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Thickness of Lipid Deposition on Oral Surfaces Depending on Oil Content and Its Influence on Mouthfeel Perception

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Summary

Lipid content in food strongly influences food perception on the level of textural properties. Lipids in contact with the tongue and palate are substantially responsible for the sensory impact of a product. The aim of this study is to investigate the impact of oil content on the thickness of lipid deposition on oral surface as well as on the mouthfeel perception. The fluorescent probe method was used to study the thickness of lipid deposition on oral surface. We observed an increase in the thickness of lipid deposition depending on the increase of oil content in oil/water dispersions. Clear correlation was shown between the thickness of lipid deposition on oral surfaces and the perception of mouthfeel. A direct measure of undisrupted deposition of food components on oral surface contributes to the understanding of the behaviour of food components in the mouth and their influence on mouthfeel perception.

Key words: fat perception, lipid deposition, mouthfeel, fluorescence method, thickness, saliva

Introduction

Full-fat food gives a lot of pleasant sensations during eating, contrary to their reduced-fat counterparts (*1*). Fat content modifies product properties, such as viscosity, density, friction, specific heat transfer and consequently influences the product perception (*2*). Reduction of fat causes many sensory modalities, such as taste, aroma and texture, most strongly affecting the food texture (*3–5*), especially in semi-solid or liquid foods. Fat replacers are good in deceiving perception until swallowing; however, it is still an unsolved challenge to reach a similar perception of full fat with reduced fat counterparts after swallowing (*6*). After swallowing, residues of food are left on oral surfaces close to the tactile and taste receptors in the oral mucosa influencing perception of mouthfeel, aftertaste and residual aroma (*7*). Mouthfeel is influenced by the fat content. Lipids in close contact with the tongue and palate are substantially responsible for the sensory impact of a product. To understand the underlying mechanisms of in-mouth lipid behaviour, it is important to study the spreading and persistence of different lipids in the mouth. Therefore, methodological approaches to quantify lipid deposition on oral surface after the ingestion of fatty foods have been developed (*6,8–10*). It was shown that after swallowing pure lipids leave a patchy deposition in the mouth. Lipid deposition is thicker on the back or central area of the tongue than on the lateral area (*8*). The thickness of lipid deposition (TLD) on oral surfaces is reduced by more than 50 % just after 1 min after the first spitting out, which could be due to weak forces between lipids and saliva and oral surface (*9*). TLD of pure oil influences sensory perception and is

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correlated with the fatty and lubricating film attributes. A direct measure of undisrupted deposition of food components on oral surface will provide valuable information and contribute to the understanding of the behaviour of food components in the mouth and their influence on mouthfeel perception.

The objective of our study is to investigate the impact of oil content on the TLD on different oral surfaces. Testing the hypothesis that higher content of lipids will increase the TLD on the oral surface evenly will allow us to understand if TLD has a direct impact on the perceived intensity of mouthfeel sensation of fatty and lubricating films.

Materials and Methods

Materials

Samples used were medium chain triglycerides (MCT), Delios® V by Cognis GmbH, BASF (Manheim, Germany), curcumin 95 % as a natural extract from Naturex (Avignon, France) and bottled Vittel water by Nestlé (Vittel, France). Plastic Pasteur pipettes and 10-mL Falcon tubes by Becton Dickinson Labware (Le Pont de Claix, France) were used to deliver samples to subjects.

Samples and their delivery

Two series of samples were used at room temperature: pure MCT and MCT/water dispersions with different percentages of MCT (5, 10, 20, 40, 50, 80 and 100 %). For both series of samples the same volumes of MCT were used (0.25, 0.5, 1, 2, 2.5, 4 and 5 mL). MCT/water dispersions were filled up with water to reach total volume of 5 mL of the Falcon tubes. The tubes were shaken manually for 10 s just before the intake in order to disperse the oil in water. For determination of the TLD, 65 ppm of curcumin was solubilised in MCT.

Oral processing protocol

Prior to the test, subjects were asked to rinse their mouth with water at room temperature. Samples were freely moved around the mouth for 30 s and spat out in two spits (processing time of about 5 s). After spitting out, the subjects moved the tongue back and forth against the palate. Either the TLD or the perceived intensity was determined immediately (T0). After 1 min (T1), the subjects spat the residuals from their mouth again, followed by the same evaluation.

Determination of the TLD on the tongue and palate

Twelve points of measurement were evenly distributed on the dorsal surface of the tongue (Fig. 1) and three points of measurement on the palate. Five measurements were taken in the lateral area of the tongue, including one on the tip. Other measurements were taken in the central part of the tongue, which was separated into front and back areas (Fig. 1). Three points were measured on the palate, just behind the teeth, middle and back. Fluorescence intensity was measured with a Cary Eclipse from Varian (Mulgrave, Victoria, Australia) coupled with a fibre optic probe for remote fluorescence reading fitted with a tip for measurement of solid surfaces. Measurements were performed with a fluorescent-probe method as described previously (*9*). Fluorescent intensity was translated into the thickness with calibration curve made from various amounts of MCT spread on a Petri dish. Each sample was measured in three or six repetitions, performed at an excitation wavelength of 440 nm and an emission wavelength of 515 nm, with an average measuring time of 0.5 s at 32 °C. An analysis of variance (ANOVA) was performed to estimate the impact of MCT volume intake and time on the TLD. A 95 % confidence level was applied for all tests.

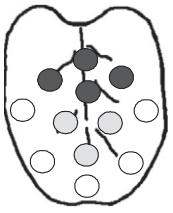

Fig. 1. Positions on the tongue for the measurement of TLD and grouping into different tongue areas (○ – lateral area, ◎ – central area, ● – back area)

Calculated thickness ratio between oil/water (o/w) dispersions and pure oil was calculated using the percent of oil in total volume in the mouth (oil+water+saliva). For the calculation, an estimation of salivary secretion of 1 mL was used. This was compared with the measured thickness ratio between the TLD of o/w dispersions and the TLD of pure oil.

Example of the calculation of thickness ratio at 0.5 mL of MCT is as follows:

$$\begin{aligned}\text{Calculated thickness ratio}&=\\ =((V_{MCT}/V_{tot})_{o/w}/(V_{MCT}/V_{tot})_{MCT})\cdot 100&=\\ =((0.5\text{ mL}/(0.5+4.5+1)\text{ mL})/&\\ /(0.5\text{ mL}/(0.5+0+1)\text{ mL}))\cdot 100&=25\ \%\end{aligned} \qquad /1/$$

Example of the calculation of thickness ratio for the lateral area at 0.5 mL of MCT is as follows:

$$\begin{aligned}\text{Thickness ratio}&=(TLD_{o/w}/TLD_{MCT})\cdot 100=\\ &=(2.7\ \mu m/6.4\ \mu m)\cdot 100=42\ \%\end{aligned} \qquad /2/$$

Mouthfeel perception of residuals

The sensory panel consisted of 9 subjects (women, mean age 45), who had previously been trained how to use the defined sensory attributes (Table 1) for evaluating the sensations in the mouth triggered by consuming semi-liquid food products. The evaluation occurred only after spitting out the product and not during oral processing. Consequently, the attention of the panellists was drawn towards the perception of the actual deposition of lipids on oral surface and not to the primary perception of oil volume put in the mouth. The perceived intensity of only two attributes describing lipid deposition (lubricating film, fatty film) was evaluated. Mouthfeel was evaluated immediately after and again 1 min after spitting out the product. Tests were done in duplicate.

The subjects were seated in sensory booths with controlled temperature and ventilation. Red light was used in order to minimize the visual clues. To avoid possible olfactory clues, the subjects wore nose clips throughout the testing. The subjects received all five samples during

Table 1. Description of sensory attributes and the protocol for evaluation

Sensory attribute	Intensity description (from 'none' to 'very')	Evaluation protocol
Lubricating film	Sensation of a thin deposition film covering the mouth. It is essentially perceived on the lips and the palate/ tongue and makes them slide with ease on one another.	After spitting out the product: slide your tongue on the palate and on the lips, then slide your lips.
Fatty film	Sensation close to feeling of having a layer of fat or oil covering the mouth.	After spitting out the product: slide the tongue on the palate and lips, and the lips on one another.

a session of an hour, which was replicated 3 days later. Sample presentation was balanced among panelists according to the Latin square design. The samples were coded with 3-digit codes and were served and manipulated in the same way as for the determination of TLD. During the sessions, panelists were allowed to drink and rinse their mouth with water *ad libitum*. Scoring was made through a computer on an unstructured linear scale anchored on each end with the labels 'none' (value of 0.0) and 'very' (value of 10.0) presented according to the test design by the FIZZ software (Biosystems, Couternon, France). An analysis of variance (ANOVA) was performed on the raw sensory data to estimate the impact of MCT volume intake and time on the TLD. Duncan's pair comparison test was selected as the comparison procedure. A 95 % confidence level was applied for all tests. MCT intake volume and time after spitting out were chosen as factors for ANOVA.

Results and Discussion

Influence of oil content on the TLD on oral surface

TLD is a result of interaction between the sample consumed, saliva secreted and oral surfaces, which defines the building up of lipid deposition, its retention and washing out. Pure oil samples had significantly higher TLD at the same MCT content compared to o/w dispersions. The median TLD of pure oil at 1 mL was 23 μm and at 4 mL it was 45 μm for total oral surface, whereas for o/w dispersion it was 8 and 28 μm respectively (Fig. 2).

When oil is dispersed in the mouth with water and saliva, the amount of oil and water influences the TLD. The difference between pure oil and o/w dispersions is the addition of water, which might be responsible for better dispersion of oil in water/saliva mixture. The better the dispersion of oil, the less oil is available to cover oral surface and potentially deposit on it. During one ingestion, limited amount of saliva is secreted and in case of pure oil, the saliva secretion might not be sufficient to incorporate all the oil. Consequently, more lipids will deposit on the oral surface. Deposition of emulsion droplets and its influence on the oral texture perception has been indicated previously (*10*).

It has been shown previously that with 5 mL of pure MCT, the TLD is at its maximum (*11*). Already a small volume of pure MCT is sufficient to reach high levels of TLD, therefore 65 % of maximum thickness is reached already with 2.5 mL of pure oil. The increase of TLD in function of volume of MCT seems to follow logarithmic curve (*11*). The TLD of o/w dispersion increases slowly and reaches only about 30 % of maximum TLD at 2.5 mL of MCT and 60 % of maximum thickness at the MCT content of 4 mL. For o/w dispersion, it seems that the logarithmic curve of pure oil is closer to linear line (Fig. 2).

The effect of saliva on TLD can be observed when comparing TLD of pure oil after 1 min and o/w dispersion immediately after spitting out. Interestingly, the values of small MCT volumes show similar TLD of pure oil after 1 min and of o/w dispersion immediately after spitting out (Figs. 3–6). Therefore, the effect of saliva is similar to the effect of water volumes, from 2.5 to 4.5 mL, on TLD. On the contrary, at 4 mL of MCT, TLD of o/w dispersion immediately after spitting out seems to be higher than of pure oil after 1 min (Figs. 3–6). The effect of saliva secreted during 1 min is much stronger than the effect of 1 mL of water. This is an indication that saliva has a key role in lipid behaviour on oral surfaces. Salivary importance had been shown in previous studies in which saliva significantly decreased the friction coefficient of emulsions depending on the surfactant and the amount of fat used (*12*). Whole saliva

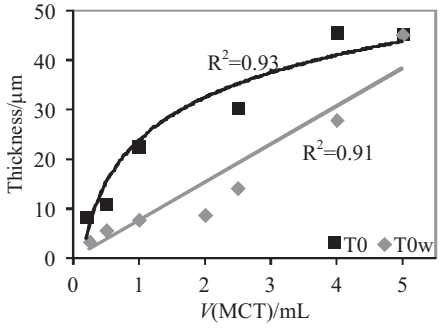

Fig. 2. The median TLD on total oral surfaces after the ingestion of samples of pure MCT (T0) and MCT/water dispersions (T0w) immediately after spitting out

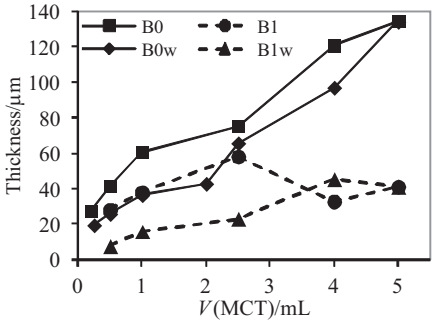

Fig. 3. Median TLD on the back area of the tongue after the ingestion of pure MCT (B0), pure MCT after 1 min (B1), MCT/water dispersions with different MCT content (B0w), and MCT/water dispersions 1 min after spitting out (B1w)

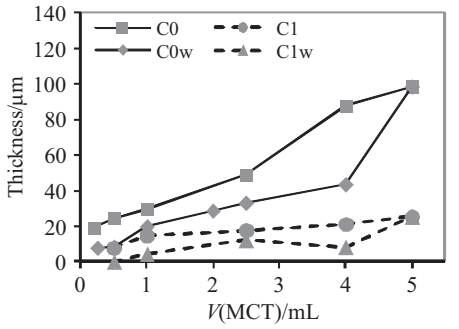

Fig. 4. Median TLD on the central area of the tongue after the ingestion of pure MCT (C0), pure MCT after 1 min (C1), MCT/water dispersions with different MCT content (C0w), and MCT/water dispersions 1 min after spitting out (C1w)

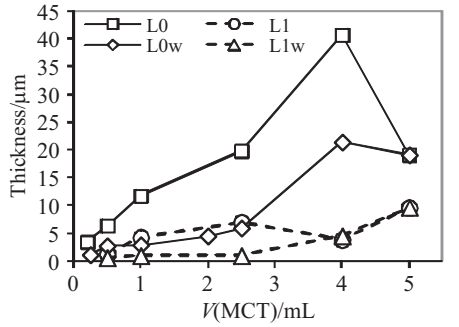

Fig. 5. Median TLD on the lateral area of the tongue after the ingestion of pure MCT (L0), pure MCT after 1 min (L1), MCT/water dispersions with different MCT content (L0w), and MCT/water dispersions 1 min after spitting out (L1w)

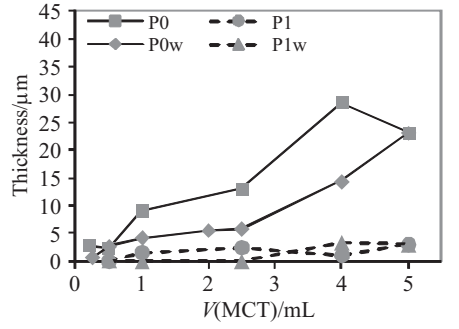

Fig. 6. Median TLD on the palate after the ingestion of pure MCT (P0), pure MCT after 1 min (P1), MCT/water dispersions with different MCT content (P0w), and MCT/water dispersions 1 min after spitting out (P1w)

induces emulsion flocculation, which is driven by two different main mechanisms: depletion flocculation and electrostatic attraction (*13*). Variations in salivary components were correlated with texture perception, such as flavour, mouthfeel and afterfeel attributes (*14*).

The addition of water to oil samples also contributes to a washing out effect. From the observed kinetics, we could think that the binding of oil on the mouth surfaces is very weak, as previously suggested (*10*). The system of o/w dispersion functions in a way that the amount of added water is inversely related to the TLD. However, if we take into account the indicator thickness ratio, this is no longer the case. For MCT volumes smaller than 1 mL, the thickness ratio between the TLD of o/w dispersions and that of pure oil is much higher than the calculated thickness ratio (Fig. 7). This indicates that the oil in o/w dispersion shows better affinity towards oral surfaces (Fig. 7). Smaller volumes of MCT in o/w dispersion are able to build proportionally higher TLD on oral surfaces than pure oil samples. This suggests that the interactions do have an effect on TLD, which has also

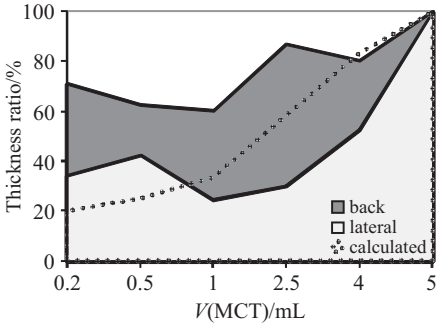

Fig. 7. Thickness ratio of lipid deposition on tongue surface (back – back area, lateral – lateral area), compared to the calculated thickness ratio (calculated). Thickness ratio shows higher affinity of MCT towards the back area, compared to the lateral tongue area as well as higher affinity of smaller MCT volumes in o/w dispersions compared to higher MCT volumes

been shown previously for the emulsions (*13*). In the presence of water, hydrophobic forces attract oil to the oral surface. Despite the harsh tongue movements, hydrophobic forces are important in building TLD on oral surfaces. It would be interesting to further investigate interactions among lipids, saliva and oral surfaces.

TLD was measured in 4 different areas on the oral surface, different areas of tongue dorsal surface (Figs. 3–5) and palate (Fig. 6). Back tongue area had significantly higher TLD than other oral areas, when comparing the same sample (Figs. 3–6). Lateral tongue area and palate had the lowest TLD. This was confirmed by calculating the thickness ratio, which showed differences amongst different areas of an oral surface. The thickness ratio of the back area of the tongue was much higher than of any other area of the tongue, especially the lateral one (Fig. 7). Oil seems to adhere to the back area of the tongue much more than to any other area, especially the lateral one (Fig. 7). This might be due to the difference in the roughness of the tongue surface; back area is known to be covered with larger papillae (*15*). The thickness ratio calculation shows that the difference between the back and the lateral area is not only due to the functional movements during swallowing (*16*).

TLD decreases also with time after spitting out. Even 1 min after the first spitting out, the differences in TLD are still observed among different samples or different oral areas (Figs. 3–6).

Mouthfeel perception

Evaluation of fatty and lubricating film attributes is essential part of mouthfeel perception. Greater volume and content of MCT increased the perceived intensity of

fatty and lubricating films (Figs. 8 and 9). The trained panel perceived a significant increase in the attribute of lubricating film between the samples with 0.5 and 4 mL or higher volumes of pure oil. However, when water was added to the oil, significant differences were perceived between all the samples except for the samples with 0.5 and 1 mL of oil (Fig. 9). Even after 1 min, the intensity of lubricating film of high-oil samples was significantly different from the lowest.

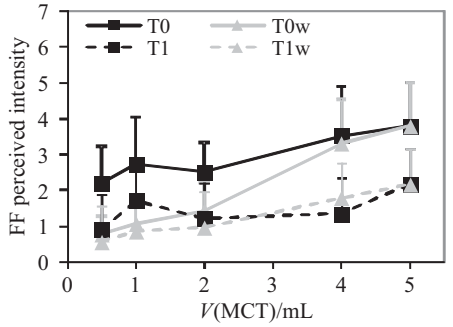

Fig. 8. The perceived intensity of fatty film attribute after the ingestion of pure MCT (T0), pure MCT after 1 min (T1), MCT/water dispersions with different MCT content (T0w), and MCT/water dispersions 1 min after spitting out (T1w)

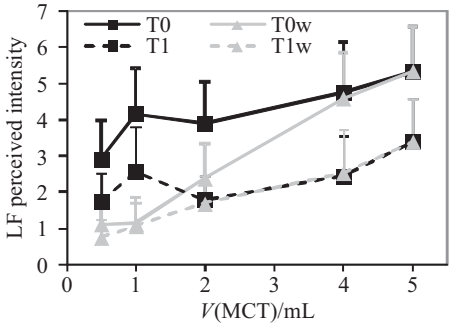

Fig. 9. The perceived intensity of lubricating film attribute after the ingestion of pure MCT (T0), pure MCT after 1 min (T1), MCT/water dispersions with different MCT content (T0w), and MCT/water dispersions 1 min after spitting out (T1w)

The trained panel perceived a significant increase in fatty film attribute between the lowest (0.5, 1 and 2 mL) and the highest (4 and 5 mL) volumes of pure oil. After 1 min, the intensity of fatty film attribute of the highest oil sample volume (5 mL) was significantly different from the lowest one (0.5 mL). The panel wore nose clips and were instructed to focus on the intensity and evaluate it after spitting out. Despite that, it might be difficult to completely ignore the oral processing sensation. Besides TLD, volume and density differences might contribute to the evaluation. It is obvious that when pure oil is ingested, already a small volume is sufficient to give a desirable mouthfeel perception. The addition of a small volume of water is already sufficient to manipulate the mouthfeel perception significantly. We used MCT that do not contain volatiles which might influence the aroma or some taste-irritating properties. Therefore, in our study, the perception of mouthfeel was unlikely to be affected by the aroma, by the oral trigeminal impact of the sample (irritating, cooling or astringent, *etc.*) or by taste impact.

Link between the TLD and the perceived intensity of fatty and lubricating film attributes

Higher content of lipids increases the TLD on oral surface and has a direct impact on the perceived intensity of mouthfeel perception of fatty and lubricating film attributes. TLD of pure oil and o/w dispersions showed different patterns (Fig. 2); however, similar patterns were observed in the perceived intensity of fatty and lubricating film attributes (Figs. 8 and 9). The correlations between sensory attributes and lipid depositions were made for each oral surface separately (Figs. 10 and 11). Palate and lateral tongue area seem to be more sensitive compared to the back and central tongue area. Friction/ lubrication is probably related to the thickness of the lipid layer where the two surfaces, tongue and palate, touch most strongly. Mouth is a very sensitive organ most densely innervated with nerve fibres and receptors, and

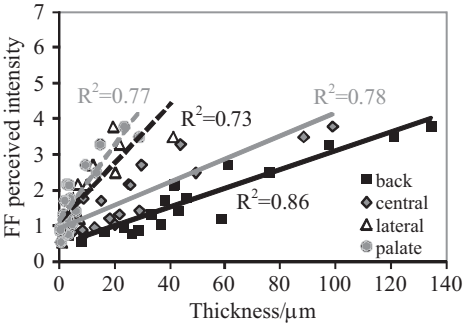

Fig. 10. Correlation of the sensory attribute fatty film with the median TLD on different areas of oral surface

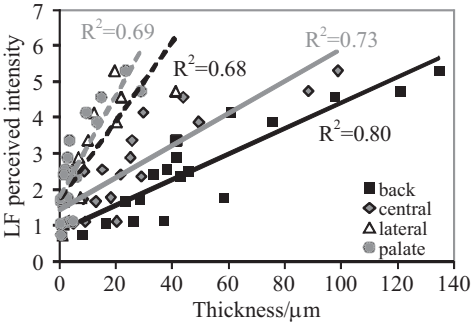

Fig. 11. Correlation of the lubricating film sensory attribute with the median TLD on different areas of oral surface

is exquisitely sensitive to tactile stimulation (*17*). A study performed by Engelen *et al.* (*18*) using a different approach in which palate was not exposed to food indicated that palate could strongly contribute to the texture perception. Also, thresholds for detection of light touch are the lowest on the tip of the tongue and hard palate (*17*). Our results show that the TLD is not only influenced by the volume of oil, but also by its composition. The addition of water to oil reduces the TLD significantly, and also changes the mouthfeel. The correlation of the TLD with a fatty or lubricating film perception was clearly shown, and similar patterns were observed for different sample types. It is important to study the be-

haviour of food in the mouth to gain valuable insights of parameters influencing perception. Identifying oral surfaces that are the most responsible for perception may give new directions to focus future efforts in better understanding of the perception of lipids.

Conclusions

We showed high importance of oil content on the TLD on oral surface. The interaction of oil and mouth has been clearly demonstrated through patchy deposition on different tongue areas as well and the palate. Our work describes the behaviour of food lipids with different fat content in the mouth and its influence on texture perception. Lipids that are in contact with the tongue and palate strongly influence the sensory impact of a product. The addition of water to oil sample reduced the TLD and also the perception of mouthfeel. The contribution of different oral areas to texture perception is postulated through differences in TLD and the mouthfeel. Therefore, direct measurement of undisrupted residue provides valuable information and contributes to the understanding of the behaviour of food components in the mouth and their influence on the perception. The impact of oil content on the distribution, deposition and retention of lipids on the tongue and palate upon ingestion has helped to understand better the sensory perception of lipids.

Acknowledgements

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