher increase of the force compared to product K for up to 5 seconds. Note here that the duration of the chewing cycle duration was imposed to 10 s. As the force level reached about 300 N, complex fracture mechanisms lead to a decrease of the force in the case of product B in the first cycle from 300 to 200 N. Further increase of the force up to 350 N corresponded to the densification of the chewed particles. During the last two cycles, the force stabilised to a value lower than 200 N before an increase of the force which, was inferred to a spatial rearrangement of food fragments in the mouth. Such stabilisation of the force suggested that no further fractures occurred. In the case of product K, the chewing force increased continuously up to 350 N during all the chewing process and the continuous increase of the force was not altered by the chewing cycles. This means that particle breakdown was still operating for K.

In-vitro flavour release from solid matrices in mastication conditions. Superposition of the total ionic current obtained for 3 replicates made in the same conditions showed the good reproducibility of the in-vitro flavour release measurements obtained by coupling the chewing simulator directly to APCI-MS. The initial speed of release (initial slope) and maximum intensity were extracted for diacetyl (m/z 89) and 3-octanone (m/z 129) from the release curves for each detectable ion (Figure 1).

![Figure 1](image.png)

**Figure 1. In-vitro flavour release from a flavoured lipoproteic matrix by direct coupling of the chewing simulator with APCI-MS apparatus (3 replicates).**

**Conditions:**
- Initial volume of saliva: 1 mL
- Salivary flow rate: 1 mL/min
- Compression force: 250 N
- Shearing angle: 3°
- Fat/protein: 0.5

**Volatile compounds (ppm):**
- Butyric acid (10)
- Diacetyl (3)
- 2-Heptanone (5)
- 2-Nonanone (5)
- 3-Octanone (5)
- Ethyl hexanoate (5)
- Ethyl butanoate (4)
- Dimethyl disulfide (10)
For diacetyl, no significant effect of saliva flow rate and food composition (fat/protein ratio) on both initial speed of release and maximum intensity of released diacetyl was observed. The only observed effect was a negative effect of bite force on diacetyl release speed as the effect at 250 N was significantly more important than at 350 N. Concerning 3-octanone, a negative effect of bite force on maximum release intensity was observed, as for diacetyl, and at higher bite force, lower F/P ratio released less volatiles. The same results were obtained for initial release speed. These first results were rather surprising but explanations can be proposed. The negative effect of force could be due to higher agglomeration of particles after breakdown at higher forces, reducing the release phenomenon. The effect of fat could be explained by texture differences: as though fat is well known to retain apolar volatile compounds, the matrices containing higher quantity of fat had a lower hardness and were more easily broken down, leading to a more important release of compounds. That should be confirmed by further experiments.

In conclusion, this device allows getting food breakdown and flavour release results very comparable to in-vivo data. Compared to existing systems, its high level of functionalities (real teeth, both bite and shear forces) allows to faithfully mimicking human mouth process as each function can be independently programmed. It is an essential tool to identify the main physical or physiological phenomena explaining the active compound release and to validate the proposed assumptions to model in silico flavour release.

References