



## Table of contents

Abstract .....	v
Kurzzusammenfassung .....	vi
Danksagung.....	vii
Table of contents .....	x
1 Introduction.....	1
1.1 Motivation .....	1
1.2 Objectives.....	9
2 Fundamentals .....	10
2.1 Definition of foam .....	10
2.2 Theory of foam formation .....	11
2.2.1 Basic principles of foaming.....	12
2.2.2 Blowing agent .....	15
2.2.3 CO <sub>2</sub> -based foaming process .....	16
2.3 Aging phenomena.....	18
2.4 Microcellular foams.....	20
2.5 Biodegradable foams .....	21
2.5.1 Foams from wheat proteins .....	21
2.6 Biopolymers and proteins.....	25
2.6.1 Definition and introduction .....	26
2.6.2 Protein packing.....	31
2.6.3 Disulfide bonds .....	32
2.7 Wheat storage proteins .....	33
2.7.1 Gliadin structure.....	38
2.7.2 Main gliadin types.....	41
2.7.3 Glutenin proteins (insoluble fraction) .....	43
2.7.4 Aggregation.....	45



2.7.5	Structural changes .....	45
2.7.6	Effect of pressure and temperature treatment .....	46
2.7.7	Protein-solvent interactions.....	46
2.7.8	Viscoelasticity of gluten proteins.....	48
2.7.9	pH.....	49
2.7.10	Film formation.....	49
2.7.11	Interfacial properties of wheat proteins .....	49
2.8	Rheology.....	51
2.8.1	Ideally elastic behavior.....	53
2.8.2	Ideally viscous behavior.....	53
2.8.3	Viscoelastic behavior .....	54
2.8.4	Glass transition.....	55
3	Experimental results.....	56
3.1	Generation of micro- and nanocellular foam from gliadin.....	56
3.2	Extraction of gliadin from wheat gluten.....	57
3.2.1	Gliadin plasticization.....	63
3.2.2	Effect of mixing time and water concentration .....	66
3.3	N <sub>2</sub> .....	68
3.3.1	Preliminary experiments .....	68
3.3.2	Degree of hydration.....	71
3.3.3	Cooling rate .....	74
3.3.4	Influence of swelling time.....	76
3.3.5	Processing pressure .....	78
3.3.6	Processing time .....	80
3.3.7	Processing temperature .....	83
3.3.8	Effect of pH.....	87
3.3.9	Silica particles as nucleation centers.....	90
3.3.10	Indirect plasticization .....	93



3.3.11	Pressure variation .....	95
3.3.12	Summary I .....	97
3.4	Foaming experiments with scCO <sub>2</sub> .....	98
3.4.1	CO <sub>2</sub> vs. N <sub>2</sub> .....	99
3.4.2	Degree of hydration.....	102
3.4.3	Increase of porosity .....	107
3.4.4	Effect of pH.....	109
3.4.5	Processing temperature .....	111
3.4.6	Past-expansion treatment.....	115
3.4.7	Directly soaked gliadin film.....	117
3.4.8	Summary II.....	122
3.5	Variation of plasticizer .....	123
3.5.1	Aqueous ethanol as plasticizer .....	123
3.6	Variation of plasticizer content – N <sub>2</sub> .....	130
3.7	Variation of plasticizer content – CO <sub>2</sub> .....	132
3.7.1	Pressure variation .....	134
3.7.2	Swelling and pressure variation .....	136
3.7.3	Free expansion.....	141
3.7.4	Post-expansion treatment .....	154
3.7.5	<i>T</i> -stability during pressure drop .....	159
3.8	Investigation of the sample state at high <i>p</i> and <i>T</i> .....	161
3.8.1	Sample preparation.....	163
3.8.2	Freeze-fracture, replication and electron microscopic investigation by TEM and SEM.....	164
3.9	Rheology.....	168
4	Discussion .....	179
4.1	The starting material.....	180
4.1.1	Protein hydration .....	180



4.1.2	Film formation.....	184
4.1.3	Processes at the molecular scale.....	187
4.1.4	Voids at the nanoscale.....	195
4.2	The foaming process.....	198
4.3	A foam formation mechanism .....	206
4.3.1	Rheological behavior.....	208
4.4	The foaming process.....	210
5	Conclusion .....	215
6	Appendix.....	A-1
6.1	Abbreviations and symbols .....	A-1
6.2	Chemicals used.....	A-5
6.3	Physical data.....	A-6
6.4	Methods used.....	A-7
6.4.1	High pressure cell.....	A-7
6.4.2	Scanning Electron Microscopy (SEM) .....	A-9
6.4.3	Freeze-Fracture Electron Microscopy (FFEM).....	A-10
6.4.4	Rheological measurements.....	A-10
6.5	Solubility of N <sub>2</sub> and CO <sub>2</sub> in water as function of <i>T</i> and <i>p</i> .....	A-11
6.5.1	Estimation of foam number density .....	A-12
6.5.2	Estimation of foam porosity .....	A-12
6.6	Hierarchical structure .....	A-13
6.7	Additional foaming experiments .....	A-14
6.7.1	Variation of pressure drop rate and sample cooling.....	A-14
6.8	Foams prepared from glutenin.....	A-15
6.9	Additional information from the rheological measurements.....	A-17
7	References.....	A-19
	Versicherung .....	A-48
	Curriculum Vitae.....	A-50