Modeling Melting Profiles in Chocolate Pieces for Optimizing their Sensory Properties

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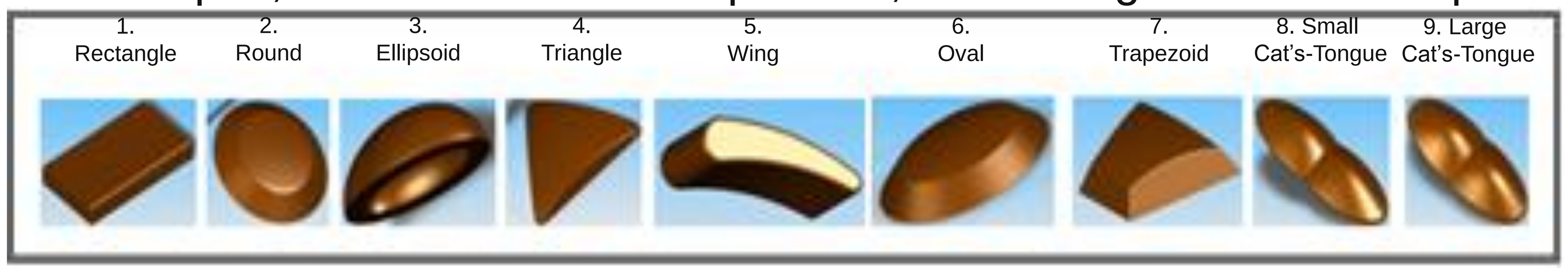
Introduction

Chocolate is a pleasurable product largely consumed over the world. It is known that ingredients, process and particle size distribution largely impact the chocolate sensory perceptions. It was hypothesized that a suitable choice of chocolate size and geometry modifies in-mouth melting and aroma release and modulates flavour and oral texture perception.

Sensory & In-vivo measurements

Sample

- 9 shapes; same chocolate composition; same weight for each shape



Subjects and Protocol

- 9 subjects; 5 replicates

They were instructed to let the chocolate melt in their mouth and consume the chocolate with their mouth closed. The subject's breathing was regulated following a light on/light off timer.

1. Sensory study

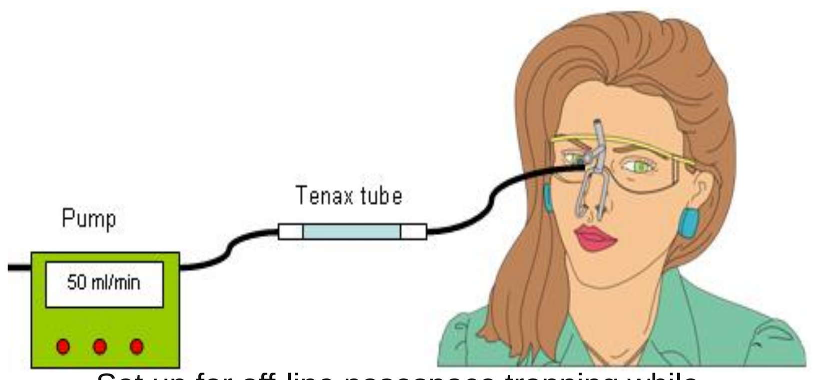
It results that in mouth perception of samples was different on 3 flavour attributes: cocoa, caramel and aftertaste and on 4 texture attributes: deformation, melting, smooth and powdery.

- *Unexpected result was that cocoa intensity and perceived melting were negatively correlated.*

2. Off-line nosespace study

The exhaled air, prior (blank) and during chocolate consumption was trapped, then desorbed and analyse (GC & PTR-MS).

- *It resulted from the study that significant differences of aroma release kinetics were observed between the chocolate shapes.*



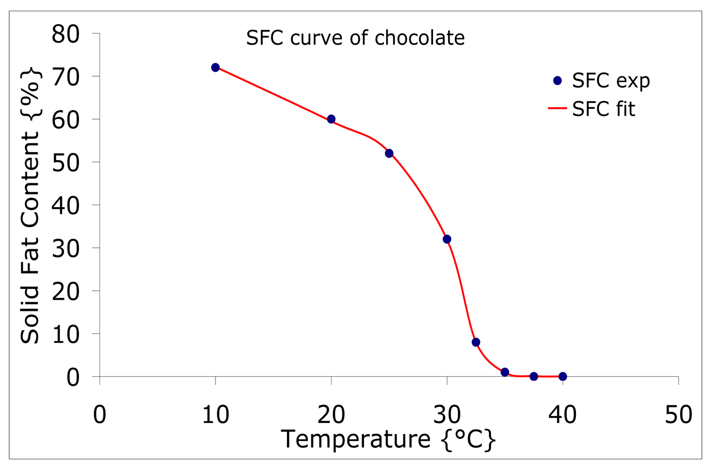
Set up for off-line nosespace trapping while breathing with/without chocolate in mouth

Since in-vivo experiments on chocolate melting in mouth appear at the limit of feasibility a numerical (computer based) modeling approach has been chosen. A conductive heat transfer simulation was made to provide the identification of the major parameters of in-mouth heat transfer and of the in-mouth melting profiles of different chocolate designs, where melting is considered as pre-requisite for release of taste and aroma compounds.

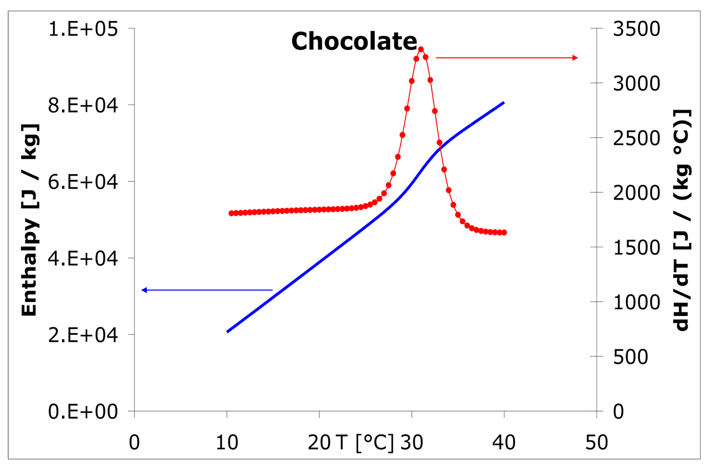
Computational methods

- As the chocolate is heated up in the mouth, it melts. The melting translates the phase transition from a crystalline to liquid form of the fats. This phase transition consumes heat.
- The melting kinetics is modeled using the Fourier equation of heat transfer (conductive heat transfer from Comsol), to which the fat phase transition and its latent heat balance are included. However the changes in topology during the melting process are neglected: neither the expansion of the chocolate mass, nor the shape, nor the motion / deformation of the oral surfaces changes versus time:
- Chocolate having fats experiencing phase transition (solid <-> melt) we used such equation instead:
- We estimated the specific enthalpy of chocolate from the following formula:

With F_C as Fat content, LHF as Latent Heat of Fusion and SFC as Solid Fat Content.



Solid Fat Content versus temperature for chocolate from experimental data



DSC measurements on chocolate (blue line) and its derivative (red line).

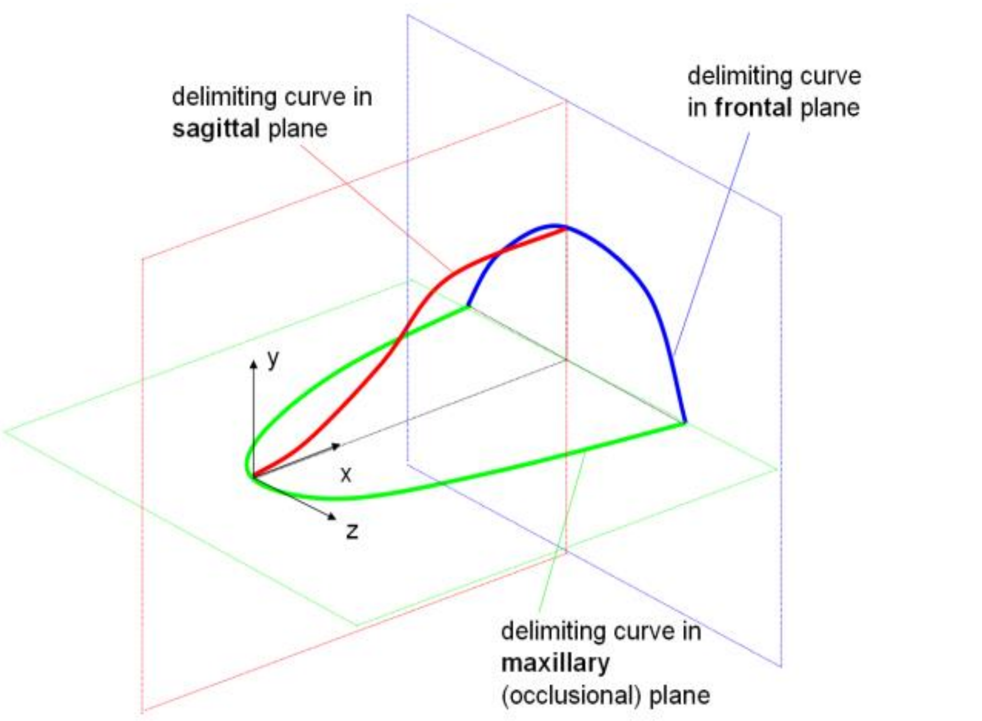
$$\rho C_p \frac{\partial T}{\partial t} - \nabla.(k\nabla T) = 0$$

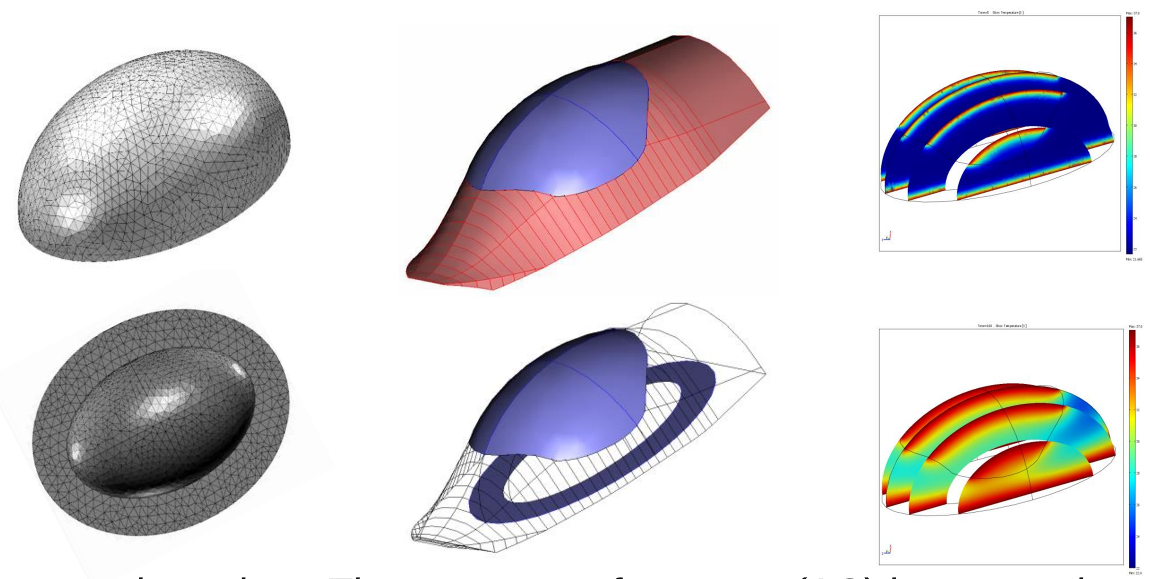
$$\rho \frac{dH}{dT}\frac{\partial T}{\partial t} - \nabla.(k\nabla T) = 0$$

$$H(T) = F_C LHF[1 - SFC(T)] + C_p T$$

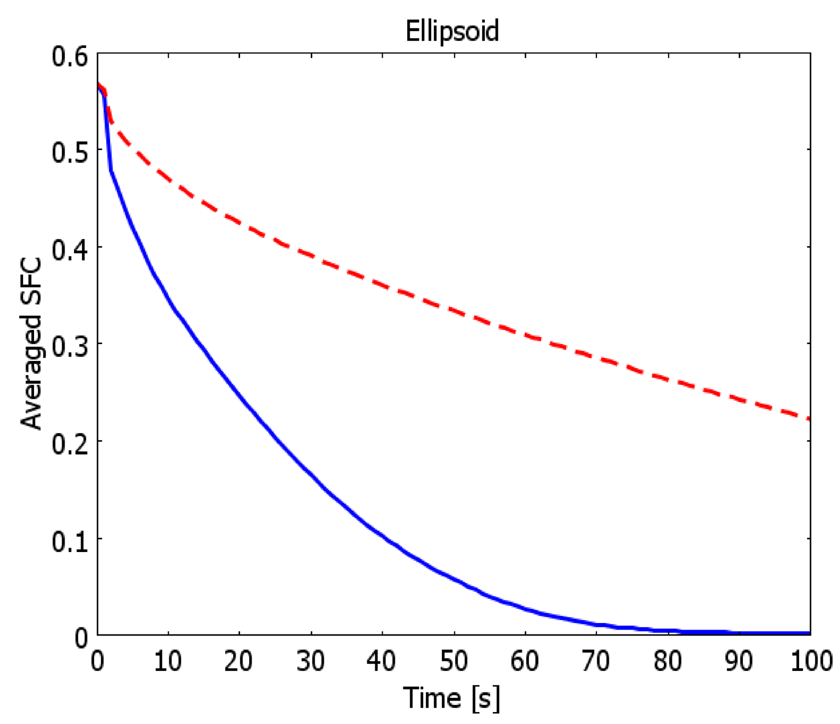
We used published equations to build a model palate from biometric data (refs 1,2).

The initial contacts between the chocolate piece and the heat sources (palate, tongue) remain the only contacts all along each study. Temperature was set there to 37° C.





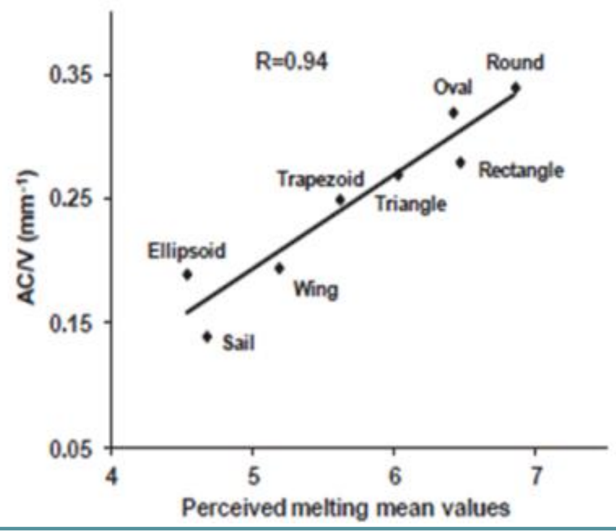
Docking of a shape on the palate. The contact surface area (AC) between chocolate and palate and chocolate and tongue are coloured in blue. Snapshots of Temperature profile at 2 different times.

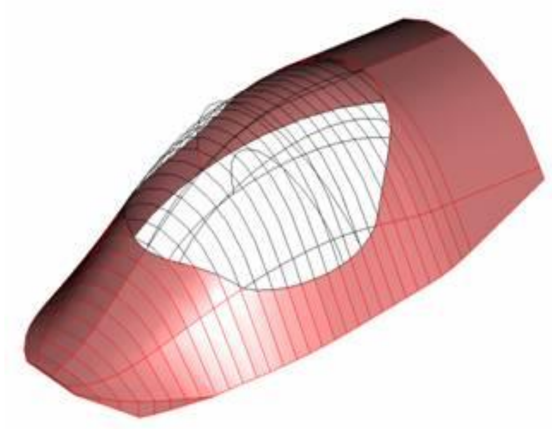


Results

Chocolate shape has a significant impact on *in vivo* aroma release despite the fact that the chocolate composition and the chocolate weight were kept constant and despite the interindividual differences.

AC/V is the contact surface to volume ratio. This parameter is a descriptor of rapid heat transfer and propagation in the chocolate as driver of physical melting.





OVV is the open void volume, i. e. the volume in the mouth which is initially available for freely circulating air (aroma release and transport) once the piece of chocolate is in mouth.

Conclusions

Current numerical simulation is an approach to study conductive heat transfer of chocolate in mouth.
Due to their non negligible difference in compaction the different shapes studied melt with more or less efficiency (Isothermal boundary conditions). More than that, depending on the proportion of heat exchange surface area (AC/S), the situation can be completely changed (In mouth boundary conditions). The slowest shape to melt means also the possibility to have aroma release on a longer time scale. Combined to a large open void volume (OVV) or volume available in mouth for aroma release, makes from it a good candidate for being the shape for which the aroma / taste is more pronounced. This Finite Element modelling method remains a way to study each invented shape.

References

1. Ferrario VF, Sforza C, Colombo A, Dellavia C, Dimaggio FR. 2001. Three dimensional hard tissue palatal size and shape in human adolescents and adults. Clin Orthod. Res 4: 141-147
2. Ferrario VF, Sforza C, Schmitz JH, Colombo A. 1998. Quantitative Description of the Morphology of the Human Palate by a Mathematical Equation. Cleft Palate-Craniofacial Journal 35 (5): 396-401

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