



**MASSEY UNIVERSITY**  
COLLEGE OF SCIENCES

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**MODELLING FOOD BREAKDOWN AND BOLUS  
FORMATION DURING MASTICATION**

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**A thesis presented in partial fulfilment of the requirements for the degree of  
Doctor of Philosophy in Bioprocess Engineering  
at Massey University, New Zealand**

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2016

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## ABSTRACT

Mastication is a complex process that transforms food into a bolus which can be swallowed safely. However, it can be simplified within an engineering context, where the mouth is the equipment carrying out a unit operation to convert ingested food (raw material) into a safe-to-swallow bolus as the process output. Two questions emerge from this observation (i), 'What processes transform the food from its initial state into a bolus?' and (ii), 'How do humans assess when the food is ready to initiate swallowing?' This research examines these questions and a mathematical model is developed which can track the bolus properties during mastication.

A range of common foods with contrasting textures were examined in an observational study to investigate the rate processes of mastication. A wide range of breakdown pathways and textures were observed, from the brittle fracture of carrots to the work softening of a fibrous beef steak. However, despite differences in their structure and properties, breakdown is dominated by a small number of rate processes. Size reduction and work softening occur at occlusion and account for majority of the structural breakdown. Absorption, dissolution and melting are generally more subtle. These are facilitated by mixing, which is the circulation, gathering, folding and placement of food on the occlusal plane.

Mechanical sensory testing (MST) occurs simultaneously to breakdown as the food is manipulated around the mouth during occlusion and between chews. During occlusion this provides gross information about the toughness and hardness, whereas between chews the tongue-palate interactions provide more detailed information about yield and flow. These MST's assess the properties of volume, adhesion, bolus deformation, particle deformation and particle size. Adhesion refers to the binding forces between the food particles and the oral surfaces. Bolus deformation is important for boluses that do not contain individual particles. If they do then swallowability is constrained by their size and individual deformability.

In order for safe swallowing, thresholds for each of the MST properties must be met. These were justified using a *hazard and operability* study of swallowing, on the premise that attempting to swallow a bolus which does not meet the threshold property could result in aspiration or choking. As mastication proceeds, the properties assessed by the MST's are evaluated against the required threshold properties and contribute to the decision making process of whether to swallow or continue chewing.

From this analysis, this work proposes a universal conceptual model of mastication that combines the rate processes, the MSTs and a decision making model. The conceptual model was then described mathematically. It is universal, that is, it is not specific to any food type, because solid foods follow similar physical breakdown paths where occlusion is of primary importance followed by the incorporation of saliva and the other rate processes. Model parameters require *in-vivo* experiments about the breakdown dynamics of specific foods. Subject variability was avoided by using single subject studies for three separate foods; brown rice, a sweetened gelatine gel and peanuts embedded in a food matrix. Each case study explored a limited number of rate processes and food properties. Bolus properties predicted by the model were compared to the experimental data. The output of the model, including particle size distribution and moisture content, closely matched the data during mastication and at swallow point using input parameters fitted from the single subject experiments.

This work provides a platform for further research into mastication modelling. It is recommended the mathematical model be expanded to mechanistically describe the mixing and work softening of non-particulate food boluses. Additional experimental work would achieve a better understanding of the heat transfer in the mouth which would improve the models ability to handle heat sensitive foods.

The model developed here has the potential to aid future food design where a particular breakdown pathway is desired and will reduce the number of time intensive *in-vivo* experiments needed.

## ACKNOWLEDGEMENTS

I would like to thank my supervisors Professor Jim Jones and Professor John Bronlund for their enduring and unwavering support and encouragement throughout this project. I will be forever grateful. Also a special thank you to Marco Morgenstern for his support, input and kind words over the years.

Thank you to the Riddet centre of Research Excellence for funding this project and to the School of Engineering and Advanced technology at Massey University for accommodating me. Furthermore, the support and encouragement from the academic, technical and administrative staff was fantastic and made this work possible. I would like to particularly thank Warwick Johnson, Anne-Marie Jackson, John Edwards, Linda Lowe and Michelle Wagner.

Thanks to all my friends, colleagues and class mates who have shared this journey and experience with me. Being able to shoot the breeze and share our trials and tribulations made this process so much more enjoyable and manageable. In no particular order, thank you Konrad, Melissa, Yashwant, Gonzalo, Georg, Colin, Sureewan, Mazidah, Sadia and Tiyaorn.

A special thanks to Scott Hutchings for his thoughts and guidance and to Anuchita Moongngarm, Camille Ollier and Jenny Loi for their help in the lab. I must also thank my volunteers who helped throughout this project.

Last but definitely not least, I would like to thank my family. They have graciously shared, or should I say endured, this journey with me. To my Dad and wicked step mother, I am so very grateful for your love, encouragement, and unfaltering support over the years. Thank you Mum for your love, support and kind words. Luke you have been an incredibly understanding brother and housemate and have been generous to a fault. Chris, Fleur and Olivia your encouragement and all the times you have helped me relax and unwind from the daily grind was a godsend. To Oliver, thank you for keeping me on my toes and for your consistent hard line of enquiry.

Lastly, it would be remiss of me not to end this section with some noble insight or pearl of wisdom. Therefore, I leave you with this. There are two types of people in the world, those who can extrapolate from incomplete data sets.

**Warning:** This thesis may contain traces of nuts!



## LIST OF PUBLICATIONS AND PRESENTATIONS

### Refereed conference papers:

Gray-Stuart E., Jones, J. R., Bronlund, J. E., & Morgenstern, M. P. (2012) Rate processes during mastication important for modelling mastication. In: *Chemeca 2012*. Wellington, New Zealand 23-26 September 2012.

Gray-Stuart E., Jones, J. R., Bronlund, J. E., & Morgenstern, M. P. (2012) Control loops in mastication: whether to keep chewing or prepare for swallowing. In: *Chemeca 2012*. Wellington, New Zealand 23-26 September 2012.

Gray-Stuart E., Jones, J. R., Bronlund, J. E., Moongngarm, A., & Morgenstern, M. P. (2011) A discrete population balance to simulate the particle size distribution in a bolus of chewed rice. ICEF 2011, Athens, Greece.

### Conference presentations and posters:

Gray-Stuart E., J R Jones., Bronlund, J.E. and Morgenstern. M. Modelling the Food During Mastication. Oral presentation, Food Oral Processing, Wageningen, 29th Jun - 2nd July 2014.

Gray-Stuart E., Jones, J. R., Bronlund, J. E. A mathematical model to simulate the breakdown of a gelatine based gel during chewing (2010). Oral presentation, International Conference on Food Oral Processing, 5-7 July 2010, Leeds, UK

Gray-Stuart E., Mongngarm, A., Jones, J. R., Bronlund, J. E. (2010). A conceptual model of particle size reduction during chewing of brown rice. Poster presentation, International Conference on Food Oral Processing, 5-7 July 2010, Leeds, UK



## TABLE OF CONTENTS

ABSTRACT.....	III
ACKNOWLEDGEMENTS.....	V
LIST OF PUBLICATIONS AND PRESENTATIONS.....	VII
TABLE OF CONTENTS.....	IX
LIST OF FIGURES.....	XI
LIST OF TABLES.....	XXIII
Chapter 1 PROJECT OVERVIEW.....	1-1
Chapter 2 LITERATURE REVIEW.....	2-1
2.1 Introduction.....	2-1
2.2 Oral Physiology.....	2-2
2.3 Oral Processing of Food.....	2-9
2.4 Food Properties that Influence Mastication.....	2-14
2.5 Food Texture.....	2-20
2.6 The Bolus.....	2-23
2.7 Comminution Models.....	2-30
2.8 Relevance of the Literature to the Objective of this Thesis.....	2-47
Chapter 3 QUALITATIVE ANALYSIS OF FOOD BREAKDOWN DURING MASTICATION.....	3-1
3.1 Introduction.....	3-1
3.2 Methodology.....	3-2
3.3 Observations.....	3-3
3.4 Discussion and Conclusions.....	3-23
Chapter 4 PROCESS ENGINEERING OF MASTICATION.....	4-1
4.1 Breakdown.....	4-2
4.2 Mixing.....	4-7
4.3 Mechanical Sensory Testing.....	4-9
4.4 Linking the Rate Processes to the Bolus Properties.....	4-23
4.5 Decision Making.....	4-26
4.6 Conclusions.....	4-28
Chapter 5 MODEL DEVELOPMENT.....	5-1
5.1 General Assumptions.....	5-1
5.2 System Composition.....	5-3
5.3 Governing Equations.....	5-7
5.4 Constitutive Relationships.....	5-16

5.5 Thresholds to a Swallowable Bolus .....	5-20
5.6 Model Implementation.....	5-21
5.7 Summary.....	5-23
Chapter 6 CASE STUDIES.....	6-1
6.1 Case Study One – Brown Rice.....	6-1
6.2 Case Study – Gelatine Gels .....	6-35
6.3 Case Study - Peanuts Embedded in Different Food Matrices .....	6-69
Chapter 7 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH .....	7-1
7.1 Conclusions.....	7-1
7.2 Recommendations.....	7-3
REFERENCES.....	8-1
APPENDIX A .....	A-1
APPENDIX B .....	A-5
APPENDIX C.....	A-9
APPENDIX D .....	A-15
APPENDIX E.....	A-21
APPENDIX F.....	A-23
APPENDIX G .....	A-27

## LIST OF FIGURES

Figure 2-1: A conceptual model depicting food oral processing as a sequence of events. Decision boxes are shown as diamonds while process boxes are rectangular (from Lucas et al., 2002). ..... 2-10

Figure 2-2: The process model of feeding (from Hiimeae 2004). ..... 2-11

Figure 2-3: Sirognathograph record of a human subject eating an unpeeled apple. The arrows highlight the different jaw movement profile during swallowing (from Hiimeae, 2004). ..... 2-12

Figure 2-4: The mouth process model. A food may be swallowed when the ‘degree of structure’ has been reduced below the plane ABCD and its ‘degree of lubrication’ has crossed the plane EFGH. Key:(1) Tender juicy steak (2) tough dry meat (3) dry sponge cake (4) Oyster (5) liquids and semisolids From Hutchings and Lillford (1988)..... 2-13

Figure 2-5: Correlation between the hardness of food and the number of chewing cycles. 10 cm<sup>3</sup> samples were fed to 266 healthy adult subjects (from Chen. 2009)..... 2-15

Figure 2-6: Correlation between the moisture content of food and the number of chewing cycles. 10 cm<sup>3</sup> samples were fed to 266 healthy adult subjects (data from Engelen et al., 2005). ..... 2-15

Figure 2-7: Loading of a food particle between the molar cusps. The food particle bends like a beam and the crack starts remote from the cusps) (from Agrawal et al. (1996))...... 2-17

Figure 2-8: Rapid crack propagation and an arrested crack pushed apart by the cusp (from Lucas et al 2002). ..... 2-17

Figure 2-9: The correlation between the breakage function and the mechanical food property group  $RE$  .for 38 foods; 1-9 are nuts; 10-27, cheeses; 28-32, fruits and vegetables; 33-36, breads; 37 – a type of soybean curd; and 38, monocrystal sugar. .... 2-18

Figure 2-10: The relationship between the breakage function and properties of: (a)  $(R/E)^{0.5}$ ;  $R^2 = 0.828$ , (b)  $(ER)^{0.5}$ ;  $R^2 = 0.230$ , (c) n.s, (d)  $R^2 = 0.410$ . From Lucas et al (2002). ..... 2-19

Figure 2-11: Force-displacement curve obtained from a double compression test using the texture profile analysis approach (from Chen, 2009)..... 2-22

Figure 2-12: Average sequence of texture sensations over the mastication period (▲ brittleness, + crispness, □ crackliness, △ dryness, ○ grittiness, ● hardness, ■ lightness, - stickiness). Two horizontal lines account for chance limit (---) and significance limit (—), from Lenfant et al. (2009)..... 2-23

Figure 2-13: Relationship between the mean particle size of food boluses and the measured food hardness for 19 different types of food (from Chen et al., 2013). The correlation between mean particle size and hardness fits a power law relationship. ....2-25

Figure 2-14: Relationship between the  $d_{50}$  in expectorated boluses and the inverse of the fragmentation index for peanuts, raw carrot and cheese (data adapted from Lucas et al. (2002), Peyron et al. (2004) and Jalabert-Malbos et al. (2007))......2-25

Figure 2-15: Rheological characteristics of the bolus during the course of mastication, measured at either 20% or 65% deformation (from Peyron et al., 2006). The mastication sequence was divided up into nine stages and normalised. Definitions are given in Figure 2-11. ....2-27

Figure 2-16: The cohesive force plotted against the number of chewing strokes for brazil nuts (top) and raw carrot (from Prinz and Lucas 1997). ....2-29

Figure 2-17: Ratio of  $n_s/n_b$  as a function of  $n$  for a single chew. The data is fitted to Eq. 2-9 (from van der Glas et al., 1992). Where  $O_1$  is the particle affinity,  $n_s$  is the number of selected particles,  $n_b$  is the number of breakage sites and  $n$  is the number of particles offered. ....2-35

Figure 2-18: Cumulative weight percentage undersize as a function of the logarithm of the sieve aperture for an individual after various numbers of chewing strokes for a) Optosil and b) peanuts. The solid lines are best fits through the data points using Rossin-Ramler distribution (from Olthoff et al. (1984)).....2-43

Figure 2-19:  $X_{50}$  versus the number of chewing strokes  $N$  on a log log plot for the seven subjects chewing Optosil, lines are best fit according to Eq. 2-25, (from Olthoff et al., 1984).....2-43

Figure 3-1: Schematic diagram of a skeletal muscle (from Swartz et al., (2009)) .....3-4

Figure 3-2: Cooked beef steak expectorated after different numbers of chewing strokes up to and past the swallow point (sp). ....3-6

Figure 3-3: A carrot bolus expectorated after various numbers of chewing strokes up to and past the swallow point (sp). ....3-9

Figure 3-4: Chewed banana expectorated after different numbers of chewing strokes up to and past the swallow point (sp). ....3-11

Figure 3-5: Peanuts after different numbers of chewing strokes up to and past the swallow point. ....3-13

Figure 3-6: Wine biscuit expectorated after different numbers of chewing strokes up to and past the swallow point. ....3-16

Figure 3-7: White bread expectorated after different numbers of chewing strokes up to and past the swallow point.....	3-18
Figure 3-8: A cube of Edam cheese expectorated after different numbers of chewing strokes up to and past the swallow point (sp). .....	3-20
Figure 3-9: A piece of chocolate expectorated after different numbers of chewing strokes up to and past the swallow point (sp).....	3-22
Figure 4-1: Mechanical processes of mastication. The mouth is considered as a process unit operation containing oral structures (teeth, tongue and palate) housed in a volume (oral cavity, buccal pouches). During mastication <i>mixing</i> facilitates both food <i>breakdown</i> and the continuous <i>mechanical sensory testing</i> to facilitate decision making.....	4-2
Figure 4-2: The mechanical processes of mastication showing how mixing both circulates the food which simultaneously undergoes breakdown by a number of rate processes and is subjected to mechanical sensory tests which are then compared to some criteria stored in the central nervous system. The outcome is a decision whether to continue chewing or prepare for partial or terminal swallowing. ....	4-10
Figure 4-3: Forces applied during occlusion are measured by the periodontal mechanoreceptors. Shown is a particle caught between the upper and lower teeth a distance $s$ apart and to which a normal force $F_N$ and a shear force $F_S$ are applied. ...	4-11
Figure 4-4: Schematic of particle and bolus measurement between the tongue and palate showing the papillae measuring both compressive and shear forces during mild and stronger compression. ....	4-13
Figure 4-5: Mechanical processes of mastication. The rate processes of breakdown affect the bolus properties detected through the mechanical sensory testing by the oral structures within the mouth. The criteria define a safe-to-swallow phase space of properties.....	4-15
Figure 4-6: Phase space diagram that defines a swallowable region. Stars and arrows indicate the direction of change in properties from the initial chew to the swallow point for a hypothetical food.....	4-23
Figure 4-7: Connections between rate processes and the food/bolus properties assessed by the oral structures within the mouth and for which a phase space of threshold values defines a swallowable bolus. ....	4-24
Figure 4-8: Proposed state diagram relating size and particle properties to the swallowable threshold, a) represents a brittle food with constant mechanical properties, , b)	

represents chewing gum and c) represents a food that work softens and decreases in size.....	4-25
Figure 4-9: Overview of oral processing. The dotted line shows the conceptual mastication model.....	4-27
Figure 5-1: Mass flow balance within the oral cavity during mastication. Saliva is the only addition of mass during mastication. Flows of mass occur between the food particles and the interstitial free liquid phase due to processes of wicking absorption, the release of molten fats, dissolution of soluble solids and expression of liquid from food during occlusion. Small particles below a threshold size are also assumed to enter the liquid phase. ....	5-8
Figure 5-2: Volume flow balance within the oral cavity during mastication. Only saliva enters the oral cavity, which enters into the well-mixed interstitial free liquid phase. Subsequently there is a volume flux between the free liquid-phase and particle-phase due to the rate processes of wicking absorption, melting, dissolution of soluble solids, expression of liquid from foods at occlusion and some transport of undersize particle which are below a threshold are assumed to exist in suspension in the liquid. Occlusion can also cause some loss of pore volume in porous foods.....	5-9
Figure 5-3: Heat balance within the oral cavity during mastication. Heat is added from saliva and the walls of the oral cavity to the well-mixed interstitial free liquid-phase. From here, it transfers between the particles and the liquid-phase by heat convection and mass convection. The mass convection processes are wicking absorption, melting, dissolution of soluble solids, expression of free liquid during occlusion and some transport of undersize particle which are below a threshold are assumed to exist in suspension in the liquid. There are no heat losses from the oral cavity. $U$ is the overall heat transfer coefficient [ $\text{W m}^{-2} \text{K}^{-1}$ ], $C_p$ is the specific heat capacity [ $\text{J kg}^{-1} \text{K}^{-1}$ ], $V_{saliva}$ is the saliva flow rate [ $\text{m}^3 \text{s}^{-1}$ ], $A$ is area [ $\text{m}^2$ ], $M$ is mass [ $\text{kg}$ ]. Subscripts <i>saliva</i> , <i>oc</i> , <i>liq</i> and <i>p</i> are saliva, oral cavity, interstitial liquid and particle respectively. ....	5-10
Figure 5-4: Discretised population balance within the oral cavity during mastication. Particles are tracked individually. A particle selected for occlusion is recorded as a death and the resulting daughter particles are births. Any particles that fall below a threshold size are no longer tracked; their death means their mass and volume are apportioned to the interstitial free liquid-phase.....	5-13
Figure 5-5: Process flow diagram showing schematically how the model is implemented.....	5-22

Figure 6-1: PSD of the fractional volume versus the characteristic dimension of rice particles sampled at selected chew numbers. The characteristic dimensions are presented by the Mastersizer in a power series but are plotted here on a linear scale. .... 6-7

Figure 6-2: PSD of the fractional volume versus the characteristic dimension of rice particles sampled at selected chew numbers. The characteristic dimensions are presented by the Mastersizer in a power series as shown here by the logarithmic scale. . .... 6-8

Figure 6-3: Fraction of dried solids recovered from the bolus and rinsings from the second subject. For the boluses that were sieved the data points are the mean of four replicates and the error bars show the standard deviation. The two boluses (and rinsings) that were collected at each chew interval and were dried without sieving are shown as individual points..... 6-10

Figure 6-4: Mass fraction of rice retained on each sieve as a fraction of total solids recovered, mean and standard deviation of four replicates. The sieve apertures are plotted on a linear scale. .... 6-13

Figure 6-5: Mass fraction of rice retained on each sieve as a fraction of total solids recovered, mean and standard deviation of four replicates. The sieve apertures are plotted on a logarithmic scale. .... 6-13

Figure 6-6: Mass fraction of rice retained on each sieve as a fraction of total solids recovered, mean of four replicates. The mass fractions and sieve apertures are both plotted on a logarithmic scale, the purpose being to highlight the small quantities of particles on the smaller sieves..... 6-14

Figure 6-7: Solid fraction recovered in each size class as a fraction of the total solids ingested after removal of the hydrolysis effect in order to determine the influence of mastication alone on the PSD..... 6-15

Figure 6-8: Saliva incorporation expressed as grams of saliva per gram of rice in the expectorated bolus for the two subjects throughout mastication, Subject 1 data is the mean and standard deviation of four samples and for subject 2, each replicate is shown..... 6-16

Figure 6-9: Ratio of number of particles selected to the number of breakage sites as a function of the particles offered. .... 6-18

Figure 6-10: Mass fraction (mean  $\pm$  stdv) of rice from the occluded particles that are retained on the sieves after a single chew stroke, the subject was served 40 grains and six replicates were performed. .... 6-19

Figure 6-11: Number of breakage sites for the particles in different size classes, these were measured for whole and half rice kernels and extrapolated for the smaller particle sizes from Eq. 6-4. ....6-21

Figure 6-12: Breakage function fitted to the distribution of single rice kernels after occlusion. 6-22

Figure 6-13: Schematic model flow diagram of the comminution model of the rice. This is a specific case of the generalised diagram in Figure 5-5. ....6-24

Figure 6-14: PSD predicted by the model compared with the experimental PSD of the rice bolus analysed with wet sieving with the volume fraction on a linear scale. The red dot is the model prediction and the black dot is the experimental data. Simulations were run 20 times and the error bars represent the standard deviation of these. The error bars for the experimental results represent the standard deviation of 4 trials. ....6-25

Figure 6-15: PSD predicted by the model compared with the PSD of the rice bolus from the subject which were analysed with wet sieving with the volume fraction on a log scale. The red dot is the mean model prediction from 20 simulations; the black dot is the mean value of the experimental data from 4 replicate boluses. ....6-26

Figure 6-16: Volume fraction of rice selected per chew (mean and standard deviation of 20 simulations). ....6-27

Figure 6-17: Change in mass fraction in the different size classes resulting from changing the fragmentation variable of breakage by  $\pm 25\%$ . The model base case uses  $r = 0.43$ . .6-28

Figure 6-18: Change in mass fraction in the different size classes resulting from changing the fraction of an occluded particle that is pasted to below  $355\mu\text{m}$  by  $\pm 25\%$ . ....6-29

Figure 6-19: Key size parameters of the rice bolus changing with chew number. Model predictions in black compared with values interpolated from the wet sieve data. ...6-30

Figure 6-20: Interstitial liquid content expressed as ratio of liquid to solid phase, the liquid phase includes the added saliva and the rice particles pasted to below the threshold size, mean and standard deviation of 20 simulations. ....6-31

Figure 6-21: Cumulative distribution of bite weight for the ten subjects; Cadbury Crunchie ( $\diamond$ ) and Tasti Product Fruit and Nut Bar (x), green line is the 75<sup>th</sup> and 25<sup>th</sup> percentile. ....6-37

Figure 6-22: Cumulative distribution for number of chews required for each bar; Cadbury Crunchie. ....6-38

Figure 6-23: A gel in the aluminium mould. ....6-39

Figure 6-24: Typical force vs time plot for the two-bite compression test on a rectangular sample of 30% sucrose 10% gelatine gel (1cm x 2 cm x 1 cm), displacement rate = 5 mm/s, compression ratio = 75%. ....6-39

Figure 6-25: Cumulative particle size distribution of the same bolus. The bolus was scanned and re-disbursed and scanned again, repeated three times. Scan 1 $\Delta$ , scan 2 $\square$ , scan 3 $\circ$ .	6-42
Figure 6-26: Schematic representation showing how a gel particle can be cleaved and is positioned on the teeth during occlusion, the dotted line shows the cleavage point.	6-45
Figure 6-27: Schematic model flow diagram for the oral processing of gelatine gel, this is a specific case of the generalised diagram in Figure 5-5.	6-47
Figure 6-28: Saliva flow rate for the different recipes at different stages of mastication (mean $\pm$ stdv), (blue) 30% sucrose 15% gelatine, (red) 30% sucrose 10% gelatine, (green) 50% sucrose 15% gelatine and (purple) 50% sucrose 10% gelatine.	6-51
Figure 6-29: Cumulative area fraction of the bolus at swallow point for the three replicates of each type of gel, (a) 30% sucrose 15% gelatine, (b) 50% sucrose 15% gelatine, (c) 50% sucrose 10% gelatine and (d) 30% sucrose 10% gelatine.	6-53
Figure 6-30: Cumulative area fraction of the gelatine boluses at swallow point where the three replicate boluses are combined into a single cumulative area fraction.	6-54
Figure 6-31: Key size parameters of the bolus at the swallow point for the different gels, (mean and standard deviation).	6-54
Figure 6-32: Number of particles in the bolus at different stages of mastication for the different gels, (mean and standard deviation).	6-55
Figure 6-33: Relationship between the $d_{90}$ in the bolus at the swallow point and the particle inverse fragmentation index for several foods, vertical error bars are the standard deviation of the $d_{90}$ , horizontal error bars are the $(E/R)^{0.5}$ with toughness of 100 and 1000. (data for the other foods from Lucas et al. (2002), Peyron et al. (2004) and Jalabert-Malbos et al. (2007)).	6-56
Figure 6-34: Fraction of the gelatine cube melted over time for the gels made with 30% sucrose, the cube was initially at 20° before being suspended in a beaker of water immersed in a water bath at 37°C.	6-56
Figure 6-35: Fraction of the gelatine cube melted over time for the gels made with 50% sucrose, the cube was initially at 20°C before being suspended in a beaker of water immersed in a water bath at 37°C.	6-57
Figure 6-36: Amount of the gel cube that was melted during mastication for the different gel recipes (mean $\pm$ stdv).	6-59

Figure 6-37: Cumulative area fraction in each size class for the three replicate boluses at the swallow point for the 50% sucrose 15% gelatine gel, the red dot and error bars show the model predictions (mean  $\pm$  stdv of 25 replications) .....6-60

Figure 6-38: Cumulative area fraction in each size class for the three replicate boluses at the swallow point for the 50% sucrose 10% gelatine gel, the red dot and error bars show the model predictions (mean  $\pm$  stdv of 25 replications). .....6-60

Figure 6-39: Cumulative area fraction in each size class for the three replicate boluses at the swallow point for the 30% sucrose 15% gelatine gel, the red dot and error bars show the model predictions (mean  $\pm$  stdv of 25 replications). .....6-61

Figure 6-40: Cumulative area fraction in each size class for the three replicate boluses at the swallow point for the 30% sucrose 10% gelatine gel, the red dot and error bars show the model predictions (mean  $\pm$  stdv of 25 replications). .....6-61

Figure 6-41: Amount of gel that melts during mastication of the 30% sucrose 15% gelatine recipe; -- is the means and standard deviation from 25 model simulations,  $\square$  mean and standard deviation of the *in-vivo* measurements with the subject. ....6-63

Figure 6-42: Amount of gel that melts during mastication of the 50% sucrose 15% gelatine recipe; -- is the means and standard deviation from 25 model simulations,  $\square$  mean and standard deviation of the *in-vivo* measurements with the subject. ....6-63

Figure 6-43: Amount of gel that melts during mastication of the 50% sucrose 10% gelatine recipe; -- is the means and standard deviation from 25 model simulations,  $\square$  mean and standard deviation of the *in-vivo* measurements with the subject. ....6-64

Figure 6-44: Amount of gel that melts during mastication of the 30% sucrose 10% gelatine recipe; -- is the means and standard deviation from 25 model simulations,  $\square$  mean and standard deviation of the *in-vivo* measurements with the subject. ....6-64

Figure 6-45: Fraction of gel that melts during mastication of the four gel recipes, the best fit model compared to the data; -- lines are the means and standard deviation from 25 model simulations,  $\bullet$  is the mean and standard deviation of the *in-vivo* measurements with the subject. ....6-66

Figure 6-46: Recovered dry weight of peanuts in the bolus that are retained on a 355  $\mu\text{m}$  sieve after different number of chews. Peanuts in chocolate matrix  $\blacksquare$ ; peanuts in gelatine matrix  $\square$ , (mean  $\pm$ SE). Data from Hutchings (2011). ....6-71

Figure 6-47: Values of the shape factors used to get the best fit for the peanut particle volume. ....6-74

Figure 6-48: Predicted volume of retained particles vs actual volume of retained particles, where particles are assumed to be quarter ellipsoids..... 6-75

Figure 6-49: Schematic model flow diagram of the comminution model for the peanut component of the matrix, this is a specific case of the generalised diagram in Figure 5-5. .... 6-77

Figure 6-50: Volume fraction of particles in each size class, the recovered peanut particles was divided by the initial peanut volume ingested, (a) the chocolate matrix and (b) the gelatine matrix. Data from Hutchings et al. (2011). .... 6-78

Figure 6-51: Best fit model prediction using a constant selection function that does not vary with chew number. PSD volume fraction of peanuts in (a) chocolate and (b) gelatine matrices after 5, 10, 15, 20 and 25 chews: model prediction red dot● is mean of 50 simulations with standard deviation vs experimental data black dot ●average with standard deviation error bars ..... 6-80

Figure 6-52: Best fit model prediction using a constant selection function that does not vary with chew number. PSD volume fraction of peanuts in (a) chocolate and (b) gelatine matrices after 5, 10, 15, 20 and 25 chews: model prediction ● is mean of 50 simulations vs experimental data mean ●. .... 6-81

Figure 6-53: Mean and standard deviation of the volume fraction of peanut particles in the chocolate and gelatine matrix selected with a selection function parameters unchanged. The number of simulations was 50. .... 6-82

Figure 6-54: PSD volume fraction of peanuts in chocolate (left) and gelatine (right) matrices after 5, 10, 15, 20 and 25 chews using the selection parameters with parameters in Table 6-21: ● is the mean of 50 simulations with standard deviation vs experimental data ● average with standard deviation error bars. .... 6-83

Figure 6-55: PSD volume fraction of peanuts in chocolate (left) and gelatine (right) matrices after 5, 10, 15, 20 and 25 chews using selection function with the parameters in Table 6-21 : ● is the mean of 50 simulations with standard deviation vs experimental data ● average with standard deviation error bars. .... 6-84

Figure 6-56: Mean and standard deviation of the fraction of original peanut volume selected per chew in the chocolate matrix (a) and gelatine matrix (b). The number of simulations was 50..... 6-85

Figure 6-57: Sensitivity of PSD of the peanuts in the chocolate matrix to the fragmentation variable,  $r$ , after 5 and 25 chews. □ 1.0, ○ 1.5, < 2.0, \* peanut data. .... 6-86

Figure 6-58: Sensitivity of PSD of the peanuts in the chocolate matrix to the bimodal variable (the pasted fraction) after 5 and 25 chews. □ 0.74, ○ 0.84, < 0.94 , \* peanut data. ...6-87

Figure 6-59: Model output for the PSD of the peanuts from the chocolate matrix using the data after five chews as the initial feed distribution. ● is the mean of 50 simulations with standard deviation vs experimental data ● mean with standard deviation error bars. 6-88

Figure 6-60: Model prediction of the PSD of the peanuts from the gelatine matrix using the data after five chews as the initial feed distribution, swallow point is fixed at 43 chews. ● mean of 50 simulations with standard deviation vs experimental data ● mean with standard deviation error bars.....6-89

Figure 6-61: Change in the chocolate particle temperature and mass of solid fat in the particle with time. ....6-93

Figure 6-62: Schematic model flow diagram of the comminution model for the peanuts and matrix where the melting is included for the chocolate and dissolution is included for the gelatine, this is a specific case of the generalised diagram in Figure 5-5. ....6-95

Figure 6-63: Model PSD of the chocolate matrix and embedded peanuts throughout mastication and the peanut bolus data, the volume in each size class is normalised to the initial peanut volume • chocolate matrix, • embedded peanuts, \* peanut data.6-96

Figure 6-64: Model PSD of the chocolate matrix and embedded peanuts throughout mastication and the peanut bolus data, the volume fraction is on a log scale and the volume in each size class is normalised to the initial peanut volume; • chocolate matrix, • embedded peanuts, \* peanut data.....6-97

Figure 6-65: Cumulative mass of the chocolate matrix that is melted during mastication and enters the liquid-phase of the bolus predicted by the melting model (mean value of 10 model replications).....6-98

Figure 6-66: Model PSD of the gelatine matrix and embedded peanuts throughout mastication and the peanut bolus data, the volume in each size class is normalised to the initial peanut volume; • gelatine matrix, • embedded peanuts, \* peanut data.....6-99

Figure 6-67: Model PSD of the gelatine matrix and embedded peanuts throughout mastication and the peanut bolus data, the volume fraction is on a log scale and the volume in each size class is normalised to the initial peanut volume; • gelatine matrix, • embedded peanuts, \* peanut data. ....6-100

Figure 6-68: Cumulative mass of soluble solids in the liquid-phase of the bolus as a result of dissolution from the gelatine matrix. .... 6-101



## LIST OF TABLES

Table 2-1: Mean contribution (expressed as % of the total) of the different salivary glands to the total salivary production under different stimulation (from Aps and Martens, 2005) .....	2-5
Table 2-2: Salivary flow rates in response to citric acid and chewing various foods (from Watanabe and Dawes, 1988).....	2-6
Table 2-3: Salivary flow rates in response to chewing different foods (from Gaviao et al., 2004) .....	2-6
Table 2-4: Average salivary flow rates at rest and after stimulation with custard odour, Parafilm chewing and citric acid (from Engelen et al., 2003).....	2-6
Table 2-5: Classification of textural characteristics (from Szczesniak, 2002)) .....	2-21
Table 2-6: Definitions of mechanical parameters of texture (from Szczesniak, 2002).....	2-21
Table 2-7: Particle sizes and number of particles used in the one-chew experiments .....	2-35
Table 2-8: Values and standard deviations of points from Figure 2-19.....	2-44
Table 3-1: Size and description of the food samples. (The dimensions are given as width x height x length for the cuboid samples, diameter x height for the cylinders and the peanut is half an ellipsoid). .....	3-2
Table 3-2: Number of times the food was chewed before being expectorated and photographed, the last two columns are the average normal swallow point and twice this number.....	3-3
Table 4-1: Hazard operability study of the passage of food during swallowing. The table explores the cause and consequence of involuntary swallowing food with the property/guide word combination. Actions are inherent within the natural masticatory decision making processes.....	4-20
Table 6-1: Bite weight and number of chews Crunchie and Fruit and Nut bars of previous population and the selected subject (mean $\pm$ SD).....	6-2
Table 6-2: Number of either whole or half kernels served in the single chew experiments and the number of replicates .....	6-5
Table 6-3: Fitting parameters for mixed Weibull distribution to the rice bolus for various chew numbers. ....	6-9
Table 6-4: Solids recovered in the bolus and rinsings after a serving of rice was chewed to the natural swallow point. The expectorated boluses were either dried without sieving or sieved immediately after collection. (Values are the mean and standard deviation of four replicates).....	6-12

Table 6-5: Saliva flow rate for both subjects, calculated from the slope of Figure 6-8 between 8 chews and the swallow point. (Note that the chew number is converted to minutes using the subjects chewing frequency). .....6-16

Table 6-6: Number of breakage sites and particle affinity for the subject in the single chew study. ....6-18

Table 6-7: Composition of the gelatine gels used for the study. ....6-38

Table 6-8: Nomenclature and units for the size reduction and melting of gelatine. ....6-47

Table 6-9: Reproducibility of the recipe 50% sucrose 15% gelatine, the hardness is defined as the peak force F1 value on the first compression cycle from a ‘two-bite’ compression test (displacement rate = 5 mm/s, compression ratio = 75%) this was performed on a rectangular piece of gel (1cm x 2 cm x 1 cm). ....6-48

Table 6-10: Comparison of the hardness of the different recipes, the hardness is defined as the peak force F1 value on the first compression cycle from a ‘two-bite’ compression test (displacement rate = 5 mm/s, compression ratio = 75%) this was performed on a rectangular piece of gel (1cm x 2 cm x 1 cm), 10 replicate measurements were performed.....6-49

Table 6-11: Young’s modulus of the gels derived from the stress-strain curve of the first compression in the ‘two-bite’ test, (mean and standard deviation of 10 replicate measurements.....6-49

Table 6-12: Number of chews taken to swallow 1 cm<sup>3</sup> of the gel (mean ± stdv of six replicates, <sup>a,b</sup> means with different letters are significantly different).....6-49

Table 6-13: P values from the two-way ANOVA showing the effect of the recipe and hardness on the number of chews before swallowing. ....6-50

Table 6-14: Chewing frequency of the subject for different gels when chewing to swallow point (mean ± stdv of six replicates).....6-50

Table 6-15: Solids recovered in the bolus at the swallow point for the different gel recipes (mean ± stdv of six replicates).....6-51

Table 6-16: Initial melting rate of the gels and time taken for the each gel to completely melt (mean ± stdv).....6-57

Table 6-17: Parameters of the selection function used to obtain the best fit for the area fraction in each size class,  $v$  and  $w$  are the fitted parameters in the power law selection function. The  $r^2$  value for each gel is also shown. ....6-62

Table 6-18: Comparison between the initial in-vitro melting rate and the melting rate that provided the best fit between the model and in-vivo experimental results. ....6-67

Table 6-19: Mean (± SEM) moisture content of the quarter peanuts.....6-72

Table 6-20: Summary of 16 quarter peanut particles occluded and wet sieved on 355 $\mu\text{m}$ mesh. .....	6-73
Table 6-21: Best fit selection function variables for the peanut particles in the chocolate and gelatine matrix. ....	6-85
Table 6-22: Values used to test sensitivity of model predictions to breakage .....	6-86
Table 6-23: Biot number for spherical chocolate particles where $h = 250 \text{ W}/(\text{m}^2 \cdot \text{K})$ .....	6-92

